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An assessment of the economic effects of drought in the Hirmand basin in the east of Iran: The application of the decision support system (DSS) approach

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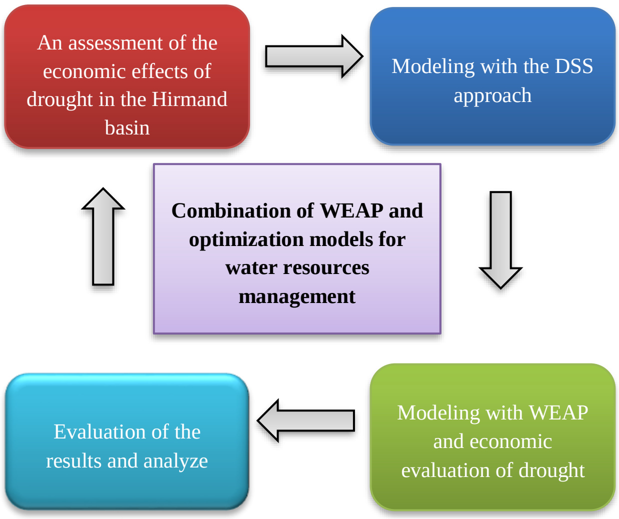
GRAPHICAL ABSTRACT



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ABSTRACT

The issue of water resource management has become extremely complicated due to the droughts of the last two decades and the competition among the drinking sector, agricultural sector, and international Hamoun wetland to use water. To analyze the status and help managers in policy analysis and decision-making, this research adopted an integrated water resource model (WEAP) with a decision support system (DSS) approach to study the effect of drought on rural and agricultural development and its economic impacts in the region. So, the Iranian government's water development projects were simulated within 11 scenarios for a medium-term period (up to the 2030 horizon) and the implications of their implementation for the development of the rural and agricultural sectors were assessed. According to the results, if Afghanistan observes Iran's water rights, there will still be a great amount of unmet water demand (314.53 million m^3) for the agricultural and wetland sectors. However, if this scenario is realized, the unmet demand will decrease by about 196 million m^3 versus the status quo and the agricultural sector's profit will increase by about 314 billion IRR, which will be very helpful for rural development. So, relevant officials should put their best effort into realizing the water right. It is suggested to strengthen water diplomacy between the two main stakeholders in the region in order to reduce the persistence of drought.

1. Introduction

In the new global view, water is regarded as a socio-economic commodity that is a basic human need (Karamouz, Elyasi, and Ahmadinia, 2008; Farajzadeh et al. 2014; Karimi and Mousavi. 2021; Kiani Ghalehsard et al. 2021; Moslemi et al. 2021; Ghafari Moghadam et al. 2022a). However, a long-term goal of strategic water management in Iran is to establish a balance between water demand

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and existing water resources (Saeidinia et al. 2012; Bagheri Harouni and Saeed. 2013; Ghafari Moghadam et al. 2021). Water resources are relatively fixed in the world, the aggravating water crisis can be attributed to the increasing population growth, unbalanced distribution of surface and underground water resources (Bouwer. 2000; Sandoval et al. 2008; Bagheri Harouni and Saeed. 2013). The involvement of numerous consumers with different utilities and priorities in the issues related to the management and planning of water resources brings about remarkable conflicts and stress regarding water resources, provoking concerns of managers and planners (Purkey et al. 2008; Madani and Lund. 2010; Alfarra et al. 2012).

One of the most important basins in Iran is the extraterritorial basin of Hirmand, which is shared by Iran and Afghanistan and plays a key role in the life of the Sistan region where people’s livelihood severely depends on the Hirmand River. The Sistan plain has an arid and hyper-arid climate and its economy, agriculture, employment, environment, and rural development have been damaged by extremely low rainfall (an average of 50 mm/year, i.e., about one-fifth of the mean annual precipitation of Iran) and extremely high evaporation (4000-5000 mm/year, i.e., about 2.5 times larger than Iran’s average) (Yaqob et al. 2015; Ghafari Moghadam et al. 2022b; Khairi, Safdari, and Sardar Shahraki, 2022; Sardar Shahraki et al. 2023). This research aims to simulate and evaluate the effects of water management scenarios on the supply of the present and future water needs of different sectors in the Hirmand basin under an integrated water resource management model and to evaluate the economic effects of these scenarios on the development of the agricultural sector. Fig. 1 displays the Hirmand basin.

