An integrated MODSIM- PSO Model for optimal Multi-Crop Planning in the agricultural Areas of the Karkheh River Basin, Iran, under the Impacts of Climate Change

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Table of content

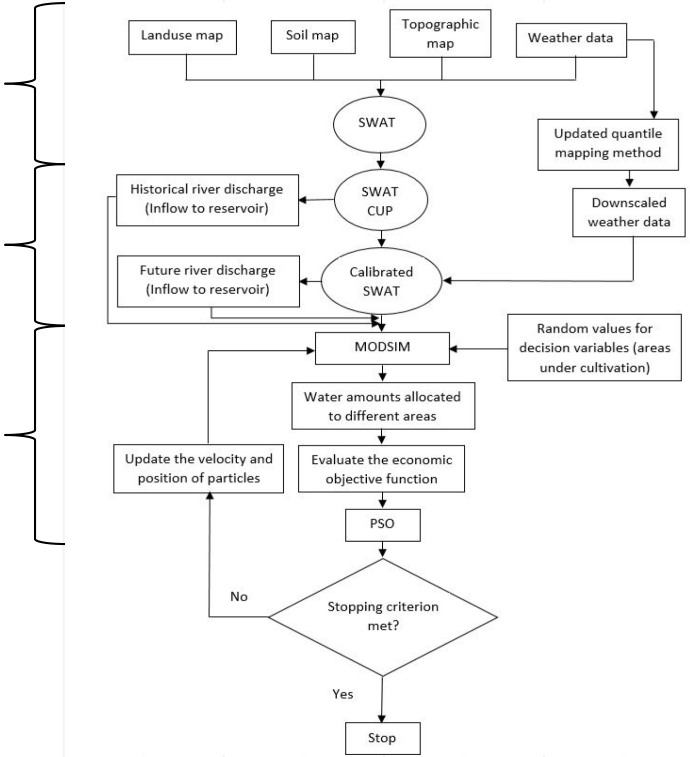
Contents

SWAT model building

Calibration & Validation of streamflow, downscaling

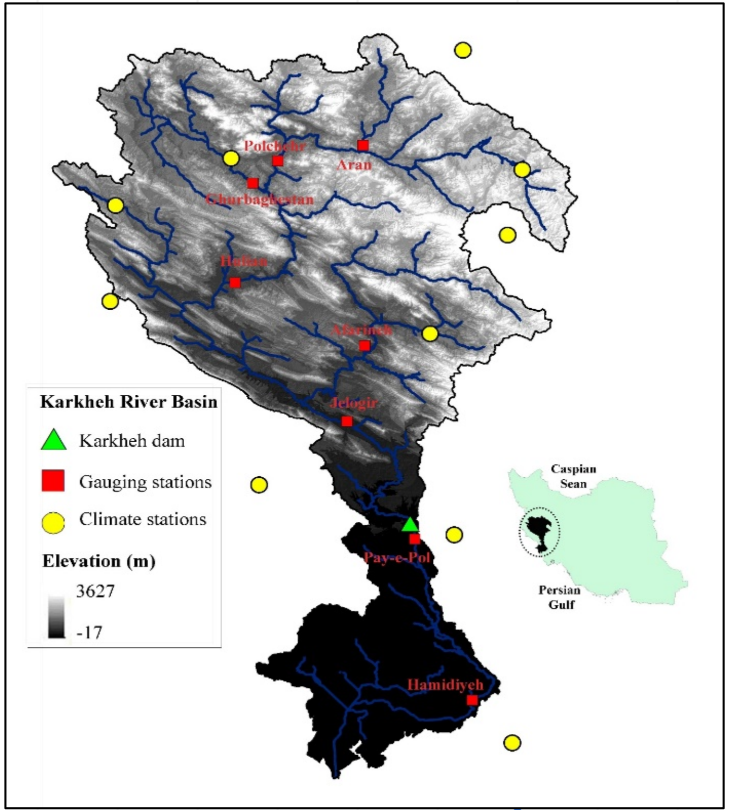
Integrated MODSIM-PSO model and Economic analysis

