RISK ANALYSIS AND INTEGRATED WATER RESOURCES MANAGEMENT BASED ADAPTATION STRATEGIES FOR ZAYANDEH RUD IRRIGATION SYSTEM, IRAN

STRATEGIES D'ADAPTATION COMPTE TENU DE L'ANALYSE DES RISQUES ET DE LA GESTION INTEGREE DES RESSOURCES EN EAU DU SYSTEME D'IRRIGATION ZAYANDEH RUD, IRAN

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ABSTRACT

One of the most important consequences of climate change is its impacts on water resources. Evaluation of adaptation strategies to cope with this phenomenon is an essential action, which construct the objectives of the present research work. For this, the uncertainties of 7 AOGCM models with A2 emission are evaluated for the Zayandeh Rud basin during two future periods (i.e. 2010-2039 and 2070-2099) and probability distributions of possible changes on rainfall and temperature are estimated. Similarly, impacts of these changes are evaluated on water resources and agricultural decision indices (e.g. water supply, crop yield, irrigation demand and water use efficiency). Furthermore, DSSAT package is applied to assess different adaptation strategies at the field level. These strategies include changing cultivar, increasing irrigation efficiency, planting dates and deficit irrigation. Also, trans-boundry water project and changing dam operation are the evaluated strategies at basin level. To apply these strategies with respect to integrated water resources management paradigm, an allocation water model are developed, too. The results show that changing cultivar and water transfer would have higher positive impacts on the decision indices.

Key words: *Climate Change, Adaptation, Risk analysis, DSSAT, Zayandeh Rud Basin.*

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RESUME

L'une des conséquences les plus importantes du changement climatique est son impact sur les ressources en eau. L'évaluation des stratégies d'adaptation pour faire face à ce phénomène est une action essentielle qui forme les objectifs de l'étude de recherche actuelle. A cette fin, on a évalué les incertitudes de 7 modèles MCGAO avec les émissions d'A2 du bassin Zayandeh Rud pour les deux périodes futures (2010-2039 et 2070-2099) et l'impact des distributions de probabilité des changements possibles sur les précipitations et les températures. De même, les impacts de ces changements sont évalués sur la base des indices de décision des ressources en eau et agricoles (approvisionnement en eau, rendement des cultures, demande d'irrigation et efficience d'utilisation de l'eau).

Par ailleurs, la méthode DSSAT est appliquée pour évaluer différentes stratégies d'adaptation au niveau de la parcelle. Ces stratégies comprennent le changement des variétés cultivées, l'augmentation de l'efficience d'irrigation, et l'utilisation d'irrigation déficitaire. En outre, le projet d'eau transfrontalier et le changement de l'exploitation du barrage sont les stratégies évaluées au niveau du bassin. En outre, on a également développé un modèle d'allocation d'eau pour mettre en œuvre ces stratégies à l'égard de paradigme de la gestion intégrée des ressources en eau. Les résultats montrent que le changement des variétés cultivées et le transfert d'eau aura un impact positif sur les indices de décision.

Mots clés : *Changement climatique, adaptation, analyse des risques, DSSAT, Bassin de Zayandeh Rud.*

1. INTRODUCTION

The Intergovernmental Panel for Climate Change (IPCC) reported that the Earth's surface temperature has increased up to 0.76 °C over the last century and it is anticipated that the average surface temperature can increase up to 6.4 °C by 2100 (IPCC, 2007). These changes could have significant effect on the globe's ecosystem and especially, on water resources and agriculture productions.

These facts make adaptation issue crucial, necessary and call for more attention than the present considerations. Adaptation measures in water resources management refer to increased water storage (e.g. reservoirs, soil water and groundwater), increased economic (savings/loans) and food buffer capacities. Due to increase in hydro-meteorological extremes that increase in consecutive years of dry periods, agricultural systems will face serious water shortages. Farmer might overcome the impact of a one-year drought followed by a normal year, but a period of two or more years of drought will be catastrophic to them (Droogers and Aerts, 2005).

Rosenzweig et al. (2004) conducted an integrated study to examine the changes in crop water demand and water availability for the reliability of irrigation with respect to climate change, taking into account changes in competing municipal and industrial demands. They explored the effectiveness of adaptation options in maintaining reliability. Their approach was applied to major agricultural regions of the world like Argentina, Brazil and the US. Their results showed that even in these relatively water-rich areas, changes in water demand due to climate change effects on agriculture and increased demand from urban growth will require timely improvements in crop cultivars, irrigation and drainage technology, and water management. They had applied the Decision Support System for Agrotechnology Transfer (DSSAT) (IBSNAT, 1989), a software package that includes crop models and routines for analyzing climate inputs, model results, and management strategies.

Morid and Massah (2008) suggested changing in cropping patterns and shifting from water demanding crops like rice to less water demanding crops like wheat as well as structuring the pricing policy that would make crops with higher caloric values more beneficial as adaptation strategies to climate cahnge. Droogers and Aerts (2005) investigated different adaptation strategies between seven contrasting river basins throughout the world and examined strategies like deficit irrigation and intensification. For example in case of Walawe basin in Sri Lanka, they showed that even with the adopted strategies, food security was difficult to maintain.