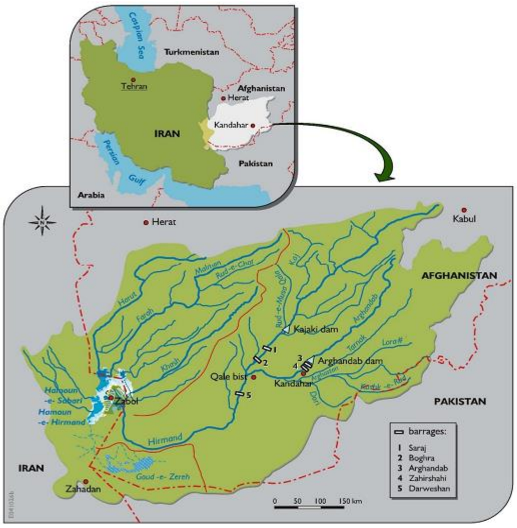

Fig. 1. Map of the study area.

In this respect, various models have been developed. For example, water evaluation and planning system (WEAP), WBALMO, AQUATOOL, WATER WARE, and WARGI-SIM , are the models that are used in the management of water resources with the simulation approach (Hollermann, Giertz, and Diekkrüger, 2010; Condom et al. 2011; Choi et al. 2010; Mounir, Ming, and Amadou, 2011; Mutiga et al. 2010; Vonk et al. 2014).

In the present study, the WEAP model was selected and used to simulate water resource management in the Sistan region. The distinction of the present study from similar works is the economic assessment of the simulated scenarios in a certain basin and the determination of its impacts on rural and agricultural development, which have not been studied so far. The application of the WEAP model can help to simulate and optimize in this area to advance water resource management scenarios. This area has a complex water system that has been investigated in this research with all dimensions in the WEAP model.

2. Materials and methods

WEAP (Water Evaluation and Planning System) was developed by Stockholm Environment Institute's U.S. Center. This method makes calculations by considering a demand location where simplified hydrological and agro-hydrological processes like precipitation, evapotranspiration, and plant growth happen and by emphasizing precipitation and agricultural irrigation. The calculations are made by the following equations in which LC represents the land cover, HU represents the hydrological unit, I represents irrigated, and NI represents non-irrigated (Sieber et al. 2005; Dimovaa et al. 2014; Vonk et al. 2014). Consequently, the actual yield can be calculated by:

$$PrecipAvailableForET_{LC} = Precip_{HU} \times Area_{LC} \times 10^{-5} \times PrecipEffective_{LC} \quad (1)$$

$$ETpotential_{LC} = ETreference_{HU} \times Kc_{LC} \times Area_{LC} \times 10^{-5} \quad (2)$$

$$PrecipShortfall_{LC,I} = Max\left(0, ETpotential_{LC,I} - PrecipAvailableForET_{LC,I}\right) \quad (3)$$

$$SupplyRequirement_{LC,I} = \left(1/\,IrrFrac_{LC,I}\right) \times PrecipShortfall_{LC,I} \quad (4)$$

$$SupplyRequirement_{HU} = \sum_{LC,I} SupplyRequirement_{LC,I} \quad (5)$$

The last four equations are used to calculate extra water (i.e., above the available precipitation), which is required to meet the water requirement of evapotranspiration related to the land cover and the whole hydrological unit while considering irrigation efficiency.

