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The Changes in Sectors Demanding Water Resources on the Basis of Climate Change and Uncertainty

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Abstract: It is imperative to develop and assess approaches to adapt to climate change in order to manage its impacts. The objective of the present study was to explore the impact of the changes in climatic parameters on water resources management and to assess the efficiency of changing water uses as a strategy to mitigate the impacts of water shortage in Southeastern Iran. To assess the variations of temperature and precipitation parameters an ensemble of fifteen GCM models was used, and the emission scenarios A1 and B1 with emphasis on uncertainty and water resources management were simulated by the Water Evaluation And Planning System (WEAP) model using data derived from climate change and local station data. The calibration was done by the WEAP model algorithm. Climate change results showed a increase in temperature and precipitation. Due to the increase in temperature relative to precipitation, the region's water demand will increase. The slight increase in rainfall does not mean supplying the region's water demand, especially the agricultural demand. Therefore, the impact of climate change is having a greater impact on farmers because their livelihoods depend on water. These conditions will lead to further problems, including migration. These conditions require effective solutions. One of the best solutions is to gradually eliminate agriculture and replace it with industry. The results showed that with this scenario, the water demand of different sectors will be met, the local environment will not be destroyed, and low-income, non-permanent, and illicit jobs like fuel smuggling will be eliminated.

Keywords: Adaptation, Water Stress, Water Management, Agriculture, Industry, Environmental

Introduction

The growing population of the earth is one of the factors implicated for environmental change and degradation, and above all, for the decline of freshwater resources. Furthermore, one of the main consequences of population growth is the extensive use of fossil fuels that, in turn, has disrupted the heat balance of the planet. The disruption of earth's heat balance will ultimately lead to climate change. According to a study by the Intergovernmental Panel on Climate Change (IPCC 2014), the mean global temperature may rise by 4°C by 2100, which will strongly influence the availability of freshwater resources and its demand. The combined effect on water resources and demand is projected to widen the gap between resources and demand so that the recent challenges of water resource management will be exacerbated (Kumar et al. 2017). In addition, most people, especially rural people, are dependent on natural and agricultural resources for their welfare. On the other hand, agriculture is tied to climate variability (Salinger et al. 2005). As one can see, there is a sophisticated relationship between climate, agriculture, and water as well as climate change. Even the slightest changes in rainfall and temperature result in severe impacts on water resources, agriculture, and economy. What is important today is recognizing the future behavior of climate and the effect that this behavior has on the consumption of resources, in particular water, as well as providing adaptation strategies and mitigating the effects of this behavior change. In fact, water resource management has become necessary in these conditions.

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This is a complex task under climate change due to various reasons, including 1) disagreements about the formulation of climate change scenarios, 2) development of a method to downscale the output of atmosphere circulation models to local conditions with applicability for hydrological predictions, 3) differences in how to simplify hydrological models and nonlinear models, and 4) errors in planning and/or policies of water resource management that should not be underestimated in practical planning (Zhuang et al. 2018). Zhuang et al. (2018) developed an integrated simulation-optimization (ISO) approach to evaluate the impacts of climate change on water resources, and they concluded that the uncertainty of systems significantly influences the water resources allocation pattern

In an attempt to estimate the climate change consequences for the water balance of the Malaprabha river catchment using an ensemble of five GCM models, Reshmidevi et al. (2018) predicted the dramatic loss of annual runoff rate and groundwater recharge as we approach the end of the century. The increase in temperature and evapotranspiration forecasts an increasing rate of irrigation demand at the end of the century (Reshmidevi et al. 2018). The projection of future rainfall shows an increase in average rainfall and a decrease in moderate and short wet periods, but short and moderate dry periods will increase in future (Reshmidevi et al. 2018). However, the projected loss of water stream and groundwater recharge, as well as the increase in irrigation demand, is likely to exacerbate local water stress under future scenarios (SRES Emission Scenario). Water has a major role to play in demographic, social, and economic development (Sun et al. 2017), and the management and conservation of water resources is an important step towards accomplishing sustainable development (Yousefi and Momeni 2017). According to Napoles-Rivera et al. (2013), 1.8 billion of the world population will suffer from water scarcity by 2025 and two-thirds will be faced with water stress. Iran is expected to be challenged by severe water scarcity given its mean annual precipitation of 250 mL, which is less than one-third of the mean annual global precipitation rate (Madani 2014). This will be a major factor limiting the development of economic activities in coming decades (Madani 2014). Comparisons indicate that industries (these industries are in Libya) consume seven to eight times less water than agriculture, but they generate four to twenty times higher net profit from this water use than agriculture (Bindra et al. 2003). Since Iran is located on the dry belt of the earth, it is of crucial importance to precisely estimate and supply water requirements of the industrial sector. It also forms the basis for the development of water supply networks, treatment systems, and their required equipment.

Standards have been formulated to estimate the water requirement of the industries as per their production unit (Monzavi 2004). The amount of water consumed by similar industries as per production unit varies across countries and even across regions, greatly depending on climatic conditions, water availability, the selected technology, and many other factors (Saghir et al. 2000). To properly estimate water demand in the study area, we consider it based on water demand of the unconstructed or not-in-operation industries can be estimated with an acceptable approximation on the basis of the data pertaining to the operating plants [unclear – please revise]. Among water, livestock, fishery, agriculture, and energy sectors, agriculture is the most vulnerable sector to climate change (PICC 1990). Consequently, people are in dire need of an occupation that not dependent on agriculture. Aghakhani (2014) determined water consumption of industries by four methods: water consumption per industrial unit, per total area, per infrastructure area, and per number of employees. The method used the number of employed people in the study area to estimate water demand of the industrial sector and the minimum environmental water requirement (using the water demand of mugger crocodile (Crocodylus palustris), a unique animal species in this region). The contribution of the research was that it defined a new water demand based on local conditions and eliminated current local water demand to exit the water crisis. Given the water scarcity in Iran and the predicted future climate change, it is imperative to adopt effective, reliable strategies for water resources management in order to alleviate the future water scarcity crisis.