From another point of view the aforementioned researches and likewise others are generally based on the application of GCMs (general circulation models), which attempt to predict the impact of increased atmospheric CO_2 concentrations on weather variables. For instance Droogers and Aerts (2005) and Morid and Massah (2008) applied HadCM2 and ECHAM4 dataset, using A2 and B2 IPCC emissions scenarios projections, the so-called SRES (Special Report on Emissions Scenarios). It is obvious that projections of future climate change are plagued with uncertainties, causing difficulties for planners taking decisions on adaptation. One way is to apply more GCM datasets. For instance, Morid et al. (2006) applied CSIRO-Mk2, ECHAM4/OPYC3, ECHAM3/LSG, HADCM2, HADCM3, CGCM1, GFDL-R15-and NCAR1 GCM models to analyze uncertainties of river flows due to climate change.

This paper evaluates different adaptation strategies to climate change in the Zayandeh Rud irrigation system in an integrated modeling framework that links basin level and field scale simulations. The study focuses on the periods 2010-39 (2020s) and 2070-99 (2080s).

2. MATERIALS AND METHODS

2.1 Study Area and Data

The Zayandeh Rud basin is located in the central part of Iran and has an area of 41500 km^2 (Figure 1). The Zayandeh Rud River flows to the Gawkhoni Swamp, an internationally-recognized wetland listed in the Convention of Ramsar (1975).

The Chadegan dam is the main reservoir with a 1450 MCM (million cubic meters) capacity and has been operational since 1971. Even since the construction of this dam, water resources in the basin are not sufficient. An inter-basin transfer has been put in place by diverting water from the neighboring Karoon and Dez Rivers. The tunnels divert 300 to 400 MCM water per year. The Behesht Abad is another tunnel that is at the feasibility study stage. However, due to huge investment requirements and social unwillingness, it will take a long time for this tunnel to be operational. The total diversion of water from this tunnel is expected to be between 700 and 1000 MCM/y. Presently, the agricultural sector uses about 85% of the basin's water resources.

The major traditional irrigation and modern irrigation systems cover a total area of about 180,000 ha in this basin. Wheat, barley, rice and potato are the dominant crops of the irrigation system with approximate area of 79,000, 28,800, 7,700 and 21,800 ha, respectively. Optimum water extractions to these crops are estimated to be 9,000, 8,000, 17,000 and 11,000 m^3 ha^{-1}.

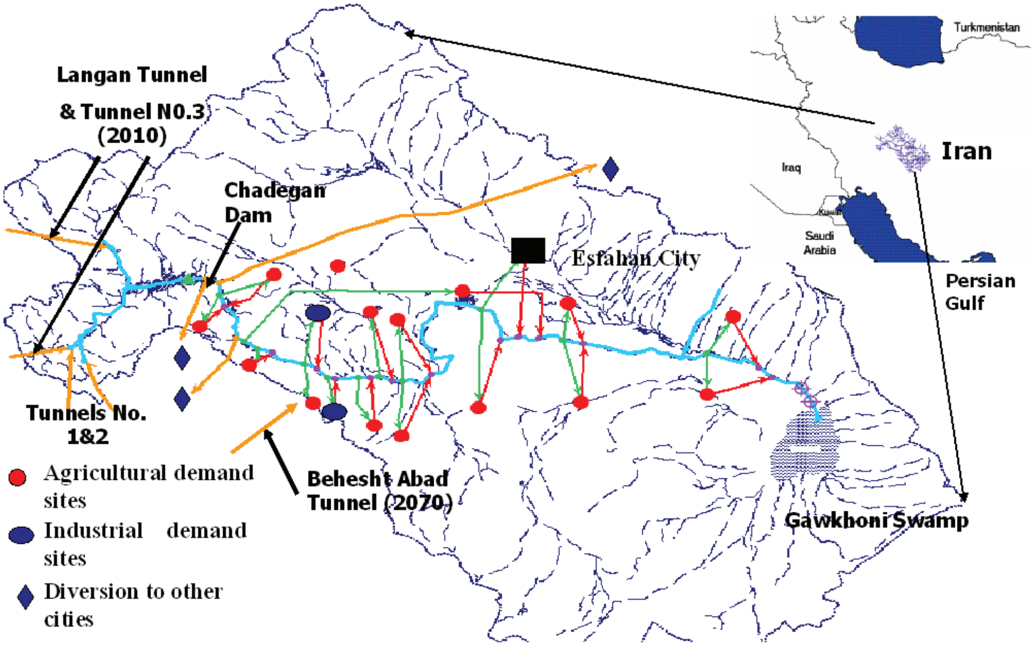

Fig. 1. The Zayandeh Rud Irrigation system and related infrastructures

2.2 A framework for adaptation strategies

The framework selected to evaluate adaptation strategies is the OECD framework (Fig. 2), which has been used in several regional studies (Droogers and Aerts, 2005). Climate change scenarios are used as input to simulation models in order to quantify the impacts of climate change on the water resources of the river basin, and, consequently, the implications on food production and security, and the environment. A set of *State indicators* are defined, which represent the value of a specific parameter of the water resources system for preserving food security and environmental quality. Impacts are defined as the change over time in the values of *State indicators*. Based on these potential impacts and indicators, stakeholders are able to develop and evaluate different adaptation strategies to alleviate negative impacts of climate change (OECD, 1994).