Flowchart

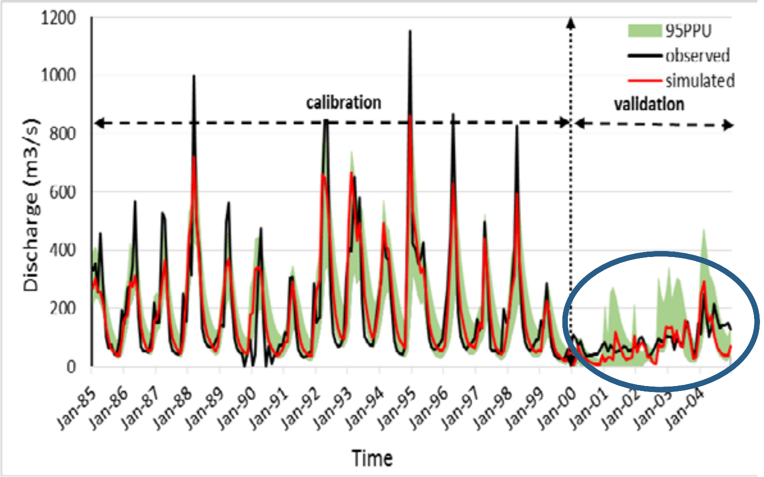


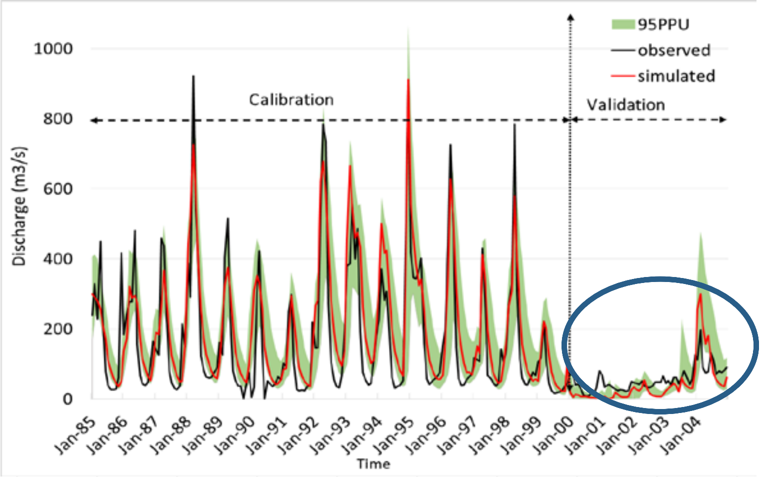
Study area

- Area: Around 51000 KM2, third largest watershed in Iran
- One of the most important basins in Iran in terms of Surface and groundwater resources, agriculture potential, hydropower generation,…
- Average annual precipitation that ranges between 150mm in the south and 7500mm
- Multipurpose Karkheh dam: designed storage capacity of about 7.5×109 m3 and live storage capacity of about 4.7×109 m3
- The objectives of the dam : providing of water for irrigation of 320,000 ha of the agricultural lands, hydroelectric power generation amounting to 934 GWh per year And flood control in the downstream sections of the river basin



SWAT- CUP Results (streamflow)





Observed and simulated monthly outflow (m3/s) for calibration and validation at Pay-e-Pol (up) and Hamidiyeh (down) stations

- Karkheh reservoir became operational in 2002
- The basin experienced a severe drought from 2000 to 2004