$$Supply_{HU} = Calculated\ by\ WEAP\ allocation\ algorithm \quad (6)$$

$$Supply_{LC,I} = Supply_{HU} \times \begin{pmatrix} SupplyRequirement_{LC,I}\ / \\ SupplyRequirement_{HU} \end{pmatrix} \quad (7)$$

$$ETActual_{LC,NI} = Min\begin{pmatrix} ETpotential_{LC,NI}, \\ PrecipAvailableForET_{LC,NI} \end{pmatrix} \quad (8)$$

$$ETActual_{LC,I} = Min(ETpotentia_{LC,I}, PrecipAvailableForET_{LC,I} + IrrFrac_{LC,I} \times Supply_{LC,I}) \quad (9)$$

$$EF_{LC} = ETActual_{LC}\ /\ ETpotential_{LC} \quad (10)$$

where, Area is the land cover area (ha), Precip is the precipitation (mm), PrecipEffective is the effective precipitation (%), i.e., the percentage of the irrigation that can be used for evapotranspiration, PrecipAvailableForET is the available precipitation for evapotranspiration, Kc is the crop coefficient provided by FAO, ETreference is the evapotranspiration of the reference crop, PrecipShortfall is the evapotranspiration shortage (if only taking precipitation into account), IrrFrac is the percentage of supplied water that is available for evapotranspiration, SupplyRequirement is the crop irrigation requirements, Supply is the amount of water supplied for irrigation, EF is the satisfied fraction of the potential evapotranspiration, Yield ResponseFactor is the factor representing yield variations when potential evapotranspiration is lower than actual evapotranspiration, PotentialYield is the maximum potential yield assuming the availability of all proper water resources, ActualYield is the actual yield assuming the available evapotranspiration, Runoff is the runoff resulting from land cover, RunoffToGW is the runoff that is converted into groundwater, and RunoffToSurfaceWater is the runoff that is converted to surface water.

WEAP is based on the basic equations of water balance according to which the water demands of the agricultural, drinking, and environmental sectors are modeled in the Sistan region. In the present research, the WEAP approach is implemented in several steps as follows:

Step 1. Developing a temporal and spatial framework, system components, and problem status in the Hirmand basin.

Step 2. Calculating and analyzing water demands of the agricultural, drinking, and environmental sectors, water rights and allocation priorities, surface water simulation, the use of reservoirs, ecosystem demands, and system vulnerability in the Hirmand basin. The results provide an image of the actual water requirements, resources, and system supply in the Hirmand basin. In this step, the key assumptions are defined regarding policies, costs, and the factors that influence water demand and supply.

Step 3. Defining managerial scenarios for the optimal use of regional water resources as per the regional conditions, managers, stakeholders, and officials’ opinions, and the policies of the Ministry of Energy. In this research, 11 water management scenarios have been developed.

Step 4. Analyzing the impact of different scenarios on the basin water use in the future and the rural and agricultural development considering the available water and water conditions in the Sistan region. The optimal model for each scenario is estimated by:

$$Max \quad \tilde{\beta}_j = \sum_{j=1}^{n}\sum_{i=1}^{m} Pcp_{ji}.Ya_{ji}.AF_{ij} - \sum_{j=1}^{n}\sum_{i=1}^{m}\sum_{k=1}^{q} Pco_{jik}.X_{jik}.AF_{ij}$$

$$Subject\,to:$$

$$P_{CP}, Ya, AF, P_{CO}, X \in WEAP\ Model$$

$$P_{CP}, Ya, AF, P_{CO}, X \geq 0$$

(11)

where, Pcpji represents the price of the ith crop in the jth region (the main products in the agricultural sector are wheat and barley, summer vegetables and grapes), Yaji represents the yield of the ith crop in the jth region, AFij represents the cultivation area of the ith crop in the jth region, Pcojik represents the price of the kth input for the ith crop in the jth region, and Xjik represents the amount of the kth input for the ith crop in the jth region.

The water management scenarios defined in this research are as follows:

Scenario 1: This is the reference scenario, which is the status quo with previous management. It is the basis for the comparison of other scenarios. In other words, if the basin is managed under the present conditions and previous policies, how will the Hirmand basin be by 2030?

Scenario 2: The direct transfer of water from Chahnimeh reservoirs to the lands of Agri.

Scenario 3: The direct transfer of water from Chahnimeh reservoirs to the lands of Agri2.

Scenario 4: The direct transfer of water from Chahnimeh reservoirs to the lands of Agri3.

Scenario 5: The second water-transfer pipeline to the city of Zahedan.

