Climate change adaptation: A case study of Sistan & Baluchestan Province in Iran

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Abstract Impacts of climate change could have far-reaching and unpredictable consequences on water resources in many watersheds. Investigation of relevant adaptive alternatives and advancement of decision support tools can help governments and policymakers at local and state levels to design cost-effective adaptive policies. In this paper, the results of a comprehensive study which has been done for assessing climate change impacts on surface and groundwater resources in Sistan & Baluchestan Province in Iran are presented. The water supply system performance in the main river basins of this province under assessed conditions of climate change till the year 2050 using A2, A1B and B1 scenarios has been simulated. Different criteria representing water supply reliability and resiliency in urban and agricultural sectors have also been used for ranking the climate change adaptation scenarios using Compromise Programming. The results of this study have shown relatively significant changes in the performance of the water supply systems in the future under different scenarios and importance of planning for climate change adaptation.
Keywords climate change adaptation; IPCC; SRES; compromise programming

INTRODUCTION

The Intergovernmental Panel on Climate Change (IPCC), founded by UNEP, have provided some probable scenarios for global warming and CO_2 generation rate. New generations of the General Circulation Models (GCM) have been also developed by various countries based on these assumptions for the current century. In this paper, effects of three SRES scenarios, namely A2, B1 and A1B, on four major dams in the Sistan and Baluchestan Province in Southeast Iran is studied. No likelihood has been attached to any of the SRES scenarios. These scenarios are briefly explained as follows (IPCC, 2007):

- A1: assumes a world of very rapid economic growth, a global population that peaks in mid-century and rapid introduction of new and more efficient technologies. A1 is divided into three groups that describe alternative directions of technological change: fossil intensive (A1FI), non-fossil energy resources (A1T) and a balance across all sources (A1B). In this study, only A1B scenario has been used.
- B2: describes a world with intermediate population and economic growth, emphasizing local solutions to economic, social, and environmental sustainability.
- A2: describes a very heterogeneous world with high population growth, slow economic development and slow technological change.

In the next section of the paper, the study area is briefly introduced.

WATER RESOURCES IN SISTAN & BALUCHESTAN PROVINCE

The Sistan & Baluchestan Province is located in Southeast Iran with an area of 1810 km^2 and population of 1.7 million. It has an annual precipitation of 190,954 m^3. This province has a dry climate and very limited precipitation which mostly occurs in the form of heavy monsoon storms during summer. These storms usually form sever flash floods in the southern part of the Province near the coasts of Oman Sea. Extreme fluctuations of surface water resources availability, ground water qualitative and quantitative limitations, high speed wind, and political conflicts regarding the shared water resources with Afghanistan and Pakistan are some of the main hydrometeorological characteristics of the study area. This region has four main river basins: Hamun-Hirmand, Hamun-Meshkil, Hamun-Jazmurian and South Baluchestan. Figure 1 shows the location of these river basins.