SWAT- CUP Results

Initial and final ranges of the 7 most sensitive SWAT calibration parameters

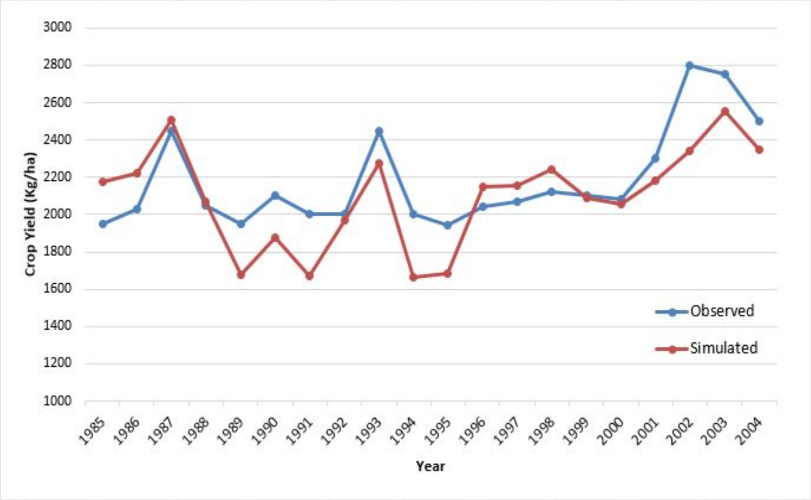
Parameter name	Definition	Initial range	Final range
r__CN2	SCS runoff curve number	-0.4 to 0.4	-0.32 to -0.16
v__GWQMN	Threshold depth of water in shallow aquifer required for return flow	1500 to 3500	1520 to 2538
v__ALPHA_BF	Base flow alpha factor	0.4 to 1	0.56 to 0.87
v__EPCO	Plant uptake compensation factor	0.2 to 0.7	0.27 to 0.55
r__SOL_BD	Moist bulk density	0 to 0.35	0 to 0.23
v__RCHRG_DP	Deep aquifer percolation fraction	0.1 to 0.7	0.25 to 0.64
v__SHALLST	Initial depth of water in shallow aquifer	2500 to 4000	2930 to 3849

Statistical measures for monthly outflows at the 8 gauging stations for calibration and validation

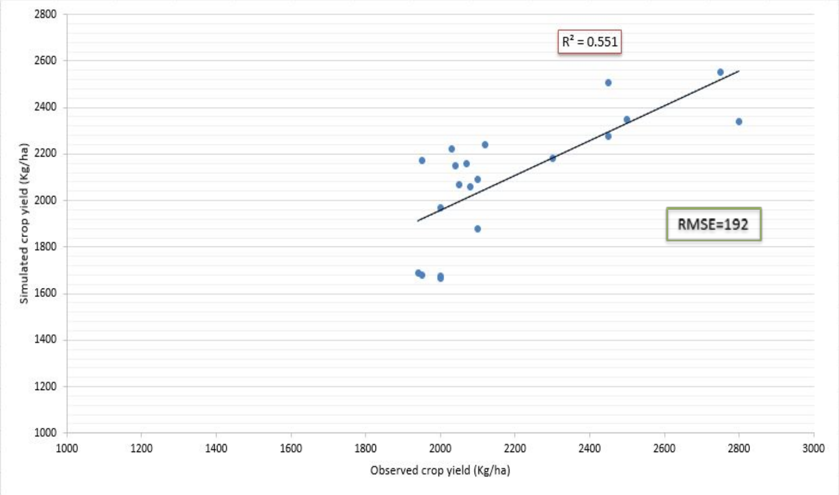
Station	P-factor cal./val	R-factor cal/val	R^2 cal/val	NSE cal/val
Aran	0.76/0.78	1.18/1.09	0.62/0.61	0.59/0.56
Polchehr	0.81/0.85	1.19/1.03	0.68/0.64	0.52/0.63
Ghurbaghestan	0.88/0.88	1.37/1.05	0.61/0.81	0.54/0.80
Hulian	0.70/0.73	0.97/0.77	0.77/0.76	0.73/0.74
Afarineh	0.94/0.88	1.26/0.82	0.70/0.69	0.62/0.52
Jelogir	0.78/0.82	1.09/0.87	0.83/0.81	0.82/0.80
Pay-e-Pol*	0.72/0.88	1.00/1.08	0.78/0.68	0.78/0.66
Hamidiyeh*	0.65/0.66	1.21/0.98	0.79/0.65	0.72/0.61

*Stations located downstream of the Karkheh dam

SWAT Results (manual calibration of crop yields)