Study Area

The Pishin study site with an area of 1713 km2 is located to the east of the catchment of the Southern Baluchestan rivers. It lies between the longitudes of 61°25’ and 61°55’ E. and the latitudes of 26°00’ and 26°35’ N. The highest point in the site has an altitude of 1580 meters above sea level and the outlet areas of the catchment form the lowest parts with the altitude of 168 meters. Figure 1 depicts the location of the study site. The Pishin dam (61°41’ E., 26°01’ N.) is located right at the intersection of the Suran Ab (Pishin) river and the Sarbaz river. The Sarbaz river is the most important river in the region. The Shir Govaz diversion dam is located 42 km downstream of the Pishin dam on the geographical coordinates of 61°28’ E. and 25°45’ N. This diversion dam supplies the drinking water of Chabahar city, with the population of 200,691 and per capita water demand is 73.8 m3/year. In addition, the Bahu Kalat irrigation network covering an area of 6,000 ha has been constructed at 7 km downstream of the Shir Govaz diversion dam. The water requirement for irrigation in this region is 12,210.4 m3 ha-1. The Sarbaz river keeps flowing after passing the Pishin dam but after the dam, it is renamed the Bahu Kalat river. It has a north-south direction and finally flows into the Gulf of Oman at Gwadar Bay. The waste of water as it flows from the Pishin dam to Shir Govaz dam is 5 MCM through evaporation.

The area between the Pishin dam and Shir Govaz diversion dam, where there is about 1,200 ha of agricultural lands that consume river water illegally, is the habitat for Iranian mugger crocodiles. The environmental water requirement has been neglected in this area, and the migration of these crocodiles has posed a danger for the local people. As crocodiles migrate and their habitat is destroyed, their population decreases, exposing them to the danger of extinction. The minimum environmental water requirement is 16.55 MCM (Ministry of Energy 2011).

The Pishin basin has the second highest rural population growth rate in Iran, at 2.07 percent. People in these regions are struggling with poverty. They have no access to safe drinking water, and they meet their water requirement from *houtaks*—small ponds where irrigation water is accumulated and where the agents of cholera and malaria propagate (Ministry of Energy 2011). Agricultural crops are the main source of income for local people who have tended toward illegal jobs like fuel smuggling due to the loss of water resources and farming areas. Southern Baluchestan has a population of 825,865 people and the male-to-female ratio and the unemployment rate is 1.02 and 11.5 percent in Sistan and Baluchestan provinces, respectively. There are 94,974 unemployed people in Southern Baluchestan, of which 47,016 are female and 47,957 are male (Statistical Center of Iran 2017). In this research, the population of unemployed women and men was assumed to be 50,000 and 60,000, respectively, instead of 47,016 and 47,957.

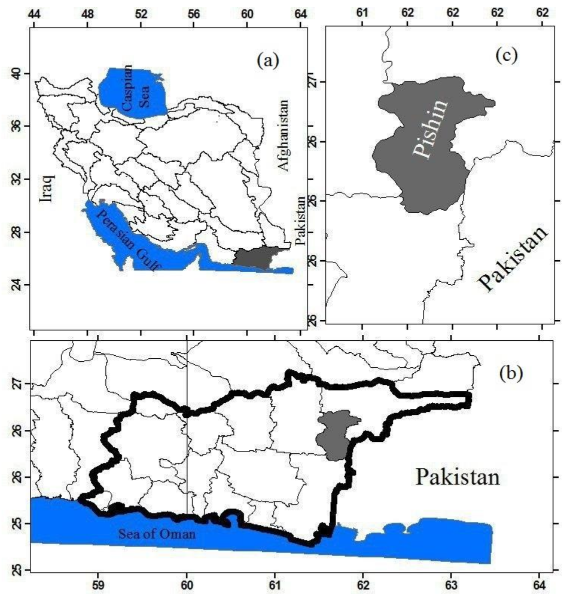


Figure 1: Location Map of the Pishin Catchment: a) The Map of Iran and the Southern Baluchestan Basin; b) Southern Baluchestan Basin and the Position of Pishin Basin; c) Pishin Basin (the Study Area)
Source: The Ministry of Energy 2011

Typically women in the area are carpet weavers and men are fishermen. The industrialization of these traditional jobs will increase efficiency and consequently increase people's income. Therefore, in their scenarios, the textile and food industries (for men and women, respectively) were considered to calculate the number of employees. The per-capita water requirement of the textile and food industries is 0.36 and 0.43 $m3/d^{-1}$ (Aghakhani 2014), amounting to 6.57 and 9.417 MCM annual water requirement for these two industries in the study site. It is illegal to exploit the wells in the study area due to the excessive loss of groundwater tables. The amount of the precipitation of the study area is 225.2 mm/yr.

Materials and Methods

Using the observational data on water discharge rate (in the Pishin hydrometer station along the river), the WEAP (Water Evaluation and Planning System) model algorithm was used for calibration. In the WEAP model, the PEST (Parameter ESTimation) tool automatically compares the output of the model with observational data and adjusts the model parameters to improve the precision. PEST can be employed to calibrate one or more variables. It is a tool to estimate non-dependent parameters and to analyze the uncertainty. General circulation models (GCMs) are computerized terrestrial systems that simulate the climatic system and the interactions among the system components mathematically (Hassan 2012). The special report on emission scenarios (SRES) has been classified into four scenario families of A1, A2, B1, and B2 that explore a wide range of greenhouse gases (GHG) emissions caused by demographic, economic, and technological factors (IPCC 2007). The present study uses the output of an ensemble of 15 GCM under A1 and B2 scenarios. Table 1 lists GCMs used in the present study. We estimate the variations of future climatic variables for the period 2025–2045 by GCMs using 1990–2010 as the base period for which the historical data are available.