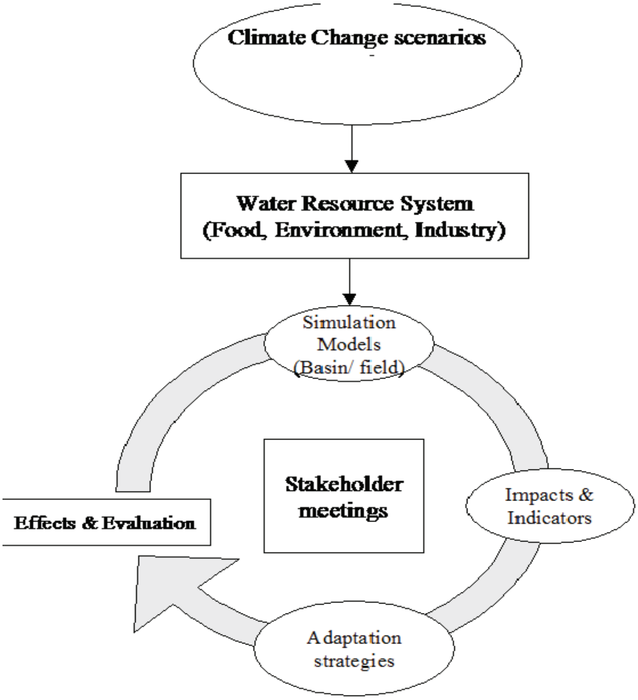

Fig. 2. The frame work selected for adaptation strategy (OECD, 1994)

2.3 Simulation Models

2.3.1. Climate Change Scenarios and uncertainties

The basic climate change data including rainfall and temperature are prepared from CSIRO-Mk2, ECHAM4/OPYC3, ECHAM3/LSG, HADCM2, HADCM3, CGCM1, GFDL-R15-and NCAR1 GCM models (http://www.ipcc-data.org/) for two periods: a near term period (2010-30) and a long term period (2070-99). Since the GCMs provide output at a low level spatial resolution (for instance, it is 2.5° x 3.75° for HadCM3 or 2.8125 ° x 2.8125 ° for ECHAM4) downscaling to local conditions was essential. Thus, the data were statistically downscaled using the 9 surrounding cells of the basin and the inverse distance weighted method. To ensure that historical data and GCM output had similar statistical properties following the various statistical transformations, the method described by Alcamo et al. (1997) was used. For temperature, absolute changes between a historical slice (1971-2000) and the two selected GCM time slices (2020s and 2080s) were added to measured values. For precipitation, relative changes between historical and future GCM output were applied to measured historical values.

Based on the results, temperature changes (ΔT) with respect to the base line (1971-2000) can varies from 0.8 ºC to 1.7 ºC and 2.9 ºC to 7.4 ºC for the two time slices, respectively. In case of rainfall (ΔP), they are -20% to 16% and -40% to 32%, too. Figure 3 shows the monthly temperature changes based on the aforementioned GCMs for the 2070-99 period. Considering the monthly ΔTs and ΔPs from pervious step and using SIMLAB model, 1000 samples of monthly climate scenarios are produced for uncertainty analyses and then, the cumulative density functions (CDF) of ΔT and ΔP are calculated. Figure 4 illustrates the 25, 50 and 75 percent changes in monthly temperature and rainfall based on uncertainty analysis and the GSM models for the 2080s period. In another word, this methodology merges results of all of the GCM models to predict possible changes in climate variables.

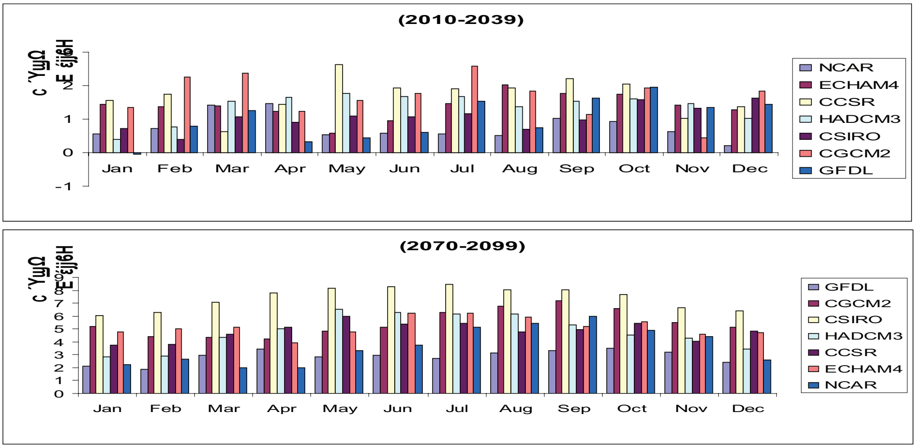

Fig. 3: Temperature climate change scenarios using CSIRO-Mk2, ECHAM4/OPYC3, ECHAM3, HADCM2, HADCM3, CGCM1, GFDL-R15-and NCAR1 GCM models (2010-2039 and 2070-2099)