Winter wheat crop yield simulation by SWAT in Dasht-e-Abbas agricultural plain



The correlation between simulate and observed wheat crop yield in Dasht-e-Abbas agricultural plain

Bias correction (Updated Quantile Mapping, Themeßl et al. (2012))

- HadGEM2-ES climate model
- RCP4.5 and RCP8.5 scenarios

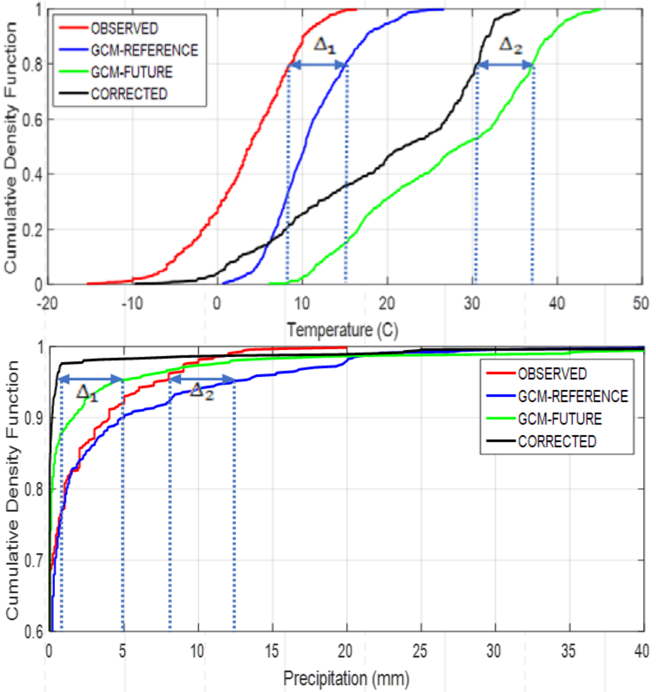
$$P_d^{GCM,ref} = ECDF_d^{GCM,ref}\left(X_d^{GCM,ref}\right)$$

$$CF_d^{GCM,ref} = ECDF_d^{obs^{-1}}\left(P_d^{GCM,ref}\right) - ECDF_d^{GCM,ref^{-1}}\left(P_d^{GCM,ref}\right)$$

$$CF_d^{GCM,ref} \xrightarrow{Extrapolation} CF_d^{GCM,fut}$$

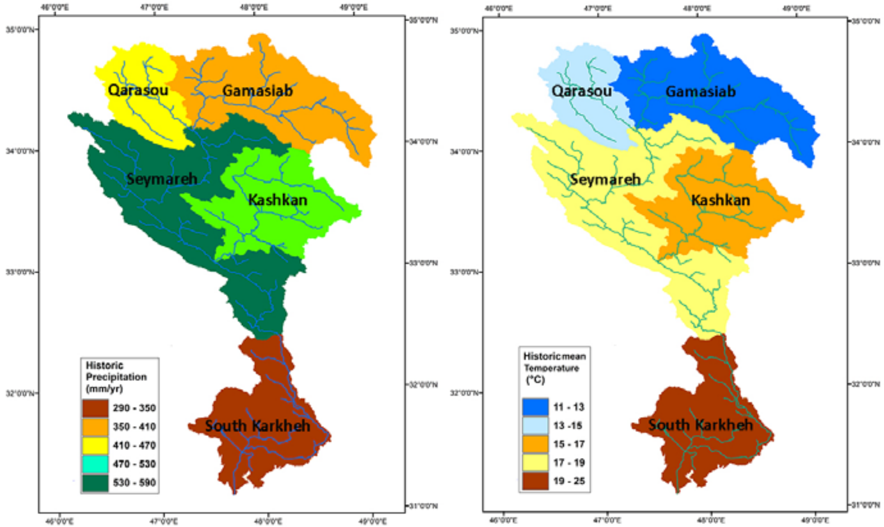
$$Y_d^{cor,fut} = X_d^{GCM,fut} + CF_d^{GCM,fut}$$

ECDF: Empirical Cumulative Density distribution Functions
X^{GCM}: raw GCM time series
Y^{cor}: corrected time series
CF: correction term
P: cumulative probability
d= representative day of the year
ref= reference period



ECDFs of GCMs versus observed daily precipitation (up figure) and daily maximum temperature (down figure) for January at a weather station for historic (1982-2004) and RCP 4.5 scenario (2038-2060).