Table 1: General Circulation Models Used in the Present Study

No	*Model Name*	*Center Acronym*	*Center*	*Horizontal resolution (Lon-, Lat)*
1	CSIROMK3	CSIRO	Australia's Commonwealth Scientific and Industrial Research Organization	1.8 * 1.8
2	BCM2		Bjerknes Centre for Climate, Norway	3.75 *3.75
3	CGCM3T63		Canadian Centre for Climate Modelling and Analysis (CCCma), Canada	2.8 * 2.8
4	ECHAM5-OM	MPI-M	Max-Planck Institute for Meteorology	1.9*1.9
5	ECHO-G		Research Institute, Germany	
6	FGOALS-G1.0	LASG	Institute of Atmospheric Physics	2.8 * 2.8
7	GFDL-CM2.1	GFDL	Geophysical Fluid Dynamics Laboratory	2.0*2.5
8	GISS-AOM	GISS	Goddard Institute for Space Studies	3.0*4.0
9	HADCM3	UKMO	Hadley Centre for Climate Prediction and Research/UK Met. Office	2.5*3.75
10	INM-CM3.0	INM	Institute for Numerical Mathematics	4.0*5.0
11	MIROC3.2 hires	NIES	Meteorological Research Institute, Japan	1.1*1.1
12	MIROC3.2 medress		National Institute for Environmental Studies, Japan	
13	MRI CGCM2.3a		Meteorological Research Institute, Japan Meteorological Agency, Japan	
14	CCSM3	NCAR	National Centre for Atmospheric Research	1.4*1.4
15	PCM	NCAR	National Centre for Atmospheric Research	2.8*2.8

Source: Madani 2014

The output of GCMs is to study and evaluate the impacts of climate change for coarse hydrology for which downscaling method should be used (Jung et al. 2013). The present study has used change factor practice (Kumar et al. 2017).

$$\Delta T_i = \overline{T}_{GCM,FUT,i} - \overline{T}_{GCM,BASE,i} \quad (1)$$

$$\Delta P_i = \frac{\overline{P}_{GCM,FUT,i}}{\overline{P}_{GCM,BASE,i}} \quad (2)$$

$$T = T_{OBS} + \Delta T \quad (3)$$

$$P = P_{OBS} \times \Delta P \quad (4)$$

In equations (1) and (2), ΔTi and ΔPi express the climate change scenario of monthly temperature and rainfall for the average long-term 21-year period; denote the average 21-year monthly temperature and rainfall simulated by the GCM model for the future period (2025–2045); and represent average monthly temperature and rainfall simulated by the Atmosphere-Ocean General Circulation Model for the observational period (1990–2010), respectively. In equations (3) and (4), T and P express the time series yielded from temperature and rainfall climatic scenario for the future period of 2025–2045; TOBS and POBS represent the time series for observational temperature and rainfall in the base period (1990–2020); and ΔT and ΔP show downsized climatic change scenario for the temperature and rainfall derived from equations (1) and (2), respectively (Chen et al. 2011).

Uncertainty Analysis of GCMs

In discussions on climate change and the assessment of its impacts on hydrology, uncertainty comes from diverse sources (Wilby and Harris 2006). But, the most important source of uncertainty is the general atmospheric circulation models (Chen et al. 2011; Prudhomme and Davies 2009; Wilby and Harris 2006). Accordingly, this study tries to use more diverse GCMs (Teng et al. 2012). To mitigate the resulting uncertainty, the bounded range method is employed (Gohari et al. 2013). Numerous methods for dealing with uncertainties of GCMs have been proposed, some of which include 1) using a bounded range with known probability distribution, 2) using a bounded range with larger range of unknown probabilities, 3) using a central prediction with error bars, and 4) expressing the results as a central prediction (OECD 2003; Gohari et al. 2013). We apply a bounded range with known probability distribution (Gohari et al. 2013) to alleviate the uncertainty of fifteen GCMs since it is the most widely used method. This technique is carried out in three steps.

Step 1: Weighting of GCMs

At the first step, ten GCMs of the study were weighted by Mean Observation Temperature-Precipitation (MOTP; Equation 5) (Gohari et al. 2013; Massahbavani and Morid 2005; Reshmidevi et al. 2017). This method weights GCMs in terms of the difference between simulated variables and the observational data on a monthly average basis. Indeed, the weight of each GCM reflects the model potential for simulating the monthly values of meteorological variables.

$$W_{ij} = \frac{\frac{1}{\left|\Delta d_{ij}\right|}}{\sum_{j=1}^{10} \frac{1}{\left|\Delta d_{ij}\right|}} \tag{5}$$

Where Wij is the weight of GCM j in month i, and is the absolute difference in the average precipitation or temperature between the observed value and the value simulated by GCM j in month i.

Step 2: Generation of Probability Distribution Functions (PDFs)

The second step deals with generating probability distribution functions (PDFs) for climatic changes with respect to the calculated weights. PDFs specify the relationship between the weight of each individual GCM and the average variations of monthly precipitation and temperature. In this study, thirty PDFs were generated for each month considering fifteen GCMs and two emission scenarios.

Step 3: Generation of Cumulative Distribution Functions (CDFs)

In this step, the discrete PDFs constructed for precipitation and temperature data in Step 2 were converted into cumulative distribution functions (CDFs) for each month. This was carried out by EasyFit Software Package. The advantage of the use of software for the fitting of data and interpretation of probability data is that it automatically matches data with different types of certain distribution patterns. This method is specifically preferred when there is little or no information about base distribution pattern and the target is to find the best distribution. EasyFit is a data analysis software package for the fitting of the probability distribution for sample data, their simulation, the selection of the best fitting sample, and the fulfillment of results for better decision-making (Mehrannia and Pakgohar 2014). We employed the Kolmogorov Smirnov test for goodness-of-fit of data. Then, the values of climate change variables were derived from the constructed CDFs at two likelihood levels of 25 and 75 percent. The climatic variables calculated for two probability percentages were applied as input data for modeling water resources management using WEAP. Figure 2 depicts the step-by-step diagram of the methods employed in the present work.

