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ORIGINAL ARTICLE

Climate change outlook for water resources management in a semiarid river basin: the effect of the environmental water demand

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Abstract Iran is a developing country with arid and semiarid regions. Poor management of water resources combined with the effects of climate change is leading to the drying of several rivers and wetlands. Several planned water development projects, primarily for agricultural expansion, will be implemented in the coming years which could worsen impacts on vulnerable aquatic ecosystems. Proper water resources management is essential to meet present and future residential, environmental, industrial, and agricultural demands in semiarid regions. This paper presents projections of how the availability of water resources will change in the Karkheh river basin of Iran for the period 2010–2059 employing sustainability criteria in the form of time-based reliability, volumetric reliability, resiliency, and vulnerability. This paper's results show that consideration of environmental receptors as a stakeholder of water use places limitations on agricultural development within the Karkheh river basin.

Keywords Water resources management · Climate change · Standard operation policy · Sustainable development · Sustainable criterion · Karkheh river basin

Introduction

Iran's aridity has been compounded by climatic change to pose severe threats to its water resources and the ability to meet its residential, environmental, industrial, and agricultural water demands. Recent estimates have shown that climate change accounts for about 20% of the increased water scarcity worldwide (Simonovic 2009). Human use of water resources accounts for the remainder of the rising scarcity. It has been forecasted that the increase in water use in Iran by the domestic, industrial, and agricultural sectors equals 89, 259, and 24%, respectively, by 2021 compared to current levels (Iran's Ministry of Energy 2012). The rising water scarcity has been reflected in Iran by the drying of rivers and wetlands and the endangerment of related ecosystems. It is imperative in this context the development of integrated water resources management that accounts for climatic trends (Intergovernmental Panel for Climate Change (IPCC) 2014; Zahmatkesh et al. 2015; Hong et al. 2016; Ngoc et al. 2016; Gergel et al. 2017).

Several authors have reported studies about climate change impacts on water resources in Iran (Abbaspour et al. 2009; Chenoweth et al. 2011; Ashofteh et al. 2015). The Karkheh river basin is the third largest basin in Iran, and it is one of its key agricultural regions. Ashraf Vaghefi et al. (2013a) predicted that climate change effects on

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water resources conditions in 2020–2040 within the Karkheh basin could be associated with increased water availability in the northern part of the basin, but water availability may be reduced in its southern portion. Climate change impacts on agricultural demand based on the cropping pattern in the Karkheh basin indicate that copping pattern adaptation strategies would be helpful to moderate adverse climate change effects on agricultural efficiency (Ashraf Vaghefi et al. 2013b). Other studies dealing with the effects of climate change on the hydrology and water resources of the Karkheh river basin have proposed approaches to achieve sustainable water development in that region (Marjanizadeh 2008; Masih et al. 2009; Davtalab et al. 2014; Kamali et al. 2017).

Several studies have relied on performance indices to evaluate reservoir functions. An assessment using system dynamics was applied by Ahmad and Simonovic (2000) to the Shellmouth reservoir operation in Canada. Similarly, the dynamic programming fuzzy rule-based (DPFRB) method was applied by Mousavi et al. (2005) to reservoir operation. The fuzzy approach was implemented to decision making under uncertainty by Moeini et al. (2011).

Several reservoir operation policies have been applied to supply downstream water demands, and their effects on performance indices have been calculated with the standard operation policy (SOP), stochastic dynamic programming (SDP), linear decision rules (LDR), and nonlinear decision rule (NLDR) policies (see, e.g., Bolouri-Yazdeli et al. 2014; Bozorg-Haddad et al. 2014). Among the cited policies, the SOP is the simplest rule of reservoir operation (Loucks and Dorfman 1975).

This paper assesses the potential impacts of: (1) climate change; and (2) water resources management practices on water availability in the Karkheh basin, Iran, using projected climate change scenarios for the period 2010–2059. The capacity of the Karkheh reservoir to meet future residential, environmental, industrial, and agricultural water uses is examined with a water evaluation and planning (WEAP) model. Reliability, resiliency, and vulnerability indices are employed in evaluating the Karkheh reservoir's performance to meet downstream water demands. WEAP is a comprehensive and integrated tool for modeling, simulation, and assessing reservoir operation. It constitutes a flexible framework to analyze water allocation policies to various sectors of water demand. WEAP applications have been reported by several authors, among them Lévite et al. (2003) dealing with the Olifants river basin in South Africa, Raskin et al. (2009) in the Aral Sea basin, Harma et al. (2012) in the Okanagan basin, Canada, and Adgolign et al. (2016) in the Didessa basin, Ethiopia.