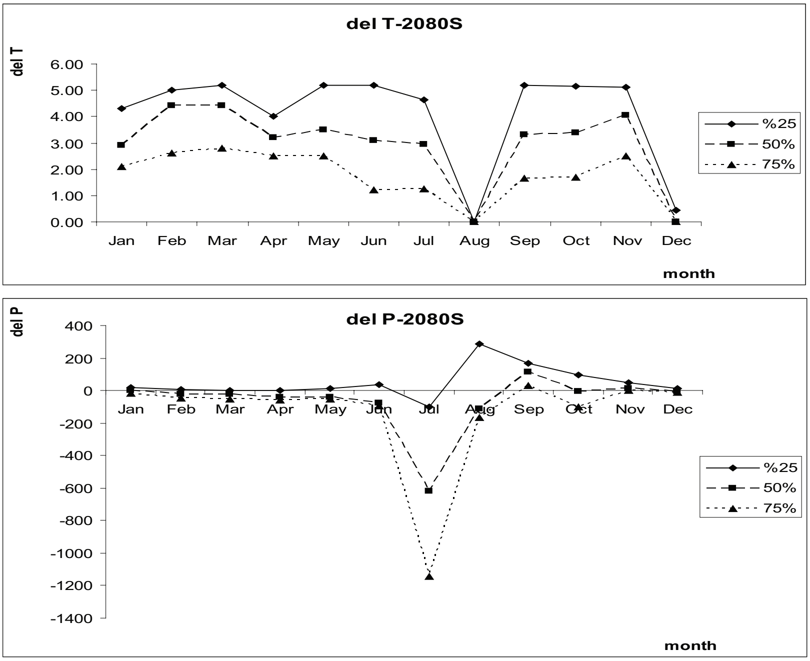

Fig. 4: 25, 50 and 75 percent changes in monthly temperature and rainfall based on uncertainty analysis and the GSM models for the 2080s period

2.3.2 Hydrological simulations

Hydrology is an important driver of the climate change processes. For this study, two models including IHACRES model (Jakeman et al., 1990) and ANFIS (Jang, 1993) technique are selected and compared for rainfall-runoff simulation. The IHACRES uses a non-linear loss module to calculate the effective rainfall and a linear routing module to convert effective rainfall into streamflow. ANFIS categorize as data-driven models that combines fuzzy logic and ANNs (artificial neural networks). This approach applies various learning techniques developed in ANN literature to fuzzy modeling or a fuzzy inference system (FIS) (Brown and Harris, 1994). As a result, this system can utilize linguistic information from the human expert as well as measured data during modeling. Both of the calibrated models use monthly temperature and rainfall as inputs. However, the ANFIS model performed much better than IHACRES (Fig. 5). For instance in case of R2, it is 0.76 for ANFIS and 0.46 for IHACRES.

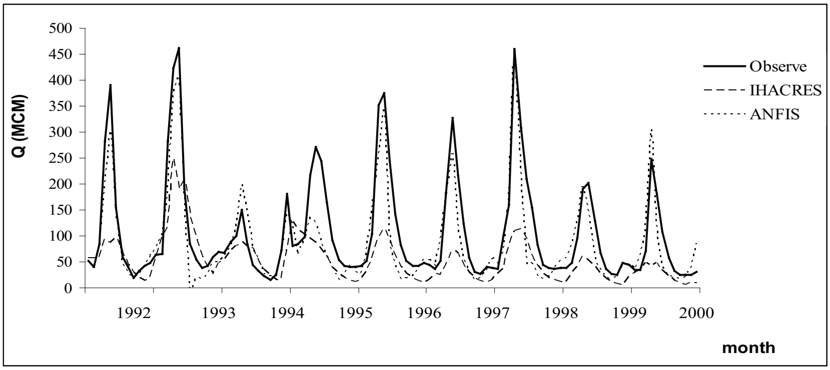

Fig. 5: Observed and estimated monthly river flows using ANFIS and IHACRES models

Using the trained ANFIS models and the results of uncertainty analysis of the previous section on climate variables, the monthly river flows are simulated for the future periods. Figure 6 shows the results for 50% probability of the river flows with respect to climate change, which is notably lesser than present situation.

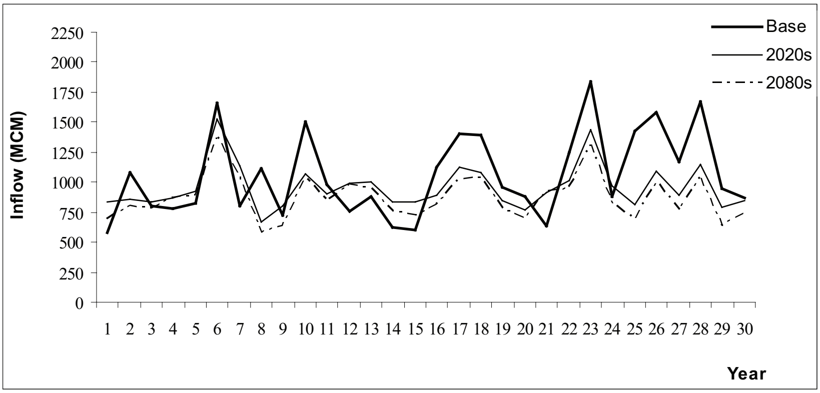

Fig. 6: Estimated monthly flows of Zayande Rud River for the 50% Probabilities occurrence of ΔT and ΔP

For water allocation, the Zayandeh Water Allocation model (ZWAM) was used. As was already pointed out, the basin is highly complex in terms of water allocation, and any change in water resources has a direct impact on all users. To deal with these issues, the ZWAM was exclusively developed for this study. The model is node oriented (Fig. 1) and is able to simulate different water-allocation policies, dam operations, and environmental issues; therefore it is ideal to build “what if” scenarios for the study area.