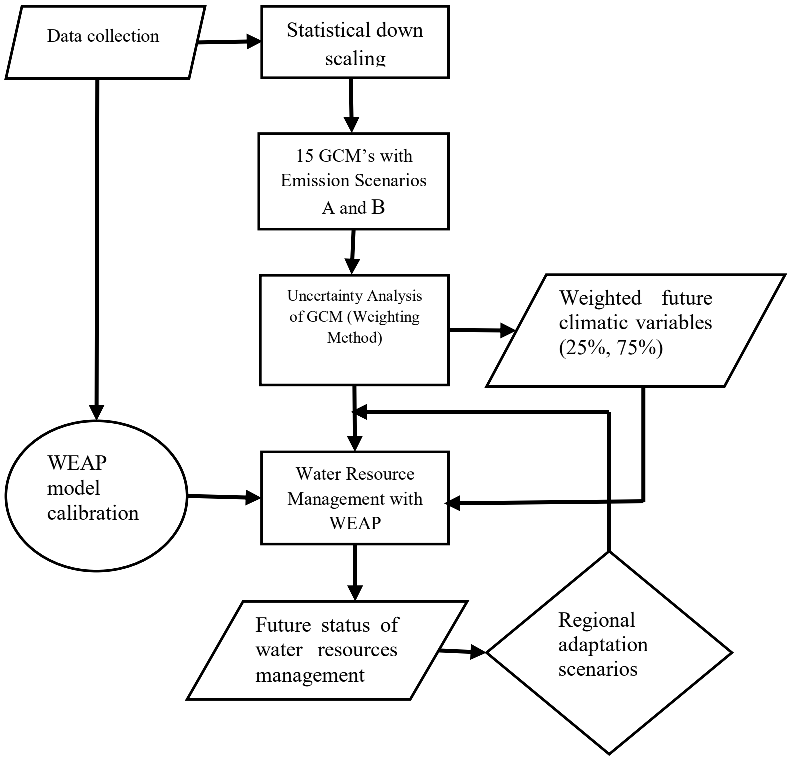


Figure 2: Methods Applied in this Present Study
Source: Zamani et al.

Water Resource Management with WEAP

Among all the water allocation models, Water Evaluation and Planning (WEAP) has been the most widely used model in different basins around the world in the last decades (Yates et al. 2009). We used the WEAP model to simulate the Pishin region. From an analysis perspective, the model can assess all aspects of water management and different solutions and can model the all-purpose, competing consumptions of a water resource system. The WEAP model uses a standard linear planning model to find solutions for water allocation problems in each time step whose objective function is to maximize the percent satisfaction of demand center requirements with respect to demand and supply priority, mass balance, and other constraints. All constraints are alternatively defined for each time step and with respect to demand and supply priority. The WEAP model calculates water mass balance equation for each node and link in each time step. It assumes that the performance of system components—except for reservoirs and soil moisture—in each time step is independent of other steps. The allocation algorithm of the WEAP model is described below (Yates et al. 2005).

For each $p = 1 \, to \, P$	For each demand priority
For each $f = 1 \, to \, F \in (D_k^{P,t-n})$	For each supply preference to demand, k

$Max \quad Z = C_P$	Coverage to all demand sites $k \in N$ with priority p

Subject to

$\sum_{j=1}^{n} x_{j,i}^{p} - \sum_{r=1}^{m} x_{i,r}^{p} + S_i^{t-1} = S_i^t$	Mass balance constraint with storage for node i to node r
$\sum_{j=1}^{F} x_{j,i}^{p} = D_k^{p,t-n}$	Demand node constraint for demand k from j sources
$\sum_{j=1}^{F} x_{j,i}^{p} = D_k^{p,t-n} \times c_k^p$	Coverage constraint for demand k from j sources
$\sum_{j=1}^{F} x_{j,i}^{p} \geq D_k^{p,t-n} \times c_k^p$	Coverage constraint for ifr and reservoirs k from j sources
$c_k^p = C$	Equity constraint for demand site k with priority p
$c_k^p \geq C$	Equity constraint for ifr and reservoirs with priority p
$0 \leq c_k^p \leq 1$	Bound for demand site coverage variables (not ifr or reservoirs)
$\begin{cases} x_{i,1}^{\succ p} = 0 \\ x_{i,1}^{p} \geq 0 \end{cases}$	For Demand Site I with priority $\succ P$ For Demand Site k with priority $= P$
$\begin{cases} x_{i,k}^{\succ f} = 0 \\ x_{i,k}^{f} \geq 0 \end{cases}$	For Demand Site k with priority $\succ f$ For Demand Site k with priority $= f$
$next \, f$	
$next \, p$	

Where P are the demand priorities, f are the supply preferences for each demand k, of N total demand sites. The constants $D_k^{p,t-n}$ are determined for each demand site k with priority P .The $x_{j,i}^{P}$ terms define the flows from nodes j to i with priority P, S_i^t are the reservoir storages at site i for time t, C_P is the total coverage for priority p, and c_k^P is the percent coverage for individual demand sites.

Definition of Scenarios

We chose 2015 (a year with adequate data and statistics) as the base year for the WEAP model and the model was fed with all system data including requirements, resources, etc., under the current conditions. The impact of the constructed scenarios as regional adaptation strategy was explored for the period 2025–2045. These scenarios analyzed water resources management in three states: 25 percent likelihood of climate change, 75 percent likelihood of climate change, and exclusion of climate change.