Case study

The Karkheh river basin is part of the Persian Gulf basin (see Fig. 1). The basin is composed of two different parts: (1) the northern-central part of the basin which is mainly mountainous with colder weather and (2) the southern half of the basin (Karkheh sub-basin riffle) where the topographic relief is low and the land elevation gradually reduces to sea level.

The Karkheh River has a length of 900 km and is the largest stream in the Karkheh basin. It discharges to the Hoor-al-Azim wetland located on the Iran–Iraq border. Irrigation projects tap on the Karkheh river flow. This consumptive use has been aggravated with rising air temperature and non-uniformly distributed precipitation associated with contemporary changing climate that threatens the water supply to the Hoor-al-Azim wetland. Average monthly temperature and rainfall in the period 1980–2009 are illustrated in Fig. 2. The total wetland area is approximately 118,000 hectares (ha). Overwintering birds, native birds, and breeding birds migrate seasonally to the Hoor-al-Azim wetland. Overwintering birds migrate from Central Asia, parts of Russia including the Siberian region to the wetland and return to their original habitats in early spring, after spending the autumn and winter in the Hoor-al-Azim wetland. The Hoor-al-Azim wetland is faced with water shortage, which causes insufficient runoff delivery that does not meet the environmental water demand. Reduced runoff has dried more than half of the Iranian section of the wetland.

The Karkheh river basin has been impacted by new water supply projects, especially those for irrigation development. A main objective of this paper is the operation of Karkheh reservoir to meet downstream water demands by the Hoor-al-Azim wetland considering the impact of irrigation water demand and the challenges posed by climate change. Table 1 lists the annual and monthly water demands downstream of the Karkheh reservoir, which include domestic, environmental, industrial, and agricultural water demands. It is evident in Table 1 that the agriculture sector is allocated the largest amount of reservoir water in comparison to the other sectors. The data in Table 1 show that domestic and industrial water demands throughout the year are relatively uniform, and the agricultural water demand from June through September is minimal. The largest agricultural water demand occurs in March. The total annual water demand from Karkheh reservoir equals 1142.7 $\times$ 10^6 m^3.

Figure 3 depicts the annual water demands by future development projects, with those at Chamran and Azadegan projects having the largest future demands. These future projects would raise the annual water demand in the