Scenario 6: A 30% reduction in the evaporation from the reservoir using 40% physical coverage.

Scenario 7: A 50% reduction in the evaporation from the reservoir using 50% physical coverage. Scenarios 6 and 7 are based on Zare Mahzabieh's (2021) empirical study on the methods to reduce surface evaporation from the Chahnimeh reservoirs.

Scenario 8: Changing resource allocation priorities.

Scenario 9: Afghanistan's respect for Iran's water rights.

Scenario 10: A combination of Scenarios 7 and 9 (water-saving scenarios).

Scenario 11: A combination of Scenarios 2, 3, 4, and 5 (no water-saving scenarios).

Table 1 presents the sites of water supply and demand with symbols. The Sistan region has three agricultural sectors, seven drinking sectors (six urban and 1 rural sector), and the Hāmūn wetland sector.

3. Results and discussion

Table 2 presents the mean water demand of different sectors over 2015-2030. The highest demand is related to Agr2 and the lowest to City6. In the reference scenario (SC1), the shares of the agricultural, drinking, and wetland sectors in the total demand are 91%, 4%, and 5%, respectively. According to the scenarios defined, the water demands of different sectors change only in SC5 and SC11 for the City1 sector.

Table 3 presents the mean unmet demand and the percentage of water supply for different sectors under different scenarios over 2015-2030. In SC1, the unmet demand of Agr1, Agr2, and Agr3, on average, amounts to 189.04, 207.69, and 79.4 million m3, respectively. The lowest amount of unmet demand is for Agr1 under SC2 whose unmet demand shows a reduction of nearly 138 million m3 versus the reference scenario. Similar results were obtained for Agr2 in SC10 (135 million m3) and Agr3 in SC4 (79 million m3). When SC5 is implemented, the amounts of Agr2 and Agr1's unmet demand will increase versus the reference scenario, but Agr3's unmet demand will not change. The amount of unmet demand was estimated at 79.4 million m3 for Agr3 in seven scenarios (SC1, SC2, SC3, SC5, SC6, SC7, and SC8), which is related to the fact that the water demand of this sector is supplied by the Paryan river, so different scenarios have no impact on its demand. Only in SC4, the water requirement of this sector is supplied from the Chahnimeh reservoirs in addition to the Paryan river, so its whole water demand is satisfied leaving no unmet demand. Wastage reduction management (SC6) will have a significant effect on the reduction of Agr2 and Lake's unmet demand. According to the WEAP model's results, the unmet demands of these two sectors in this scenario will decrease by 120.99 and 12.68 million m3 versus the reference scenario, respectively. This scenario will have a trivial effect on the Agr1 and Agr2 sectors. In SC7, the unmet demands of Agr2 and Lake will decrease by 125.577 and 13.36 million m3 versus the reference scenario. Owing to the significance of supplying drinking water in the Sistan region, the amount of unmet demand of this sector is zero in most scenarios (except for SC8 and SC11). SC8 aims to change priorities in water allocation (given that the priority of water allocation in this region is drinking, agriculture, and wetland, respectively).

Table 1. The characteristics of the water supply and demand sites in the Sistan region.