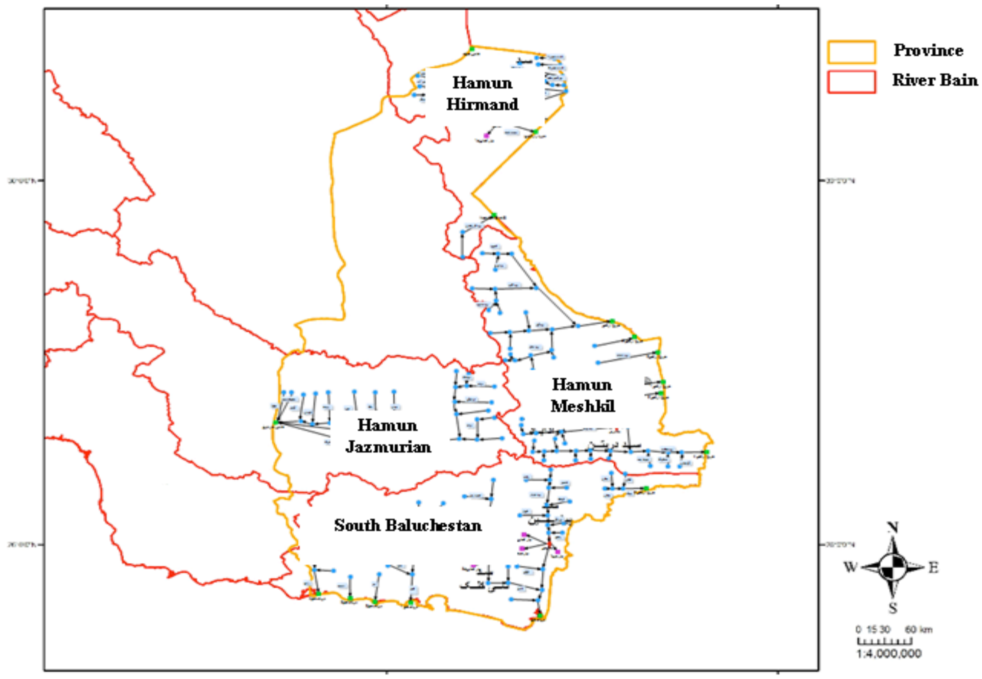

Fig 1. River basins in Sistan & Baluchestan Province

Several small to large scale dams have been constructed in this basin mainly to supply water demands and reduce flood damages. Schematic of some of these river-reservoir systems are shown in Figure 1. In this study, four of these dams have been studied as the most important water storage and regulation infrastructure in the Province.

Zirdan Dam has been recently constructed on Kajoo River in the South-Baluchestan River basin. The main objectives of building this dam have been to supply domestic demands of Chabahar and Konarak cities and agricultural demand of 3,800 hectares of Pirsohrab irrigation network. Pishin dam has been constructed on Sarbaz River in the year 1993 and is the largest dam in the province. This reservoir controls the flash floods of Sarbaz River in the Monsoon season and supplies the water demands of Chabahar city and Bahookalat irrigation network. Recently, the possibility of 10 m increase of the dam height has been studied. Kheirabad Dam has been constructed on Nikshahr River. The main objectives of building this dam have been to supply 1.9 million m^3 of Nikshahr city's domestic demands and 4.5 million m^3 of agricultural demands of 293 hectares of Nikshahr plain. Saradan Dam has been constructed on Kenaroo River in the South Baluchestan River basin. The main objective of this dam has been artificial recharge of 13 million m^3 water to the aquifer in Sarkohooran plain. For more information on these dams see Table 1.

Table 1. Major characteristics of the four major reservoirs in the Sistan and Baluchestan Province ($10^6 m^3$)

Reservoir	Total Volume	Annual Irrigation Demand	Annual Municipal Demand	Major Objectives of Dam Construction
Zirdan	207	46.7	10	Water supply to Chahbahar and Konarak Cities and Pirsohrab irrigation network and flood control
Pishin	175	10.2	26.3	Water supply to Chahbahar city and Bahookalat irrigation network and flood control
Kheirabad	27.3	1.9	4.5	Supplying Nik-shahr domestic and agricultural water demands
Saradan	12	-	-	Artificial groundwater recharge and flood control

DOWNSCALING

To assess the effects of climate change on water resources in the study area, the major influencing meteorological variables including air temperature and precipitation must be downscaled. The Group Method of Data Handling (GMDH) is among data mining techniques, which has various applications in regression and time series prediction (Nariman-Zadeh et al. 2005, Kim et al. 2009). In the current paper, this method has been used as a statistical downscaling tool. For this purpose, nine meteorological predictors including Geopotential Height (GH), Air Temperature (AT) at three levels of 200, 500 and 850 mbar, and also Sea Level Pressure (SLP), Surface Air Temperature (SAT), and Precipitable Water (PW) over 13º 94′ 37″ to 34º 22′ 54″ (latitude) and 56º 25′ to 78º 75′ (longitude) with grid resolution of 2.5º×3.75º (latitude × longitude) are considered as the GMDH model input variables (see Figure 2). The model is calibrated with observed rainfall records from 1967 to 1990 and evaluated with the same data recorded in the years of 1990 to 2000 in 21 rain gauges distributed across the study area. The time series of daily aforementioned meteorological variables is also obtained from IPCC-AR4 databank for IPSL-CM4 model. The reason for choosing this specific model is that Cai et al. (2009) has shown that IPSL-CM4 model has a relatively better performance in the study area compared with the other IPCC-AR4 recommended AOGCM models.

The study area receives almost all of its annual rain in the months of December through March and in the Monsoon season during July and August. Absolutely no rain occurs in the rest of the months in almost all of the rain gauges across the province. GMDH has been used to downscale the precipitation in the four months of December, January, February, and March.

The calibrated GMDH model has then been used for predicting the precipitation in the selected months in the period of 2001-2050 in each of the 21 rain gauges. The Inverse Distance Weighting (IDW) method has been used to estimate the areal average precipitation over each of the four watersheds. The average values of historical and predicted precipitation can be seen in Table 2. Overall, significant reduction of precipitation in January is predicted in Hamun-Hirmand and Hamun-Jazmurian basins. More precipitation is predicted in March in all of the basins. Less changes in precipitation has been predicted for the month of December. Figure 3 also shows the comparison between the average areal rainfall in the months of December through March over the four watersheds in the Province.