Climate change impacts on rainfall and temperature



Comparison of average monthly river discharge (m3s-1) between the historical and the future scenarios for five subbasins in KRB

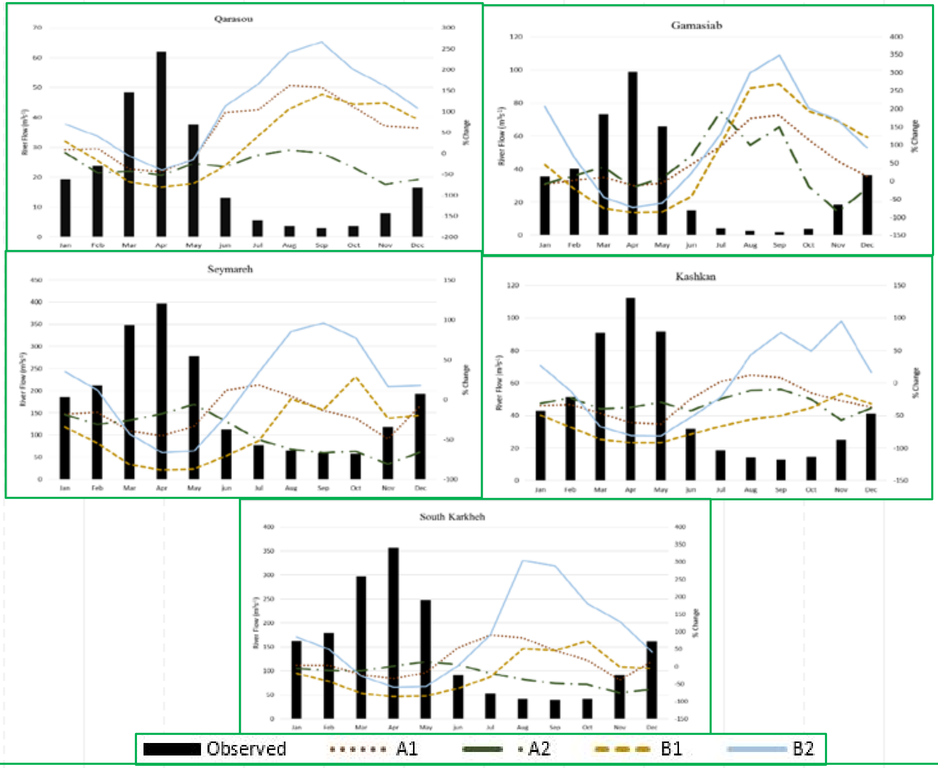
- ✓ A1: RCP 4.5 (2038-2060)
- ✓ B1: RCP 4.5 (2038-2060)
- ✓ A2: RCP 8.5 (2078-2100)
- ✓ B2: RCP 8.5 (2078-2100)

The relative changes in precipitation and mean air temperature for the future scenarios

Subbain	Precipitation				Mean Temperature			
	A1	A2	B1	B2	A1	A2	B1	B2
Qarasou	+0.08	-0.03	-0.01	+0.14	+0.12	+0.13	+0.13	+0.24
Gamasiab	+0.07	-0.02	-0.09	+0.12	+0.02	+0.08	+0.07	+0.12
Seymareh	+0.04	-0.04	-0.06	+0.08	+0.10	+0.12	+0.12	+0.18
Kashkan	+0.11	+0.005	-0.088	+0.20	+0.01	+0.005	+0.004	+0.08
South Karkheh	+0.23	+0.14	+0.06	+0.31	+0.04	+0.08	+0.05	+0.14