Sub-basin	Specifications
$Reservoir_1$	The water of the Sistan river flows into this reservoir. Its total volume is 660 MCM* and its inactive part is 320 MCM. The reservoir is the main source of water for the agricultural, drinking, and wetland sectors
Sistan and Paryan river	The Hirmand river is divided into two branches of Sistan and Paryan at Iran's borderline. The Sistan river first flows in $Reservoir_1$ and its surplus is transferred to Agr_1 and Agr_2. This river finally flows into the Hāmūn wetland. The Paryan supplies the water requirement of Agr_3.
$Reservoir_2$	It receives the surplus water of $Reservoir_1$. Its total volume is 820 MCM and its inactive volume is 200 MCM.
$City_1$ (Zahedan)	It has a population of 600,000 people and an annual water consumption rate of 55.56 m^3/person/year.
$City_2$ (Zabol)	It has a population of 142,000 people and an annual water consumption rate of 58.02 m^3/person/year.
$City_3$ (Zahak)	It has a population of 14,000 people and an annual water consumption rate of 53.34 m^3/person/year.
$City_4$ (Hamoon)	It has a population of 6700 people and an annual water consumption rate of 57.37 m^3/person/year.
$City_5$ (Hirmand)	It has a population of 7200 people and an annual water consumption rate of 47.97 m^3/person/year.
$City_6$ (Nimrooz)	It has a population of 3300 people and an annual water consumption rate of 46.01 m^3/person/year.
Rural	It has a population of 266,000 people and an annual water consumption rate of 54.75 m^3/person/year.
$Agri_1$ (Zabol agriculture)	It has a cultivation area of 49,000 ha with a water consumption rate† of 8750 m^3/ha.
$Agri_2$ (Zahak agriculture)	It has a cultivation area of 54,000 ha with a water consumption rate of 8450 m^3/ha.
$Agri_3$ (Miyankangi agriculture)	It has a cultivation area of 32,000 ha with a water consumption rate of 7950 m^3/ha.
Lake	The Hāmūn wetland has an area of 400,000 ha with water right‡ of 60 million m^3.

* million m^3; † calculated based on the regional crop pattern‡ This water right has been approved for 2500 ha of the wetland area.

Table 4 presents the results of the economic assessment of the scenarios. The effect of the individual scenarios on the cultivation area in the three agricultural sub-sectors was obtained by the WEAP model. According to the results, Agr1 will have the highest cultivation area in SC2. In this scenario, the cultivation area will increase by about 15800 ha versus the present conditions. The highest cultivation area of Agr2 will happen in SC10, showing an about 15500 ha increase compared to the present conditions. Agr3 will have its highest cultivation area in SC4, about 9000 ha greater than the present conditions.

Table 2. The water demand in different scenarios averaged for the years 2015-2030 (million m^3).

Scenario no.	Agr_1	Agr_2	Agr_3	$City_1$	$City_2$	$City_3$	$City_4$	$City_5$	$City_6$	Rural	Lake
SC_1	428.75	471.56	279.44	26	9.28	0.86	0.42	0.39	0.17	14.43	60
SC_2	428.75	471.56	279.44	26	9.28	0.86	0.42	0.39	0.17	14.43	60
SC_3	428.75	471.56	279.44	26	9.28	0.86	0.42	0.39	0.17	14.43	60
SC_4	428.75	471.56	279.44	26	9.28	0.86	0.42	0.39	0.17	14.43	60
SC_5	428.75	471.56	279.44	41	9.28	0.86	0.42	0.39	0.17	14.43	60
SC_6	428.75	471.56	279.44	26	9.28	0.86	0.42	0.39	0.17	14.43	60
SC_7	428.75	471.56	279.44	26	9.28	0.86	0.42	0.39	0.17	14.43	60
SC_8	428.75	471.56	279.44	26	9.28	0.86	0.42	0.39	0.17	14.43	60
SC_9	428.75	471.56	279.44	26	9.28	0.86	0.42	0.39	0.17	14.43	60
SC_{10}	428.75	471.56	279.44	26	9.28	0.86	0.42	0.39	0.17	14.43	60
SC_{11}	428.75	471.56	279.44	41	9.28	0.86	0.42	0.39	0.17	14.43	60

Table 3. The amount of unmet demand and the percentage of water supply in different scenarios averaged over 2015-2030.