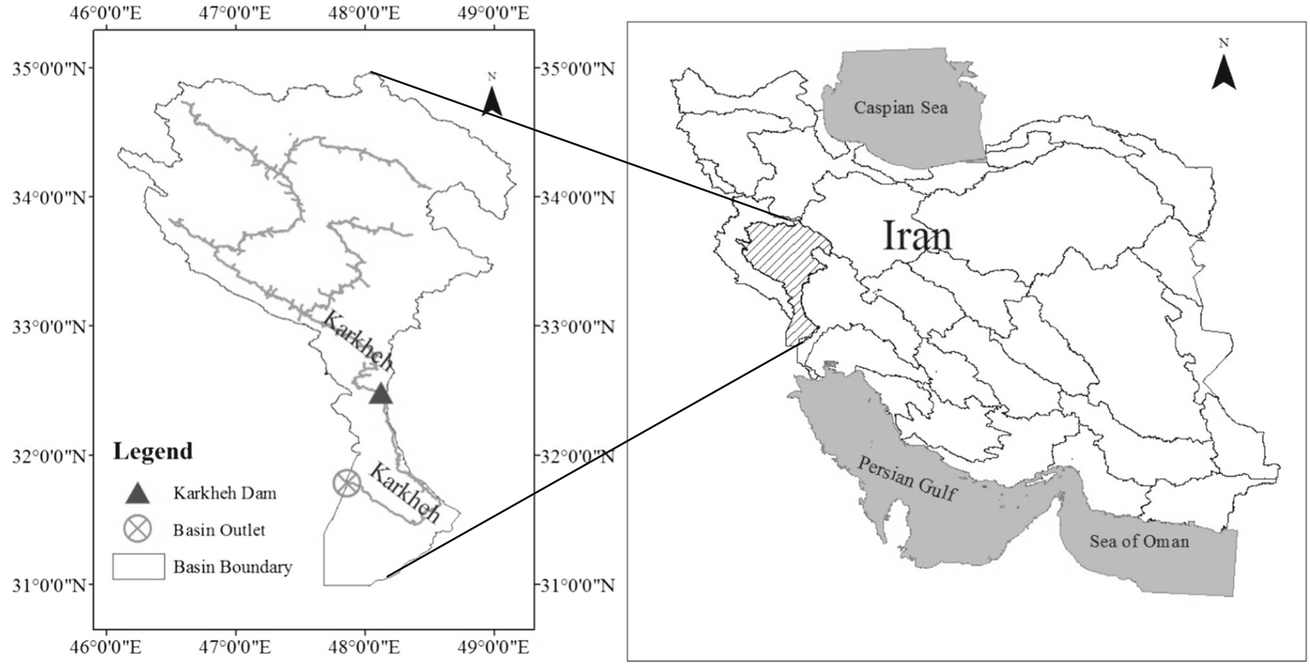


Fig. 1 Location of the Karkheh basin in Iran

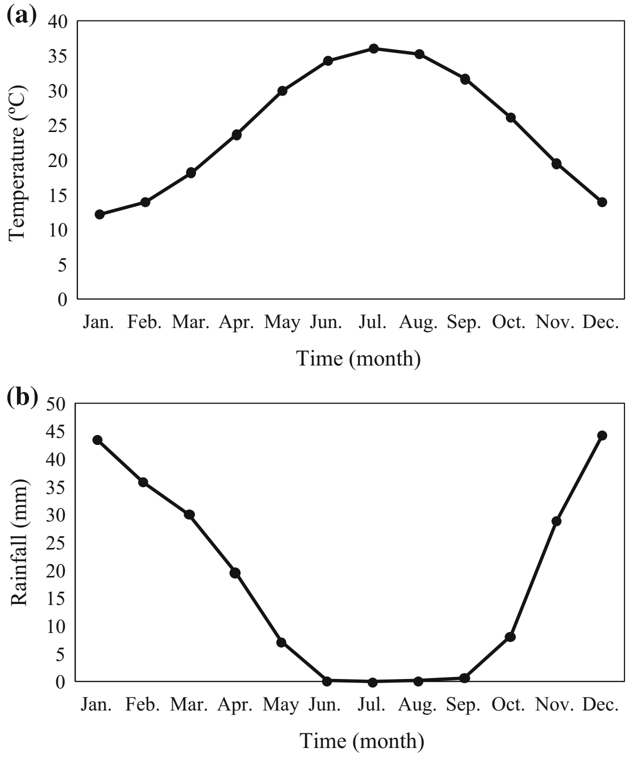


Fig. 2 Monthly, **a** temperature, **b** rainfall corresponding to the historical period 1980–2009

Karkheh basin to 2970 × 10^6 m^3. The monthly agricultural water demands of 14 development projects are listed in Table 2.

The streamflow of Karkheh River is an important factor that might be affected by contemporary climate change. Karkheh streamflow was projected in this study over the period 2010–2059 employing three climatic scenarios created by the intergovernmental panel on climate change (IPCC). The IPCC's fifth assessment report (AR5) presented four representative concentration pathways (RCPs) of greenhouse gases' concentration until 2100 (see, Fujino et al. 2006; Riahi et al. 2011; Thomson et al. 2011; Van-Vuuren et al. 2011; Wayne 2013). This paper applies the Canadian CanESM2 large-scale climate model's projections calculated under the RCPs 2.6, 4.5, and 8.5 within the Karkheh river basin to project temperature and rainfall over the period 2010–2059. The climate model's large-scale output was refined with a statistical downscaling model (SDSM) (Wilby et al. 2002) to project monthly temperature and rainfall in the Karkheh basin. The results indicated that average annual temperature and rainfall may increase relative to the baseline period 1980–2009 (Fig. 4). Moreover, monthly runoff in the Karkheh river was projected under climate change conditions applying the identification of unit hydrographs and component flows from rainfall, evaporation, and streamflow data (IHACRES) rainfall–runoff model. The historical data for period 1980–1990 and 1991–1993 were employed for model calibration and validation, respectively. The predictive skill of the hydrologic model was determined with the relative bias index, which equaled 11.48 and −18.88% for the calibration and validation periods, respectively (Sarzaeim et al. 2017). It is seen in Fig. 5 that the monthly streamflow under climate