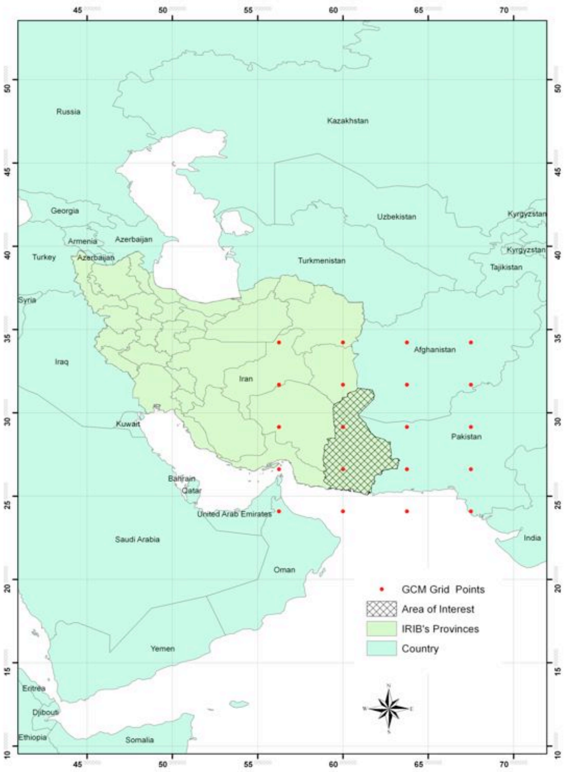

Fig 2. Sistan and Baluchestan Province and Grid Points of IPSL-CM4 Meteorological Variables

Table 2. Statistical characteristics of observed and predicted precipitation

River basin	Period/Scenario	December	January	February	March
Hamun Meshkil	1975-2000	17.23	16.41	18.32	9.29
	2001-2049 A1B	19.7	17.7	15.6	29.5
	2001-2049 A2	19.7	18.7	18.3	33.4
	2001-2049 B1	19.1	16.8	18.2	32.3
Hamun Hirmand	1975-2000	28.40	19.88	19.83	10.81
	2001-2049 A1B	23.8	7.1	19.5	32.8
	2001-2049 A2	22.7	7.3	20.4	34.4
	2001-2049 B1	16.5	7.9	18.0	29.9
Hamun Jazmurian	1975-2000	20.88	29.38	24.11	16.60
	2001-2049 A1B	29.1	6.8	33.9	47.0
	2001-2049 A2	26.4	5.9	33.3	40.0
	2001-2049 B1	24.1	8.3	28.3	41.5
South Baluchestan	1975-2000	27.22	26.96	17.89	20.28
	2001-2049 A1B	29.7	29.2	29.0	32.5
	2001-2049 A2	30.4	26.8	28.9	35.7

2001-2049 B1	28.7	25.0	27.8	34.2

CLIMATE CHANGE ADAPTATION

The operation of Zirdan, Saradan, and Kheiabad Dams have been started some times during the past 2 years. Recently, the regional water company in Sistan and Baluchestan Province has studied the possibility of increasing the normal water level in Pishin Dam and the area of irrigated agriculture downstream of this dam. The main purpose of this part of the study is to show to what extent the climate change affects the operation of these newly built dams and how different alternatives for development of Pishin river-reservoir system can be chosen based on the climate change predictions. For this purpose, the following steps have been taken:

Fig.3. Total precipitation in the months of December through Match in four main watersheds of Sistan and Baluchestan Province (historical: 1975-2000 -- climate change scenarios: 2001-2050)

1. The time series of inflows to the dams during 2001-2050 are estimated using downscaled precipitation
2. The performance of each of the four reservoirs are simulated using the predicted inflows and the impacts of climate change are assessed
3. The compromise programming is used to rank the Pishin system development under climate change scenarios.

In the next sections of the paper, first the compromise programming technique is briefly explained and then the results of the reservoir operation simulations are presented.