Scenario no.	Agr_1		Agr_2		Agr_3		$City_1$		$City_2$		$City_3$		$City_4$		$City_5$		$City_6$		Rural		Lake	
	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B
SC_1	189.04	55.91	207.69	55.96	79.4	71.59	0	100	0	100	0	100	0	100	0	100	0	100	0	100	34.86	41.9
SC_2	50.7	88.17	320.87	31.96	79.4	71.59	0	100	0	100	0	100	0	100	0	100	0	100	0	100	55.31	7.82
SC_3	195.15	54.48	78.6	83.33	79.4	71.59	0	100	0	100	0	100	0	100	0	100	0	100	0	100	52.69	12.18
SC_4	205.2	52.14	250.97	46.78	0	100	0	100	0	100	0	100	0	100	0	100	0	100	0	100	44.66	25.57
SC_5	191.35	55.37	210.22	55.42	79.4	71.59	0	100	0	100	0	100	0	100	0	100	0	100	0	100	36.02	39.97
SC_6	185.56	56.72	87.7	81.4	79.4	71.59	0	100	0	100	0	100	0	100	0	100	0	100	0	100	22.18	63.03
SC_7	180.12	57.99	82.12	82.59	79.4	71.59	0	100	0	100	0	100	0	100	0	100	0	100	0	100	21.5	64.17
SC_8	175.2	59.14	195.1	58.63	79.4	71.59	13.03	49.88	5.71	38.47	0.62	27.91	0.23	45.24	0.27	30.77	0.11	35.29	6.92	52.4	35.2	41.33
SC_9	110.21	74.3	121.01	74.34	63.59	77.24	0	100	0	100	0	100	0	100	0	100	0	100	0	100	19.72	67.13
SC_{10}	105.23	75.46	72.32	843.66	63.59	77.24	0	100	0	100	0	100	0	100	0	100	0	100	0	100	19.01	68.32
SC_{11}	155.07	63.83	176.2	62.63	59.55	78.69	21.8	24.83	7.6	18.1	0.7	18.6	0.31	26.19	0.3	23.08	0.14	17.65	13.1	9.22	58.2	3

A: Unmet demand (million m3); B = Met demand (%)

Table 4. The economic assessment of managerial scenarios for water resources in the Sistan region.

Scenario no.	Agr_1		Agr_2		Agr_3	
	Cultivation area (ha)	Profit (10 million IRR)	Cultivation area (ha)	Profit (10 million IRR)	Cultivation area (ha)	Profit (10 million IRR)
SC_1	27395.43	41.74	30216.69	45.80	22907.53	33.11
SC_2	43205.71	65.83	17256.04	26.16	22907.53	33.11
SC_3	26697.14	40.68	44999.24	68.21	22907.53	33.11
SC_4	25548.57	38.93	25260.54	38.29	32000	46.26
SC_5	27131.43	41.34	29926.97	45.37	22907.53	33.11
SC_6	27793.14	42.35	43957.16	66.63	22907.53	33.11
SC_7	28414.86	43.30	44596.15	67.60	22907.53	33.11
SC_8	28977.14	44.15	31658.41	47.99	22907.53	33.11
SC_9	36404.57	55.47	40142.72	60.85	24718.01	35.73
SC_{10}	36973.71	56.34	45718.38	69.3	24718.01	35.73
SC_{11}	20726.26	31.12	33822.72	51.27	25180.65	36.4

4. Conclusions

Based on the results of the scenarios of evaporation reduction from the reservoirs, the unmet demand decreases by about 136 and 147 million m3 in SC6 and SC7 versus the reference scenario, respectively. So, these two scenarios are appropriate for the region given its water status and droughts. However, their implementation will only expand the cultivation area of Agr2 and will have no impact on the agricultural development of the other two sub-sectors. If the policy priority is to develop agriculture in the region, the results of SC8 show that the water demand of the drinking sector will hardly be supplied so that 26.8 million m3 will be left unmet. Since the Chahnimeh reservoirs are the only source of drinking water for about 1 million people living in the region, this scenario is a serious threat to the supply of drinking water for people. If the so-called 'Delta' agreement between Iran and Afghanistan is implemented and the Afghanistan state observes Iran's water rights, the water crisis will be resolved in the region. In SC9, although a significant part of the agricultural and wetland sectors' demand for water will not be satisfied, the unmet demand will decrease by about 196 million m3 versus the reference scenario. So, the observance of Iran's water rights by Afghanistan needs Iranian officials' determination as it will greatly contribute to the agricultural and rural development in Sistan.

Author Contributions

Ali Sardar Shahraki: The analysis, modeling and editing of the article
Mahmood Mohammad Ghasemi: Collecting information and data

Conflict of Interest

There is no conflict of interest in this article.

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Data Availability Statement

Data will be available when needed.

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