Table 1 Monthly water demand of major sectors under current conditions ($\times 10^6$ m^3)

Month	Domestic demand	Environmental demand	Industrial demand	Agricultural demand
January	20.0	20.0	2.0	80.1
February	20.0	19.6	2.0	100.4
March	20.0	19.4	2.0	131.8
April	20.0	22.2	2.0	78.9
May	20.0	26.0	2.0	30.7
June	20.0	26.0	2.0	0.4
July	20.0	26.0	2.0	0.4
August	20.0	26.0	2.0	0.4
September	20.0	26.0	2.0	0.4
October	20.0	26.0	2.0	17.5
November	20.0	26.0	2.0	64.3
December	20.0	23.9	2.0	86.3
Annual	240.0	287.0	24.0	591.7

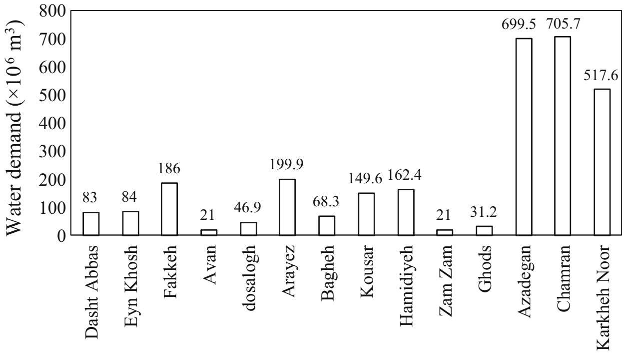


Fig. 3 Annual water demand of future agricultural projects

change scenarios is larger than the historical one. However, it is less than the historical streamflow in March, April, and October. In summary, the monthly average streamflow is projected to rise in the future, and so do the temperature and rainfall projections. The monthly environmental demand in each year was set equal to 25% of the projected monthly inflow in the previous 20 years. The calculated monthly environmental demands corresponding to the three climatic scenarios are represented in Fig. 6.

Standard operation policy (SOP)

Reservoir systems are constructed to meet domestic, environmental, industrial, and agricultural water demands. The water volume conservation of a reservoir is given by Eq. (1):

$$S_{t+1} = S_t + Q_t - \mathrm{Loss}_t - R_t - \mathrm{Sp}_t \quad t = 1, 2, 3, \ldots, T \tag{1}$$

Evaporative losses are calculated as follows:

$$\mathrm{Loss}_t = Ev_t \times \bar{A}_t \quad t = 1, 2, 3, \ldots, T \tag{2}$$

$$\bar{A}_t = \frac{(A_t + A_{t+1})}{2} \quad t = 1, 2, 3, \ldots, T \tag{3}$$

where S_t and S_{t+1} are storage volume of the reservoir at the beginning and end of the tth month, respectively; Q_t the reservoir inflow during the tth month; Loss_t the net precipitation minus evaporation in the reservoir during the tth month; R_t and Sp_t reservoir release and spill during the tth month, respectively; Ev_t evaporation depth from the reservoir during the tth month; $\bar{A}_t$ average reservoir area during the tth month; A_t and A_{t+1} reservoir areas at the beginning and end of the tth month, respectively; and T the total number of months of reservoir operation.