COMPROMISE PROGRAMMING

Classical compromise programming is a Multi-Criteria Decision Analysis (MCDA) technique for identifying the best compromise solution from a set of solutions by some measure of distance. The measure of distance, referred to as a distance metric, determines the closeness of a particular solution to a generally infeasible ideal solution. Therefore, obtaining a compromise solution is analogous to obtaining a solution that is as close as to the practically impossible ideal solution. Compromise programming

$$L = \left[W \left(\frac{f - f}{f - f^{-}} \right) \right]$$

distance metric in its discrete form can be presented as:

(1)

where:
z: index for criteria or objective (z=1,2,3,…,t);
j: index for alternatives (j=1,2,3,…,n);

$$L_j$$

$$w_z$$

$$p$$

: distance metric of alternative j;
: corresponds to a weight of criteria or objective z;
: parameter (p=1,2,…,∞);

$$f_z^-$$

and: best and the worst values for criteria z, respectively (also referred to as positive and negative ideals);

$$f_z$$

: actual value of criterion z.

The parameter p is used to represent the importance of the maximal deviation from the ideal point. If p=1, all deviations are weighted equally; if p=2, the deviations are weighted in proportion to their magnitude. Changing the parameter p from 1 to infinity, allows one to move from minimizing the sum of individual regrets (i.e., having a perfect compensation among the objectives) to minimizing the maximum regret (i.e., having no compensation among the objectives) in the decision making process. The choice of a particular value of this compensation parameter p depends on the type of problem and desired solution. In general, the greater the conflict between players is, the smaller the possible compensation becomes.

CLIMATE CHANGE IMPACTS ON THE RESERVOIRS

As it was mentioned before, three climate change SRES family scenarios were considered in this paper (A2, B1, A1B). In order to assess the performance of the reservoirs, the monthly reservoir inflows in the years of 2000 to 2050 in the three climate change scenarios have been predicted and the reservoirs performances in the three scenarios are compared with their performance using the historical observed inflows. Table 3 shows the summary of the reservoir operation simulations. As it can be seen in this table, Zirdan reservoir inflows will increase 10 to 13 percent while the deficit in supplying demands will decrease 1 to 4 percent.

The climate change scenarios also show significant increases in the reservoir spills. Kheiabad reservoir simulations show a high uncertainty in climate change impacts ranging from 16% reduction to 13% increase in reservoir inflows. The reliability in supplying demands has been increased in all of the three scenarios ranging from 1.3% to 5.8%. Table 3 shows Saradan reservoir will not be highly influenced by climate change. All the three scenarios show 19 to 23 percent reduction in Pishin reservoir inflows. Since the spills of the reservoir have been significantly reduced in climate change scenario simulations, there has been no significant impact on supplying demands from this reservoir.

RANING THE WATER RESOURCES DEVELOPMENT ALTERNATIVES

Based on the brainstorming sessions with the decision makers in the Sistan and Baluchestan Regional Water Company, 12 alternatives have been defined for water resources development in Pishin river-reservoir system. The first six alternatives are based on keeping the current normal water level (262 masl) of the Pishin reservoir and increasing the irrigation lands in the Bahookalat irrigation network from 900 ha (current area) to 5675 ha. The rest of alternatives have the same set of agricultural lands while the normal water level is increased to 272 masl. These alternatives have been ranked by assessing four main criteria: water supply reliability, resiliency, which is a criterion for assessing the speed of recovery of the reservoir from a failure in satisfying the water supply objective, average annual spill volume of the reservoir, and agricultural area irrigated by Pishin Dam. The first three criteria represent the reservoir performance while influenced by the hydrologic alterations due to climate change. The agricultural area is a sample criterion representing the social and economic status of the resident society in downstream of Pishin reservoir. Table 4 shows the relative weights assigned by the decision makers to these criteria and the values estimated for each criterion for the three climate change scenarios.

Table 3. Reservoir operation simulations (numbers are in $10^6 m^3$/year – red(blue) shows reduction(increase) compared with historical simulation)

Historical Simulation	A2 (2000-2050)	A1B (2000-2050)	B1 (2000-2050)	Operation Index	Reservoir
107.2	121.4 (13.24%)	119.4 (11.38%)	118.4 (10.44%)	Inflow	Zirdan
31	39.9 (27.8%)	34.7 (11.93%)	33.8 (9.3%)	Spill	
52.8	53.5 (1.3%)	55.7 (5.5%)	55.2 (4.5%)	Regulated Water	
8.3	7.2 (1.1%)	3.4 (4.9%)	4.3 (4%)	Deficit (%)	
18.7	19.2 (2.76%)	21.1 (12.83%)	15.6 (16.57%)	Inflow	Kheirabad
7.9	7.9 (0%)	9.6 (12.51%)	4.6 (41.72%)	Spill	
6	6.2 (3%)	6.4 (6%)	6.2 (3%)	Regulated Water	
7.4	6.1 (1.3%)	1.6 (5.8%)	4.3 (3.1%)	Deficit (%)	
25	25 (0%)	23 (8%)	26.5 (6%)	Inflow	Saradan
10	10.3 (3%)	9.7 (3%)	11.5 (15%)	Spill	
11.8	11.8 (0%)	10 (7%)	12 (1.7%)	Regulated Water	
2.9	2.3 (0.6%)	10.3 (7.4%)	0.5 (2.4%)	Deficit (%)	
220.6	177.1 (19%)	170.7 (22.6%)	172.1 (22%)	Inflow	Pishin
150.1	108.4 (28.8%)	102.4 (31.8%)	103.6 (31%)	Spill	
36.2	36.6 (1.1%)	36.2 (0%)	36.6 (1.1%)	Regulated Water	
1.3	0.1 (1.2%)	0.9 (0.4%)	0.1 (1.2%)	Deficit (%)	