Scenario 1

As reference scenario, this scenario exists as default in that data of the current conditions are considered up to the end of the 2025–2045 period. It is used as a base for comparison with other scenarios in which changes were applied to system data.

Scenario 2

This scenario assumed governmental projects for regional development, the alleviation of water waste during its transfer from the Pishin dam to the Shir Govaz dam through pipelines, and the improvement of irrigation efficiency by as high as 60 percent using sprinkler and drip irrigation techniques. In this scenario, governmental projects were analyzed under three states, including 25 percent likelihood of climate change, 75 percent likelihood of climate change, and the exclusion of climate change.

Scenario 3

This scenario addressed the elimination of agriculture and the development of the industry. Given the low efficiency and high water demand of agriculture in the studied region, the demand of this sector was removed and it was replaced with industrial sector due to its low water demand. With respect to the local conditions, we selected textile and food industries. As well, the scenario considered environmental water demand and drinking water demand of people struggling with poverty in Pishin Village where there is no access to water distribution system.

Results and Discussion

First, we calculated the results of statistical downscaling of thirty models generated from fifteen GCMs and two scenarios A1 and B1 by change factor method for monthly precipitation and temperature over the period 2025–2045. Then, the uncertainties of GCMs in forecasting temperature and precipitation were analyzed. Finally, the management of local water resources in future was explored assuming no change in climate and the impacts of climate change. In fact, the water resources management was analyzed under three states: 1) data derived from local meteorological stations, 2) data generated under the assumption of 25 percent likelihood of climate change, and 3) data generated under the assumption of 75 percent likelihood of climate change. For instance, Figure 3 depicts the results of downscaling of the FGOALS-G1 model under scenarios A1 and B1 for temperature and precipitation prediction over the period 2025–2045.

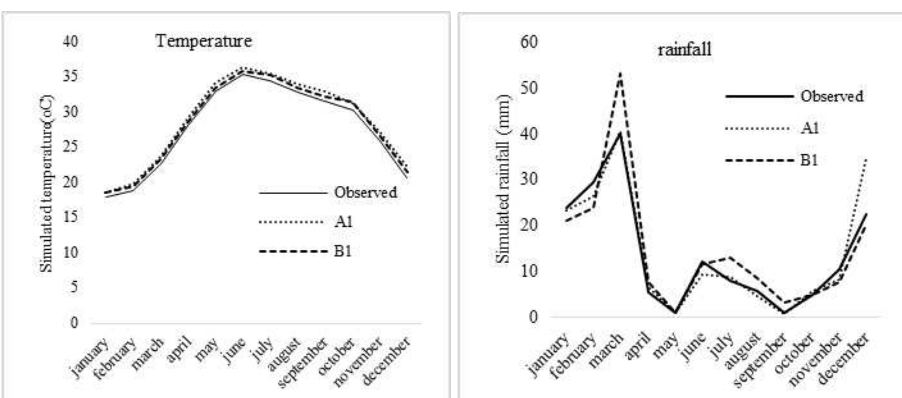


Figure 3: Monthly Temperature and Precipitation Predicted by the FGOALS-G1 Model under Scenarios A1 and B1 for the Period 2025-2045. Observational Data are Shown with the Bold Line

Source: Zamani et al.

According to the results of downscaling of temperature and precipitation that were predicted by GCMs, precipitation fluctuates much in the studied region so that models showed a drastic increase in precipitation rate (refer to Figure 3). But, temperature variations were predicted by GCMs to be insignificant, slight increases were observed in the temperature of the region. The monthly precipitation that was predicted by the MRI CGCM2.3.2.a, BCM2, CSIROMk3.0, ECHAM5OM, GFDLCM2.1, GISS-AOM, HADCM3, NCARPCM models in scenario A1 and the monthly precipitation that was predicted by the MRI CGCM2.3.2.a, BCM2, CSIROMk3.0, GFDLCM2.1, HADCM3, NCARPCM models in scenario B1 were eliminated based on the root-mean-square error (RMSE) index and their results were not included in uncertainty analysis.

Table 2: Weights Calculated for Each GCM in Simulating Monthly Precipitation under Scenario A1

	CGCM3T63	*ECHO-G*	*FGOALS-g1.0*	*INMCM3.0*	*MIROC3.2 hires*	*MIROC3.2 medres*	*NCARCCSM3*
Jan	0.04	0.02	0.62	0.02	0.03	0.23	0.04
Feb	0.02	0.02	0.05	0.01	0.02	0.01	0.88
Mar	0.25	0.02	0.52	0.05	0.02	0.11	0.04
Apr	0.14	0.21	0.16	0.11	0.18	0.11	0.10
May	0.13	0.10	0.22	0.07	0.14	0.23	0.11
Jun	0.13	0.29	0.18	0.16	0.07	0.05	0.11
Jul	0.09	0.13	0.19	0.11	0.07	0.06	0.34
Aug	0.03	0.26	0.05	0.03	0.02	0.10	0.51
Sep	0.05	0.09	0.15	0.20	0.13	0.09	0.29
Oct	0.06	0.10	0.24	0.30	0.09	0.06	0.15
Nov	0.02	0.47	0.04	0.11	0.05	0.28	0.03
Dec	0.51	0.24	0.03	0.02	0.03	0.10	0.06

Source: Zamani et al.