The SOP specifies reservoir releases on the basis of available reservoir storage in each operation period. The SOP is described by Eq. (4):

$$R_t = \begin{cases} D_t & \text{if} \quad AW_t > S_{\min} \quad \text{and} \quad AW_t - S_{\min} \geq D_t \\ AW_t - S_{\min} & \text{if} \quad AW_t > S_{\min} \quad \text{and} \quad AW_t - S_{\min} < D_t \\ 0 & \text{if} \quad AW_t \leq S_{\min} \end{cases}$$
$$t = 1, 2, 3, \ldots, T \tag{4a}$$

$$\mathrm{AW}_t = S_t + Q_t - \mathrm{Loss}_t \tag{4b}$$

Table 2 Monthly agricultural water demand of future development projects ($\times 10^6$ m^3)

Month	January	February	March	April	May	June	July	August	September	October	November	December
Agricultural demand	194.1	299.6	397.5	382.0	292.0	208.4	192.8	252.0	176.1	176.1	167.3	160.5

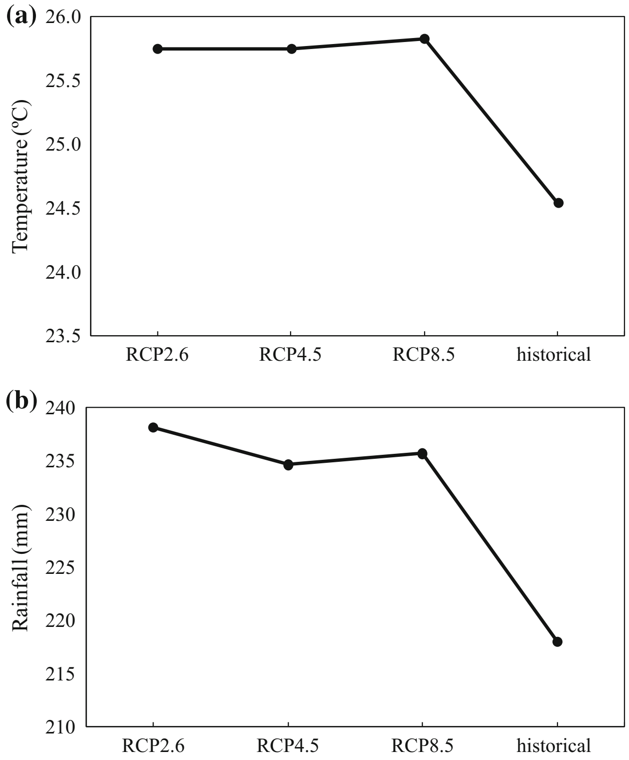


Fig. 4 Comparison of average annual, **a** temperature, **b** rainfall under climatic scenarios in period 2009–2059 and the historical period 1980–2009

where D_t is total downstream water demands in month t, $S_{\min}$ minimum reservoir storage, and AW_t available water in the reservoir in month t.

Water evaluation and planning (WEAP)

WEAP is an approach for evaluating water demands and for planning of water resources. WEAP was developed by the Stockholm Environment Institute (SEI) and the Hydrologic Engineering Center (HEC) in 1990. WEAP provides a flexible, integrated planning tool to analyze long-term scenarios for the purpose of water resources management. WEAP can be applied to analyze multiple water demands by several sectors considering water conservation, water requirements, allocation priorities, surface and groundwater sources, reservoir operation, etc.

This study simulates the Karkheh reservoir operation to supply water requirements with decreasing priority for the (1) domestic, (2) environmental, (3) industrial, and (4) agricultural sectors, where t is water users downstream of Karkheh dam.

Performance indices

Performance indices are useful for assessing operational reservoir policies. Several indices have been proposed, such as reversibility by Fanai and Burn (1997), sustainability including reliability, resiliency, and vulnerability by Loucks (1997), and the consensus criterion by Bender and Simonivic (1997). The most widely applied performance indices are reliability, resiliency, and vulnerability.