2.4 Modeling crop water demands and yields

The DSSAT (Decision Support System for Agrotechnology Transfer) (IBSNAT, 1989) is applied for the field scale simulations. The software includes a number well known models to simulate crop yield (CERES), analyzing climate inputs, irrigation water demands (CROPWAT) water generating climate data (WGEN), crop cultivars, fertilization, pesticide, and management strategies. DSSAT has been widely used for regional climate change studies (Rosenzweig et al., 2004).

Among the present basin’s crop, wheat as the most strategic crop is selected to examine the strategies. The weather information is input to the model using the created climate change data in the previous section for 50% probability of occurrence. However, more details about other probabilities and crops are available in Shahkarami (2010).

To simulate plant growth and yield, a cultivar type is needed to be introduced to DSSAT (using CERES module). Furthermore for each cultivar, there are a number of genetic coefficients relating to crop phenology, which are independence of other parameters like soil and climate. In case of wheat they are vernalization (P1V) and photoperiod (P1D), time period (GDD) of grain filling phase (P5), G1 (Potential spikelet number), G2 (Single grain weight) and G3 (Tillering coefficient). The dominant cultivar in the study is ROSHAN and these parameters are calibrated as P1V= 44 day, P1D=75%, P5= 550 oC, G1= 29 #/g,

G2=38 mg and G3= 1 g. The average annual maximum yield is estimated to be 8840 kg/ha, which is recorded as 9000 kg/ha in the study area.

3. RESULTS

This section is organized based on the OECD (1994) framework. Stakeholders’ involvement was obtained by visiting farmers, water managers and policy makers at various hierarchical levels (e.g. the directors of surface and ground water and deputy of planning of the Esfahan Water Authority).

3.1 Evaluation of water use efficiency for base line period

One of the main agricultural management indicators is “crop production”. However, other factors like “water demand” needs to be considered beside crop production. So, we applied “water use efficiency” (WUE) (crop production / water demand) to evaluate their interactions.

For this evaluation, we first applied the calibrated DSSAT model to simulate production of maximum yield within the base line period (1971-2000) (no limitation in water and nitrogen).

The results show the total water demands would be 1064 mm/ha and average WUE for the base line period is 0.83 kg/m^3 for wheat. Figure 7 (curve legend as "Base") presents the CDF of WUE in base line period under the said circumstance.

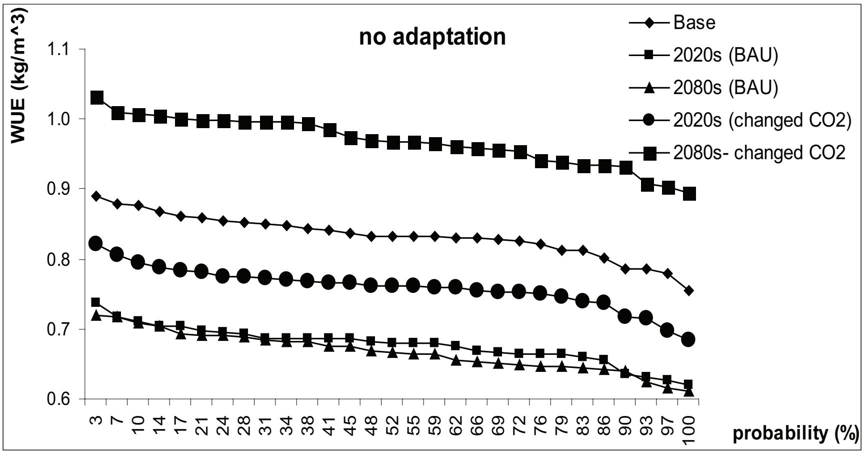

Fig. 7. Cumulative probability function of water use efficiency during different climate condition

3.2 Evaluation of water use efficiency under climate change

Considering changes in temperature and rainfall, it is expected to face with higher evapotranspiration. Figure 8 shows the CDF of possible changes in ET0 comparing with the base line period in March 2020s and 2080s.

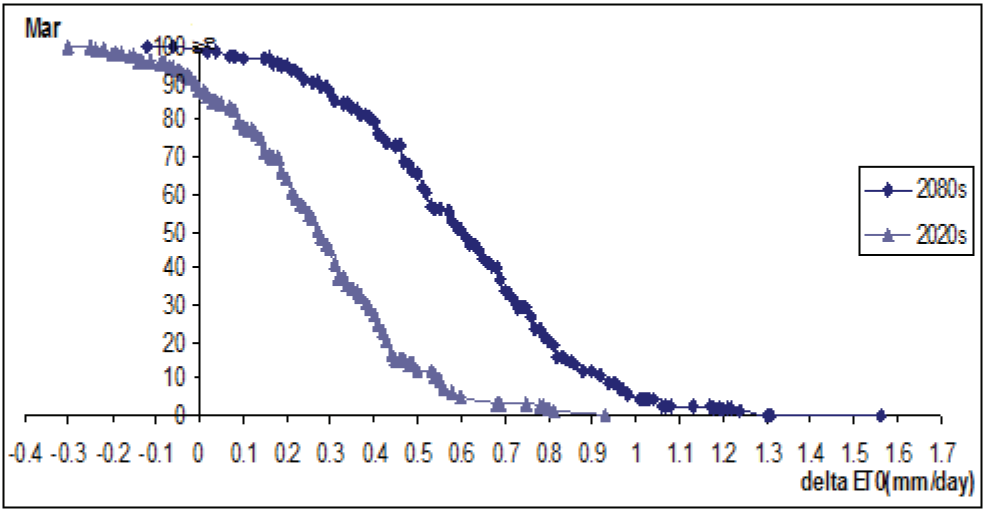

Fig. 8. Cumulative probability function of changes in ET0 during future climate change condition