Table 3: Weights Calculated for each GCM in Simulating Monthly Temperature under Scenario A1

	BCM2.0	*CGCM3*	*CSIROMk*	*ECHAM5*	*ECHO-G*	*FGOALS*	*GFCM21*	*GIAOM*	*HADCM3*	*INCM3*	*MIHR*	*MIROC*	*MRI CGCM*	*NCAR CCSM*	*NCAR PCM*
Jan	0.07	0.05	0.10	0.07	0.09	0.10	0.04	0.09	0.13	0.06	0.03	0.05	0.07	0.03	0.05
Feb	0.06	0.04	0.12	0.07	0.06	0.06	0.05	0.10	0.10	0.09	0.03	0.04	0.08	0.03	0.07
Mar	0.11	0.04	0.13	0.07	0.06	0.06	0.04	0.07	0.17	0.04	0.03	0.04	0.06	0.03	0.05
Apr	0.08	0.04	0.14	0.06	0.07	0.07	0.04	0.06	0.11	0.05	0.05	0.04	0.07	0.03	0.09
May	0.05	0.04	0.10	0.08	0.06	0.07	0.06	0.06	0.14	0.06	0.03	0.04	0.07	0.03	0.12
Jun	0.08	0.07	0.12	0.07	0.05	0.07	0.06	0.06	0.08	0.06	0.03	0.06	0.06	0.04	0.07
Jul	0.05	0.05	0.08	0.05	0.04	0.05	0.05	0.05	0.35	0.02	0.03	0.04	0.06	0.03	0.05
Aug	0.03	0.02	0.06	0.04	0.02	0.03	0.05	0.47	0.13	0.01	0.02	0.03	0.03	0.02	0.03
Sep	0.08	0.04	0.07	0.06	0.07	0.05	0.05	0.18	0.14	0.04	0.04	0.06	0.04	0.03	0.07
Oct	0.19	0.03	0.08	0.05	0.13	0.06	0.04	0.13	0.08	0.03	0.03	0.03	0.05	0.02	0.04
Nov	0.09	0.04	0.09	0.08	0.09	0.06	0.04	0.06	0.14	0.05	0.05	0.05	0.07	0.03	0.06
Dec	0.11	0.08	0.08	0.08	0.06	0.04	0.04	0.05	0.15	0.05	0.05	0.05	0.06	0.03	0.07

Source: Zamani et al.

Due to high uncertainty of the output of GCMs, we applied the bounded range with a known probability distribution. It consists of three steps: GCMs weighting, and PDF and CDF construction. Table 2 presents the weight of each GCM in the simulation of future precipitation variations under scenario A1. Table 3 presents weights in the simulation of future temperature variations under the same scenario. The GCM weights are obtained from Equation 5. The GCM model that has more weight means that it is more effective in assembling data. To be concise, we do not present the weights calculated for precipitation and temperature under scenario B1.

The second step deals with calculating PDFs on the basis of the relationship between GCMs weights derived in the first step and the relative variations of monthly precipitation and temperature. Figure 4 displays a discrete sample of PDFs for fifteen GCMs and two scenarios A1 and B1.

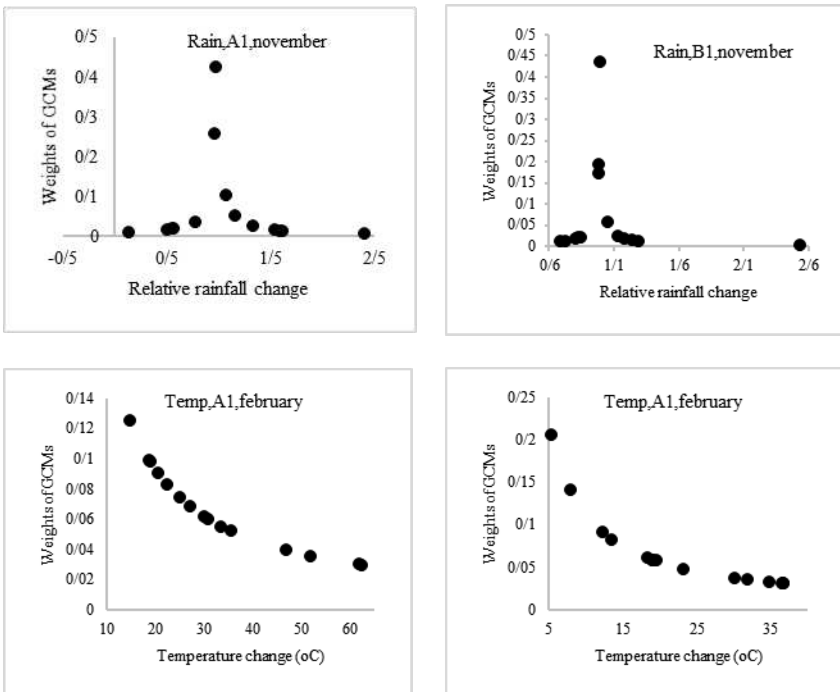


Figure 4: A discrete PDF sample for temperature and precipitation calculated on the basis of the relationship between the weights of 15 GCMs and the variations of monthly precipitation and temperature
Source: Zamani et al.

Figure 5 shows a sample of CDF constructed from PDF for the combination of two scenarios A and B and rainfall and temperature data in the months of June and November.

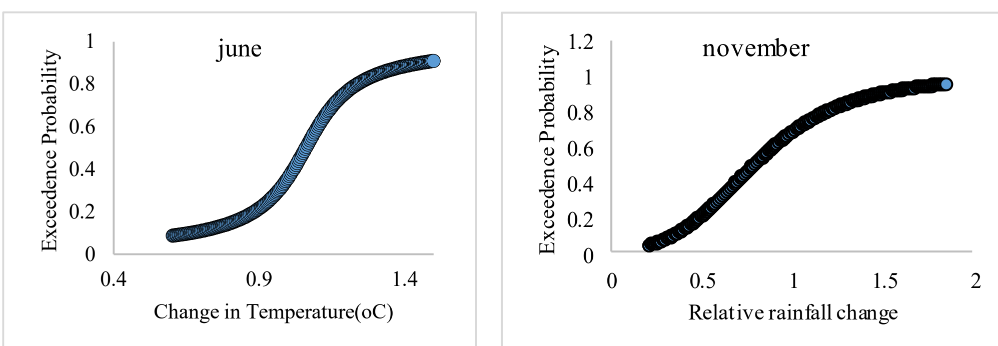


Figure 5: A Sample Temperature and Precipitation CDF Based on PDF Calculated in the Second Step
Source: Zamani et al.