Climate change impacts on river discharge

- ✓ Running SWAT with downscaled weather data
  - Wet season: there is a slight decrease in water discharge
  - Dry season: there is a slight increase in water discharge



Comparison of average monthly river discharge (m3s-1) between the historical and the future scenarios for five subbasins in KRB

MODSIM

- ✓ MODSIM is a generic river basin management decision support system (DSS) model developed for analysis of long term operational planning and short term water management, drought contingency planning, and resolving conflicts between urban, agricultural and environmental concerns (Labadie 1995).
- ✓ MODSIM uses a state-of-the-art network flow optimization (NFO) algorithm which is a very fast solver and capable of modeling extremely large-scale networks.
- ✓ NFO provides an efficient means of assuring allocation of flows in a river basin in accordance with specified water rights and other priority rankings.
- ✓ Water allocation policies can be implemented using customized code in the Visual Basic.NET or C#.NET languages that are compiled with MODSIM through the Microsoft .NET.

PSO

- ✓ Particle swarm optimization (PSO) is a population based stochastic optimization technique developed by Dr.Eberhart and Dr.Kennedy in 1995.
- ✓ Easy to implement and there are few parameters to adjust. PSO has been successfully applied in many areas
- ✓ PSO is really two populations - pbests and current positions which allows greater diversity and exploration over a single population like GA.
- ✓ The momentum effects on particle movement can allow faster convergence(e.g. when a particle is moving in the direction of a gradient) and more variety/diversity in search trajectories.

Simulation-optimization model (MODSIM-PSO)

$$Maximize\,\frac{1}{n}\left(\sum_{i=1}^{n}\sum_{c=1}^{k} P_i^c \times Y_i^c \times A_i^c\right)$$

$$S_{n+1}^{y} = S_n^{y} + I_i^c - R_i^c - EV_i^c$$

$$S_{min} \le S_n^{y} \le S_{max}$$

$$A_{min}^{c} \le A_l^{c} \le A_{max}^{c}$$

A= area under crop cultivation (ha);
Y= crop yield (kg ha-1);
P= unit benefit of crop (Rials/US$ kg-1);
n= number of years in planning horizon;
c = type of crop;
i= year of cultivation;

i= year of cultivation;
k = number of agriculture crop productions;
S= storage capacity of reservoir;
I= monthly stream flow;
R= monthly reservoir outflow;
EV = volume of reservoir evaporation.

Simulation-optimization model (MODSIM-PSO)

FAO-accepted Stewart and Hagan (1973) crop yield response to deficit irrigation:

$$Maximize: \ Y_c^a / Y_c^{max} = 1 - \sum_{i=1}^{g} k_{i,c}^{y} \left(1 - w_{i,c}^a / w_{i,c}^p\right)$$

$$0 \le w_{i,c}^a \le w_{i,c}^p$$

$$\sum_{i=1}^{g} w_{i,c}^a \le X W_c^p$$

X=1.0, 0.95. 0.9, … until Y_c^a become 0.
Y_c^a= actual crop yield (ton/ha).
Y_c^{max}= potential crop yield (ton/ha).
$w_{i,c}^a$= allocated water to crop c in stage i (m3/ha).

$w_{i,c}^p$= potential water demand of crop c water to crop c in stage i (m3/ha).
$k_{i,c}^y$= crop yield response factor to water deficit in ith growth stage.
W_c^p= total potential water demand of crop c in all growth stage (m3/ha).

✓ Potential water demand:

"Auto-irrigation initialization from unlimited source outside watershed" in SWAT was employed to apply water as needed by plants. Anytime actual plant growth falls below the water stress threshold which is a fraction of potential plant growth, the model will automatically apply water to the HRUs.

✓ Potential crop yield:

The crop yields correspond to the potential water irrigation.

Simulation-optimization model (MODSIM-PSO)

Decision variables: Areas under cultivation, priority number of demands and reservoir target storage

PSO equipped with a stretching technique to overcome the common problem of occasional convergence to local optima

MODSIM: Simulates the water allocation between different water users

PSO: Extracts the allocated water and calculate the objective function

Stopping criterion is met?