Table 4. Decision matrix for scenario A2 in Pishin Dam

Alternat	Irriga	A2	A1B	B1

ive	ted area (ha)	Spill (10^6 m^3)	Resiliency (%)	Reliability (%)	Spill (10^6 m^3)	Resiliency (%)	Reliability (%)	Spill (10^6 m^3)	Resiliency (%)	Reliability (%)
1	900	108.4	1	0.99	102.4	0.25	0.98	103.6	1	0.99
2	1950	97.9	0.5	0.98	0.92	0.18	0.97	93.9	0.33	0.98
3	3100	88.2	0.47	0.97	82.9	0.18	0.94	85.3	0.33	0.93
4	4000	81.7	0.31	0.91	77.1	0.32	0.89	79.2	0.26	0.89
5	5100	74.8	0.3	0.92	70.6	0.26	0.91	72.2	0.23	0.85
6	5675	71.4	0.32	0.85	67.6	0.28	0.83	69.9	0.24	0.85
7	900	89.2	1	0.99	83.2	0.22	0.98	84.4	1	0.99
8	1950	79.5	0.4	0.99	73.7	0.18	0.98	75.2	0.33	0.98
9	3100	69.8	0.25	0.98	64.3	0.15	0.97	66.2	0.4	0.96
10	4000	63.4	0.21	0.97	58.4	0.33	0.94	60	0.3	0.93
11	5100	56.2	0.26	0.95	51.4	0.19	0.9	52.7	0.26	0.91
12	5675	52.6	0.28	0.91	48.2	0.16	0.89	49	0.26	0.89
Best	6000	0	1	1	0	0.33	1	0	1	1
Worst	500	200	0.1	0.7	200	0.1	0.7	200	0.1	0.7
Weight	0.3	0.1	0.2	0.4	0.1	0.2	0.4	0.1	0.2	0.4

Based on the compromise programming results shown in Table 4, for the A2 scenario, alternative 11 (Normal water level of 272 masl and irrigated area of 5100 ha) shows the best level of adaptation with hydrologic predictions in this scenario. The alternative 7 (Normal water level of 272 masl and irrigated area of 900 ha) is ranked first for adaptation with the predictions in the B1 scenario. For the A1B scenario, alternative 10 (Normal water level of 272 masl and irrigated area of 4000 ha) has been chosen. Comparison between the results of different scenarios show that increasing the normal water level of the Pishin Dam is in favor of adaptation with climate change. The proper limits of expansion of agricultural lands downstream of Pishin dam is 5100 ha based on the predictions in A2 scenarios.

Since there is a high uncertainty about how realistic the climate change scenarios are, another comparison has been also made by taking into account all of the 10 criteria (irrigated land and 3 other criteria for all three climate change scenarios). Alternative 7 has been chosen as the best development policy given equal probabilities to all three climate change scenarios. Since all of the climate change scenarios predict decrease of inflows to the Pishin dam, selection of alternative 7 leads to saving the spills by increasing the dam height and also prevents high deficits in supplying irrigation demands by developing the irrigation network extensively. A sensitivity analysis has been carried out on the parameter p by changing it from 1.0 to 3.0. The best alternatives have shown no sensitivity to p value in the chosen range.

CONCLUSIONS

In this paper, a comprehensive study has been carried out to investigate the effects of climate change on a dry and strategic region in southeast Iran. However all of the three scenarios show probable increase in average rainfall in the four watersheds in Sistan and Baluchstan Province, some local effects of climate change can result in decrease of the precipitation in some specific seasons such as the case of Pishin Reservoir Basin in South Baluchestan watershed. Compromise Programming method has been successfully applied in this study for ranking water resources development alternatives based on the level of adaptation with climate change.

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