The monthly precipitation and temperature variations were derived from the CDF calculated in the third step for the combination of two scenarios A1 and B1, assuming 25 percent or 75 percent likelihood of climate change. The results are shown in Table 4. Simulations showed vast variations of precipitation in the 25 percent versus 75 percent likelihoods of climate change, but both likelihoods of climate change demonstrated similar temperature variations. In the 25 percent likelihood of climate change, the precipitation and temperature were increased 10.6 percent and 4.2 percent, respectively; in the 75 percent likelihood of climate change, the precipitation and temperature were increased 42.2 percent and 7.1percent, respectively. Due to rising rain and the lack of adequate infrastructure to control flooding, there will be widespread damage to the agricultural products, and the roads and the bridges. The average monthly variations derived for two scenarios of A1 and B1 under two likelihoods of 25 percent and 75 percent were used as the input data for the WEAP model to analyze water resources management.

Table 4: Average Monthly Variations Predicted for the Studied Period under the Studied Likelihoods and Scenarios, Q1 And Q3 are the First and Third Quartiles

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Precipitation data		23.9	29.6	40.1	5.4	1.0	12.0	7.9	5.6	1.0	5.0	10.6	22.6	13.7
Rain	25% (Q1) , A1, B1	23.8	32.0	41.3	6.2	1.0	14.8	9.6	10.1	1.6	5.5	11.3	24.9	16.5
	75% (Q3) , A1, B1	29.4	38.5	49.5	8.9	1.2	21.0	11.8	19.3	2.8	7.0	13.2	31.6	23.0
Temperature Data		17.9	18.8	22.6	28.1	33.0	35.3	34.5	32.9	31.6	30.2	26.0	20.6	27.6
Temp	25% (Q1) , A1, B1	19.0	20.0	23.8	29.6	34.4	36.7	35.2	33.7	32.5	31.3	27.3	21.9	28.8
	75% (Q3) , A1, B1	19.7	20.7	24.7	30.4	35.2	37.5	36.0	34.9	33.0	32.2	28.1	22.6	29.6

Source: Zamani et al.

Water resources management in the study area was simulated by the WEAP model using the results for monthly precipitation and temperature assuming 25 percent or 75 percent likelihood of climate change, as well as using data derived from the meteorological stations. The results showed that the average water demand for the period 2025–2045 was 73.3 MCM for the agricultural sector of Bahu Kalat, 18 MCM for drinking water sector of Chabahar, 16.55 MCM for the environmental sector, and 14.7 MCM for the illegal water exploitation by the agricultural sector. The agricultural sector was found to have the highest water demand of 82 percent. Figure 6 presents the unmet demand in the study area under three simulation states. The average unmet demand of the sectors in the reference scenario was estimated to be 63.7 MCM simulated with the assumption of 25 percent likelihood of climate change, 50.5 MCM simulated with the assumption of 75 percent likelihood of climate change, and 74.8 MCM simulated with observational data excluding climate change. As well, the unmet demand of the agricultural sector was found to be 74, 73 and 78 percent assuming 25 percent, 75 percent, or no likelihood of climate change, respectively. The water demand in the study area was not met under the three studied states. However, it is not fully met under the present conditions either whereas the local environment and agriculture are being destroyed due to the lack of adequate water.

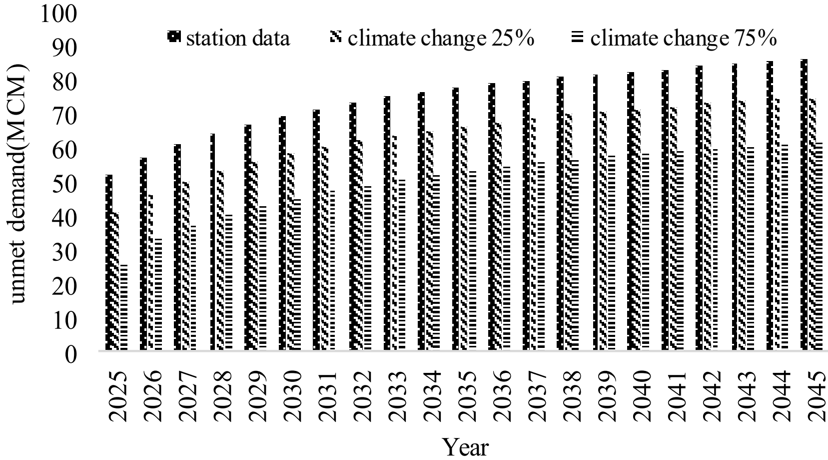


Figure 6: Average Unmet Demand of Different Demanding Sectors under Three States Including the Use of Meteorological Station Data and Assuming 25 and 75% Likelihood of Climate Change
Source: Zamani et al.

Figure 7 displays the unmet demand of different demanding sectors in scenario 2. This scenario was constructed on the basis of the governmental projects and goals for the planning and development of the Pishin region. The current irrigation efficiency in the region is 35 percent. We assumed 60 percent enhancement of irrigation efficiency using sprinkler and drip irrigation techniques over five years.