Distribution of crops in 5 main agricultural regions in south of KRB (Data source: reported by Iran Water and Power Resources Development Co. (2010))

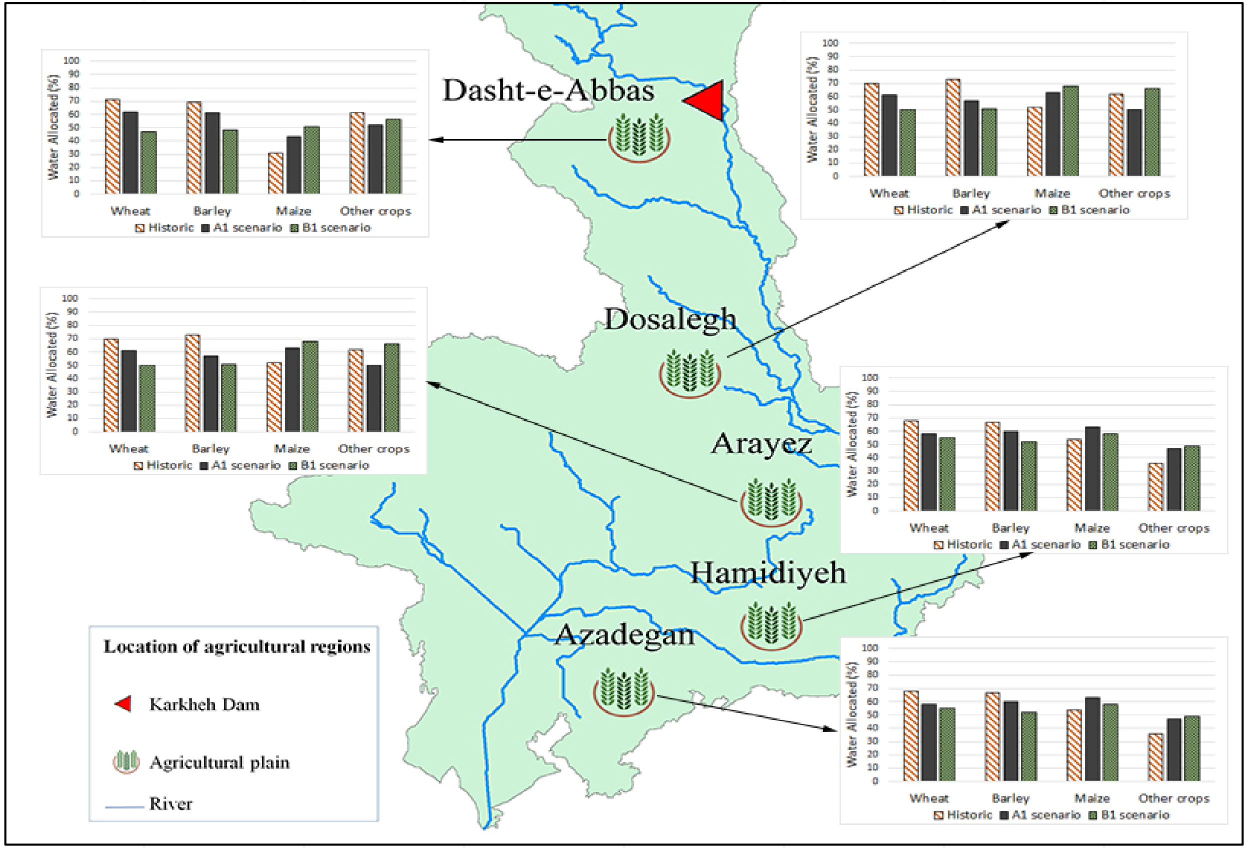
Crops	Dasht-e Abbas	Dosalegh	Arayez	Hamidiyeh	Azadegan
Winter wheat	21	16.6	23.3	21.6	26.2*
Barley	12.2	13.1	13.3	12.5	11.9*
Maize	8.9	9.6	10.7	9.1	8.5*
Broad Beans	1.9	2.2	2.1	4.3	3.3
Beans, Green	0	4.4	3.6	0	0
Sesame Seed	3.1	0	0	0	0
Cucumbers	4.7	13.1	11.7	7.4	5.5
Tomato	2.7	4	6	5	3.7
Watermelon	4.1	7.3	6.9	5.5	4
Alfalfa	18.8	19.3	16.2	10.7	8.4
Sorghum	4.1	0	0	6.1	4.6
Sugarcane	3.5	5.3	0	0	0
Rapeseed	1.6	2.2	3.4	4.5	3.5
Eggplant	4.2	0	0	8.8	6.4
Citrus	9.4	0	0	0	0
Carrots	0	3	2.7	4.5	3.5
Dates	0	0	0	0	10.5