To evaluate WUE under climate condition, two scenarios are applied that are: 1) no change in Co_2 and 2) change in Co_2. For the second scenario it is predicted that Co_2 increased up to 430 and 715 ppm for 2020s and 2080s, respectively, using the MAGICC model.

The impacts of climate change on WUE are shown in Figure 7 and with more details in Table 1. It shows that irrigation water demand increases about 16% to 20% for the two future periods and WUE increase due to CO_2 augmentation.

Table 1: Average changes in water management factors during climate change periods (%)

Future Periods	CO_2 (ppm)	Wheat				
		Yield	No. Irrigation	Water Demand	Rainfall	WUE
2010-2039	BAU	-7.3	16.3	16.3	-5.0	-15.0
	changed	3.6	16.3	15.8	-5.0	-5.0
2060-2099	BAU	-5.4	22.4	22.6	-17.4	-16.3
	changed	36.9	22.4	22.2	-17.4	21.3

BAU: Business as usual (BAU)

3.3 Adaptation Strategies at field scale

The previous results showed that the business as usual (BAU) management in agriculture can't combat expected negative impacts of climate change. Therefore, a number of adaptation strategies are selected to be evaluated at the field scale using DSSAT package.

Changing cultivar. DSSAT (using CERES module) can simulate plant growth with respected to the introduced cultivars. Here, we applied the cultivars that are already included in the package and ROSHAN as the dominate cultivar in the study area. It should be emphasized that applying the new cultivars needs more works on the genetic parameters and here we only try to evaluate possible role of this strategy for adaptation. The results are shown in Tables 2 and. It can be seen that current applying cultivar (ROSHAN) water demand may increase up to 22% and the WUE reduces up to about 20% due to more water demand. Application of new cultivars like MANITOU can be an effective strategy. For instance, WUE can increase up to about 60% and 110%, incorporating Co_2 fertilization in 2020s and 2080s. Of course, the results seem to be sententious in this case. But, it shows potential impact of this strategy for adaptation.

Increasing irrigation efficiency. Murray-Rust et al. (2004) applied 70% irrigation efficiency for 2025 in his research work for 2025. Present efficiency in the region is about 50% and we have assumed it can be increased up to 70% in 2020s and 80% in 2080s, using new technologies. The results of this strategy are illustrated in Table 4. It shows to have WUE higher than the base line, the irrigation efficiency should reach about 70%, and otherwise the system will fail. Similarly, Co_2 increasing is caused positive impact on yield production and WUE.

Changing planting date. Considering the changes in the region's temperature, changing planting date can be also considered as an adaptation strategy. Based on future changes in the pattern of monthly temperatures resulted from GCM models, different planting dates are tested and the results are shown in Tables 5 and 6. Here, the runs are based on ROSHAN cultivar. Results show the relevant time will be before middle of October, while in the present situation it is in October.

Table 2: Changes (%) in yield, water demand and WUE for different wheat cultivars in 2020s with respect to the base period

Cultivar	No CO_2 change			CO_2 change		
	Change in yield (%)	Change in Water Demand (%)	Change in WUE (%)	Change in yield (%)	Change in Water Demand (%)	Change in WUE (%)
FACULTATIVE	-34.3	-31.0	-6.0	-7.6	-34.9	37.3
MANITOU	4.8	-24.8	37.3	22.0	-25.5	61.4
SPRING-HIGH LAT	-26.3	-32.1	6.0	-0.3	-34.6	48.2
SPRING-LOW LAT	-82.8	-58.3	-62.7	-71.6	-55.2	-42.2
ROSHAN	-7.3	16.3	-18.1	3.6	15.8	-8.4

Table 3: Changes (%) in yield, water demand and WUE for different wheat cultivars in 2080s with respect to the base period

Cultivar	No CO_2 change			CO_2 change		
	Change in yield (%)	Change in Water Demand (%)	Change in WUE (%)	Change in yield (%)	Change in Water Demand (%)	Change in WUE (%)
FACULTATIVE	-71.5	-41.3	-51.8	6.1	-41.4	79.5
MANITOU	-5.4	-25.9	27.7	54.0	-26.1	109.6
SPRING-HIGH LAT	-68.4	-38.2	-49.4	4.4	-40.9	75.9
SPRING-LOW LAT	-92.3	-72.0	-75.9	-60.9	-60.8	-6.0
ROSHAN	-5.4	22.6	-19.3	36.9	22.2	16.9

Table 4: Changes (%) in yield, water demand and WUE for different irrigation efficiency with respect to the base period