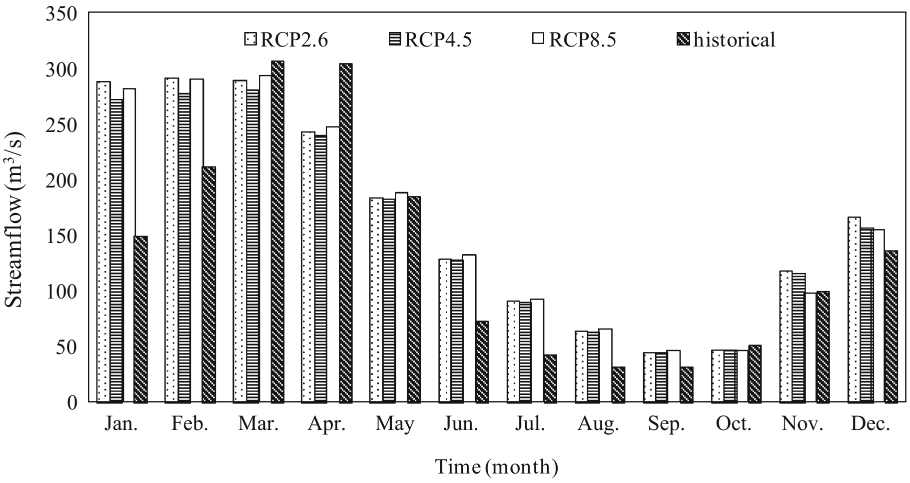
Reliability is synonymous to system operation free of failure to meet its functions as desired during a period of operation. Reliability takes two forms (1) time-based reliability and (2) volumetric reliability that are defined by Eqs. (5) and (6), respectively:

$$\mathrm{Rel}_T = \frac{\sum_{t=1}^{T} N_t}{T} \qquad t = 1, 2, 3, \ldots, T \tag{5}$$

$$\mathrm{Rel}_V = \frac{\sum_{t=1}^{T} R_t}{\sum_{t=1}^{T} D_t} \qquad t = 1, 2, 3, \ldots, T \tag{6}$$

where Rel_T and Rel_V are time-based reliability and volumetric reliability, respectively, and N_t the number of

Fig. 5 Comparison of average monthly streamflow under climatic scenarios and historical period



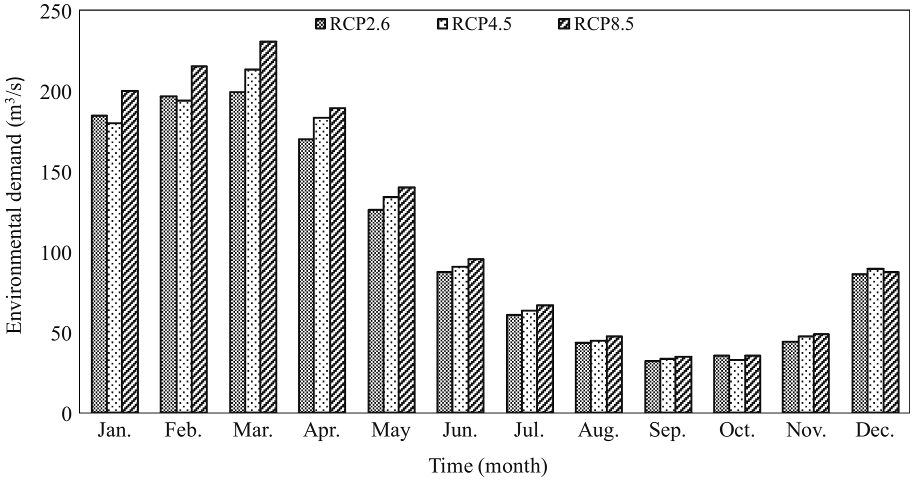


Fig. 6 Monthly environmental water demand under three climatic scenarios in 2010–2059

successful operation periods, in which the reservoir water release equals the downstream water demand, $R_t = D_t$.

The resiliency index represents the probability of reservoir system recovery from a failure, and it is defined by Eq. (7):

$$\mathrm{Res} = \frac{\sum_{t=1}^{T} N_t'}{\sum_{t=1}^{T} N_t} \quad t = 1, 2, 3, \ldots, T \tag{7}$$

where

$$N_t = \begin{cases} 1 & R_t < D_t \\ 0 & R_t \geq D_t \end{cases}$$

$$N_t' = \begin{cases} 1 & R_t < D_t \quad \text{and} \quad R_{t+1} \geq D_{t+1} \\ 0 & \text{otherwise} \end{cases} \quad t = 1,\ 2,\ 3,\ \ldots,\ T \tag{8}$$

where Res is resiliency criterion.