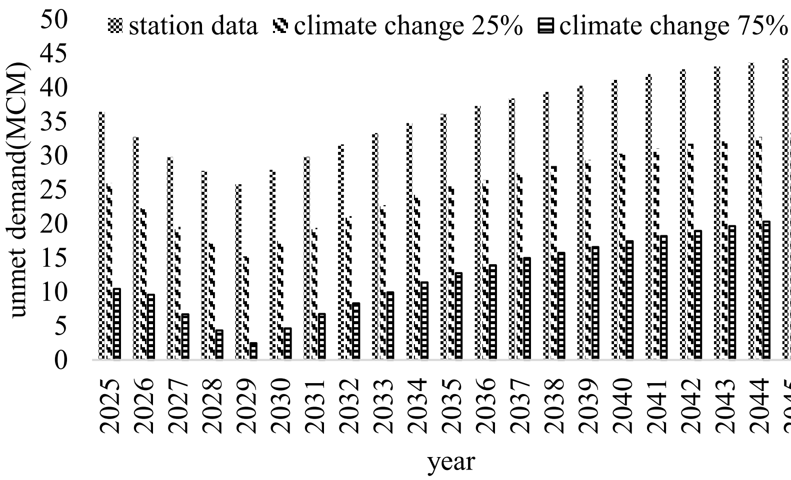
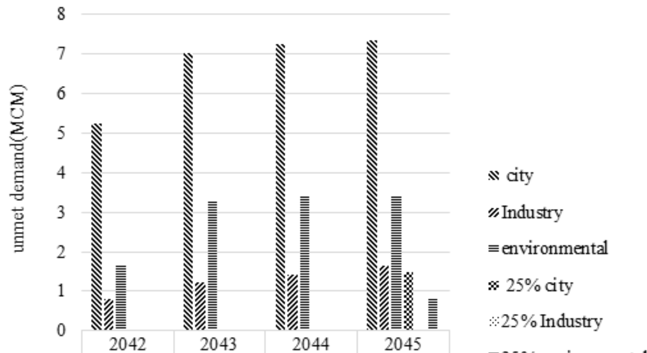


Figure 7: Average Unmet Demand of Different Demanding Sectors in Three States Considering the Governmental Projects and Goals
Source: Zamani et al.

According to the results, when the development projects that have been designed by the government are considered, water resources management is challenged and the water demand of different sectors is not fulfilled. Assuming there is improvement in irrigation efficiency, the unmet demand decreases over the period 2025–2031, but then, it starts to increase with the increase in higher temperature and surface evaporation as well as population growth. If the current conditions continue in the region, the water demand will not be met in the region and the Pishin region will be evacuated. Given high water demand and low efficiency of agriculture in

Iran on the one hand and the loss of water resources in the study area on the other hand, we replaced the agricultural sector with the industrial sector to generate employment and income for farmers and unemployed people. In addition to alleviating water stress in the region and avoiding excessive water use by the agricultural sector, this strategy will help to reduce the unemployment rate and will solve the economic problems of the region.

Figure 8 displays the results of agriculture elimination and its replacement with industry in scenario 3. This scenario analyzed the unmet demand of new water demanding sectors, including drinking water of Chabahar, industry, and the environment after the elimination of agriculture under three assumed states.



	2042	2043	2044	2045
city	5.3	7.0	7.3	7.3
Industry	0.8	1.2	1.4	1.6
environmental	1.7	3.3	3.4	3.4
25% city	0	0	0	1.5
25% Industry	0	0	0	0
25% environmental	0	0	0	0.8

Figure 8: Average Unmet Demand of Different Sectors in Two States of 25% Likelihood of Climate Change and the Exclusion of Climate Change
Source: Zamani et al.

In any three states analyzed by agriculture elimination and its replacement with industry in scenario 3 during 2025–2041, the unmet demand was zero, implying that whole water demand is met in the region. Assuming 25 percent likelihood of climate change, water demand of the sectors will be met in 2042 till 2044, but the total unmet demand was found to be 7.8 MCM, 11.5 MCM, 12.1 MCM, and 12.3 MCM from 2042 to 2045 assuming exclusion of climate change, respectively. The amounts are the total of unmet demand of city, agriculture, and industry. The unmet demand in 2045 was 2.3 MCM in 25 percent likelihood of climate change, and the water demand in newly created sector was zero. Assuming 75 percent likelihood of climate change, the unmet demand in the industry sector becomes zero and the water demand of the all sectors will be met.

Conclusion

This article explored the status of water resource users in the Pishin region assuming the impacts of climate change. The results of climate change show a drastic increase in precipitation and a slight increase in temperature in the region. Then temperature and precipitation changes were calculated based on 25 percent and 75 percent likelihood of the occurrence of climate change, and finally the impact of water resource management carried out by WEAP model

The fulfillment of governmental projects for water resources management in the region within the scenarios showed that when the impacts of climate change are excluded, the water demand of different sectors is not met, but when these impacts are included, the water demand was reduced in 25 percent and 75 percent likelihood of climate change 29 percent and 65 percent, respectively. The agricultural sector shows a very low efficiency and high water demand in the study area. When water demand of agriculture is not met, people will have to migrate since they have access to no other source of income. At present, in the environmental sector, Iranian mugger crocodiles are migrating and are in danger of extinction. To mitigate the impacts of climate change, the agricultural sector was eliminated and replaced with the industrial sector. The results revealed that the water demand will be met for different sectors over the period 2025–2041 and the impacts of the water shortage will be minimized. If the environmental demand is met over this period, the challenge of mugger crocodile migration and extinction will be alleviated. At 25-percent and 75-percent likelihood of climate change respectively 10 percent and 42.2 percent rainfall was increased; therefore, floods will increase in the area, and the lack of adequate infrastructure to prevent flood damage will cause more damage to the inhabitants. These uncontrolled waters would move out of range and out of reach. Therefore, an effective strategy to mitigate the impacts of climate change is to eliminate the agricultural sector that consumes 82 percent of available water resources and to replace it with industries. As a suggestion to reduce the problem of fresh water, considering the study area is alongside the Oman Sea, a water desalination plant should be studied.

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