* These data were missing in the reference report and collected from other references

Maximum and minimum area of crop under cultivation in five agricultural plains downstream of Karkheh dam in the drafted future plans (Data source: reported by Iran Water and Power Resources Development Co. (2010))

Agricultural plain	Crops	Max (ha)	Min (ha)
Dasht-e Abbas	Winter wheat	4710	2210
	Barley	2730	1480
	Maize	1985	735
	Other crops	12970	10470
Dosalegh	Winter wheat	3300	2050
	Barley	2600	1350
	Maize	1900	650
	Other crops	12050	9550
Arayez	Winter wheat	6280	3780
	Barley	3590	2340
	Maize	2900	650
	Other crops	14230	11730
Hamidiyeh	Winter wheat	4665	2165
	Barley	2700	1450
	Maize	1965	715
	Other crops	12300	9800
Azadegan	Winter wheat	15000	11250
	Barley	9100	6600
	Maize	6400	3900
	Other crops	34800	31050

Results (Water allocation)



Results (cropping pattern, economic analysis)

- Areas under cultivation are directly related to the water availability

- Annual benefits are directly related to the water availability

Comparison of optimal allocated area values by MODSIM-PSO under historic condition and climate change scenarios

Agricultural plain	Crops	Historic (ha)	A1 (ha)	B1 (ha)
Dasht-e Abbas	Winter wheat	4710	2210	2303
	Barley	2730	1480	1480
	Maize	1985	735	735
	Other crops	12970	11966	10470
Dosalegh	Winter wheat	3300	3300	2050
	Barley	2600	2600	2000
	Maize	1900	1900	650
	Other crops	12050	11523	9874
Arayez	Winter wheat	6280	6280	6280
	Barley	3590	3590	3590
	Maize	2900	1650	1650
	Other crops	12442	13798	12050
Hamidiyeh	Winter wheat	2165	2165	2165
	Barley	2700	2700	2000
	Maize	1965	715	906
	Other crops	9800	11940	10743
Azadegan	Winter wheat	15000	15000	11250
	Barley	6600	6600	6600
	Maize	6400	6400	3900
	Other crops	34800	33899	32644

Annual benefits from baseline and climate scenarios

Objective function	Historic (ha)	A1 (ha)	B1 (ha)
Annual total benefit (MUS$*)	94.24	88.33	72.07

* MUS$= million US dollars

Summary and conclusion

- ✓ SWAT model was built and calibrated to estimate the river discharge
- ✓ Four climate change scenarios were generated and downscaled using an updated quantile mapping method as an empirical-statistical error correction of daily climate data
- ✓ The calibrated-SWAT was run to estimate the river discharge under projected climate change scenarios
- ✓ An integrated simulation-optimization (MODSIM-PSO) model was developed to select the optimal cropping pattern in agricultural regions of south KRB in order to maximize the annual benefit
- ✓ While MODSIM is simulating the water allocation between different water users, PSO tries to find the best combination of agricultural lands under cultivation to maximize the annual benefits considering the water deficit levels for the historic period, A1 and B1 climate scenarios
- ✓ The results indicated that the model is a practical and viable tool that could be applied to all irrigation-based optimization models in complex watersheds
- ✓ A comprehensive and integrated water management modeling to determine the optimal cropping pattern selection

THANKS!

Any questions?

You can find me at

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