No changed in CO_2 2080s			No changed CO_2 2020s			
WUE	Yield	Irrigation	WUE	Yield	Irrigation	Irr.Eff
-19.3	-5.2	22.7	-18.1	-7.1	16.3	50
-4.8	-3.2	4.2	-2.4	-5.1	-1.9	60
9.6	-1.5	-9.4	12	-3.6	-14.7	70
25.3	-0.8	-21.1	*	*	*	80

Changed in CO_2 2080s			Changed CO_2 2020s			
WUE	**Yield**	**Irrigation**	**WUE**	**Yield**	**Irrigation**	**Irr.Eff**
16.9	36.9	22.2	-8.4	3.6	15.8	50
38.6	39	3.1	8.4	5.3	-2.4	60
57.8	40.2	-10.5	25.3	6.7	-15.6	70
78.3	40.6	-21.6	*	*	*	80

Table 5: Changes (%) in yield, water demand and WUE for different planting dates in 2020s with respect to the base period

Planting Date	No CO_2 change			CO_2 change		
	Change in yield (%)	**Change in Water Demand (%)**	**Change in WUE (%)**	**Change in yield (%)**	**Change in Water Demand (%)**	**Change in WUE (%)**
07-Sep	-9.9	33.8	-30.1	0.5	35.0	-22.9
23-Sep	-4.2	25.0	-20.5	7.3	25.3	-12.0
30-Sep	-4.9	20.9	-19.3	6.2	20.8	-9.6
07-Oct	-7.3	16.3	-18.1	3.6	15.8	-8.4
15-Oct	-10.7	12.3	-19.3	-0.9	10.7	-8.4
23-Oct	-15.6	8.9	-21.7	-7.1	6.9	-12.0

Table 6: Changes (%) in yield, water demand and WUE for different planting dates in 2080s with respect to the base period

Planting Date	No CO_2 change			CO_2 change		
	Change in yield (%)	**Change in Water Demand (%)**	**Change in WUE (%)**	**Change in yield (%)**	**Change in Water Demand (%)**	**Change in WUE (%)**
07-Sep	-	-	-	-	-	-
23-Sep	-2.2	32.6	-22.9	39.6	32.9	9.6
30-Sep	-4.0	27.8	-21.7	39.8	29.1	13.3
07-Oct	-5.4	22.6	-19.3	36.9	22.2	16.9
15-Oct	-	-	-	-	-	-
23-Oct	-10.1	13.7	-18.1	26.6	9.2	19.3

-) These dates are associated with very low yield and are omitted from the evaluations

3.4 Adaptation Strategies at basin level

At this stage, we aimed to see impact of climate change on the Zayandeh Rud irrigation system, which is done by the ZWAM model. According to the present water allocation policies, domestic and industrial demands have the first and second priorities, respectively. Agricultural and environmental sectors are next. With respect to the new regulations, the Esfahan Water Authority has been committed to allocate between 75 and 140 MCM/y for the river ecosystems and the industry.

The irrigation system includes 13 irrigation units (IU) that are shown in Figure 1. Also, their names are appeared in Table 6. The present population of the basin is 1970000 and its growth is estimated to be 2% for 2020s and 1% for 2070s. Also, drinking water per capita is considered to be 60 and 80 m^3/yr. There is also 1 tunnel (Behesh Abad) that is under study and can be expected to be operational for 2080s periods. Finally, present cropping pattern in the basin is more than solely wheat. But, it is assumed that this is unique over there to evaluate adaptation strategies.

These policies are embedded in the ZWAM model to estimate water requirements of different IUs. Tables 7 and 8 show water demand (MCM/ha) of different irrigation units applying BAU and other selected strategies for the 2020s and 2080s periods. The tables show significant increase in water demands of the IUs, if no adaptation is implemented.

Table 7: Water demands (MCM/ha) for the irrigation units based on the selected strategies in 2020s

Irrigation units	Base Period	No Adapt	Cultivar Manitou	Irr. Eff. 60%	Manitou Irr. Eff. 60%
Kerron	0.0085	0.0098	0.0063	0.0083	0.0053
SSI_Polzaman_R	0.0085	0.0098	0.0063	0.0083	0.0053
SSI_Polzaman_L	0.0085	0.0098	0.0063	0.0083	0.0053
SSI_Polekaleh	0.0090	0.0104	0.0067	0.0088	0.0056
Mahyar	0.0095	0.0110	0.0071	0.0092	0.0059
Neko Abad_L	0.0119	0.0138	0.0088	0.0116	0.0074
Neko Abad_R	0.0143	0.0166	0.0107	0.0140	0.0089
Abshar_L	0.0112	0.0130	0.0084	0.0110	0.0070
Abshar_R	0.0115	0.0133	0.0085	0.0112	0.0071
SSI_Rudasht_L	0.0096	0.0111	0.0072	0.0094	0.0059
SSI_Rudasht_R	0.0096	0.0111	0.0072	0.0094	0.0059
Rudasht_L	0.0112	0.0130	0.0084	0.0110	0.0070
Rudasht_R	0.0112	0.0130	0.0084	0.0110	0.0070

Table 8: Water demands (MCM/ha) for the irrigation units based on the selected strategies in 2080s

Irrigation units	Base Period	No Adapt	Cultivar Manitou	Irr. Eff. 70%	Chang. planning date	Manitou Irr. Eff. 60%
Kerron	0.0085	0.0104	0.0063	0.0076	0.0093	0.0047
SSI_Polzaman_R	0.0085	0.0104	0.0063	0.0076	0.0093	0.0047
SSI_Polzaman_L	0.0085	0.0104	0.0063	0.0076	0.0093	0.0047
SSI_Polekaleh	0.0090	0.0110	0.0067	0.0081	0.0098	0.0050
Mahyar	0.0095	0.0116	0.0070	0.0085	0.0104	0.0052
Neko Abad_L	0.0119	0.0145	0.0088	0.0106	0.0130	0.0065
Neko Abad_R	0.0143	0.0175	0.0106	0.0128	0.0157	0.0079
Abshar_L	0.0112	0.0137	0.0083	0.0101	0.0123	0.0062
Abshar_R	0.0115	0.0140	0.0085	0.0103	0.0125	0.0063
SSI_Rudasht_L	0.0096	0.0117	0.0071	0.0086	0.0105	0.0053
SSI_Rudasht_R	0.0096	0.0117	0.0071	0.0086	0.0105	0.0053
Rudasht_L	0.0112	0.0137	0.0083	0.0101	0.0123	0.0062
Rudasht_R	0.0112	0.0137	0.0083	0.0101	0.0123	0.0062

In the next step the future stream flows, which were simulated in section 2.3.2 (Figure 6) are input to the ZWAM model and the met and unmet demands are calculated for each IU and in total, over the irrigation system with respect to the selected strategies. Figure 9 shows the results of ZWAM, while applying cultivar change for 2020s.

To evaluate our strategies following criteria are applied:

- Total annual water requirements
- Percent of the years with unmet demands
- Percentage of water shortage in agricultural sector
- WUE in the selected years

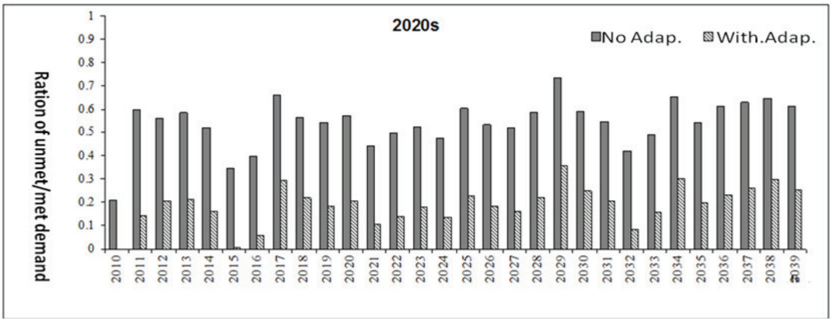

Fig. 9. Ratio of unmet to met agricultural water demand under changing cultivar adaptation in 2020s

Results of these huge calculations are summarized in Tables 9 and 10 for the strategies that have more significant impact on WUE and combating climate change. As it can be seen for 2080s, water transfer from neighboring basin is added 2080s. However, it is associated with many social conflicts in spite of very positive role to mitigate the losses. Finally, Table 11 shows combined strategies. The results shows importance and effectiveness of cultivar and water use efficiency as the main solutions for adaptation to climate change.

Table 9. Changes (%) in the agricultural sector criteria with respect to selected adaptation strategies for 2020s

Criteria Scenario	Agr. Water Demand (%)	Ration.Unmet/ met years (%)	Relative shortage of water (%)	WUE (%)
Chang.Cultivar	-35	-22	-51	96
Irr.Eff.	-15	-1	-17	16

Table 10. Changes (%) in the agricultural sector criteria with respect to selected adaptation strategies for 2080s

Criteria Scenario	Agr. Water Demand (%)	Ration.Unmet/ met years (%)	Relative shortage of water (%)	WUE (%)
Chang.Cultivar	-40	-11	-32	15
Chang.palnt.date	-10	0	-4	-9
Irr.Eff.	-27	-2	-17	7
Trans-boundary	0	0	-17	0

Table 11. Changes (%) in the agricultural sector criteria with respect to selected adaptation strategies for 2020s

Period	Criteria Scenario	Agr. Water Demand (%)	Ration. Unmet/met years (%)	Relative shortage of water (%)	WUE (%)
2020s	Chang.Cultivar+ Irr.Eff	-46.0	-35.4	-68.6	112.0
2080s	Chang.Cultivar+ Irr.Eff.	-54.9	-22.4	-57.2	214.1

4. CONCLUSIONS

This study aimed to explore a modeling system to evaluate impacts of climate change on the water resources, food productions, and assess in a quantitative manner adaptation strategies in the Zayandeh Rud irrigation system. The following conclusions were drawn:

- The developed modeling system, which was combination of DSSAT and ZWAM showed capability to include basin level simulations as well as field scale simulation and explore adaptation options with readily available data.
- The results show that the impact of climate change will cause the basin to experience more water shortages in addition to significant drop in crops yield.
- Significant need of new cultivars is illustrated in this research work.
- The results show effectiveness of increasing irrigation efficacy and planting date.
- The present available water resources of the basin will not be sufficient to meet various demands. Transfer of water from the neighboring basins to the Zayandeh Rud basin is an essential adaptation measure. The impacts of such a transfer on the original basins with respect to the climate change need to be evaluated before implementation.
- In spite of negative impact of climate change, the paper shows that this phenomenon can be managed with a scientific vision and the suggested strategies can result higher crop production even comparing with present situation.

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