The vulnerability index is a normalized value of the most severe failure of a reservoir system during an operational period. It is defined by Eq. (9):

$$\mathrm{Vul} = \frac{\max\left(\mathrm{D_t} - \mathrm{R_t}\right)}{\sum_{t=1}^{T} N_t\left(D_t - R_t\right)} \quad t = 1, 2, 3, \ldots, T \tag{9}$$

where Vul is vulnerability index of a reservoir system and N_t was defined by Eq. (8).

Results and discussion

The WEAP was applied to assess the operation of the Karkheh reservoir operation following the SOP defined by Eqs. (4a) and (4b). The reliability, resiliency, and vulnerability of Karkheh reservoir operation were calculated for the supply of the (1) domestic, (2) environmental, (3) industrial, and (4) agricultural water demands for the period 2010–2059. Domestic and industrial demands were set equal to those of the baseline period 1980–2009 conditions because it is herein assumed that the same conditions persist in the period of analysis 2010–2059; that is, it is assumed that there will not be a significant change in water demands in these two sectors. The monthly environmental demand was set equal to 25% of the projected monthly inflow, as stated above, and these values were applied to the period 2010–2059. The agricultural water demand sector was determined based on the development of agriculture projects downstream of Karkheh reservoir. The Karkheh reservoir was operated with the three climatic inflow scenarios (these correspond to the IPCC's RCPs 2.6, 4.5, and 8.5) under climate change conditions. The time-based reliability, volumetric reliability, resiliency, and vulnerability indices were calculated and are listed in Table 3.

It is seen in Table 3 that the time-based and volumetric reliabilities exceeded 99% for the domestic sector. These results suggest that the domestic sector is not likely to face serious failures under the climatic scenarios applied to the period 2010–2059. The volumetric reliability of meeting the environmental water demand equals 95.13% for the 4.5 climatic scenario. This constitutes the best result for this sector of water demand. The volumetric reliability of meeting the environmental demand equals 92.34% for the 8.5 climatic scenario. Therefore, the 4.5 and 8.5 climatic scenario represents the best and the worst conditions for meeting the environmental demand, respectively. The best and worst values of volumetric reliability of meeting the industrial water demand were, respectively, equal to 74.88 and 65.26%, which are associated with RCP scenarios 2.6 and 8.5, respectively. The lowest volumetric reliability corresponds to the agricultural sector, where the best and worst values are, respectively, 64.64 and 50.00%, associated, respectively, with RCP scenarios 2.6 and 8.5.

It is evident from Table 3 that the resiliency and vulnerability indices were relatively low in most instances. This is so because recovering from a failure condition is difficult.

Table 3 Performance indices corresponding to the three climatic scenarios (%)

Performance index	Demand sector	Climatic scenario		
		2.6	4.5	8.5
Time-based reliability	Domestic	99.66	99.83	99.50
	Environmental	75.00	73.66	66.33
	Industrial	74.50	72.50	65.66
	Agricultural	25.83	20.66	19.66
Volumetric reliability	Domestic	99.92	99.96	99.74
	Environmental	94.68	95.13	92.34
	Industrial	74.88	73.39	65.26
	Agricultural	64.64	54.86	50.00
Resiliency	Domestic	50.00	100	33.33
	Environmental	38.62	33.10	23.60
	Industrial	23.72	28.78	20.67
	Agricultural	21.34	15.75	14.92
Vulnerability	Domestic	0.06	0.03	1.10
	Environmental	0.22	0.20	0.21
	Industrial	0.16	0.16	0.16
	Agricultural	0.26	0.26	0.26

However, the failures incurred during reservoir operation period are not considerable. These two effects combined reflect a desirable performance of the Karkheh reservoir during the climatic scenarios entertained in this work.

This paper's results have established that the environmental water demand would be significant for the operation of Karkheh reservoir under climate change. Furthermore, this paper's results indicate that the projected agricultural water use could not be met under climatic change conditions reliably.

It is therefore essential to consider the sustainability conditions of the Karkheh basin. The present trend of agricultural development in the Karkheh basin appears to be in conflict with sustainability requirements of the environmental sector, which is in a critical state currently and could worsen in the future if proper measures are not taken. Large-scale agricultural development may increase food production in the study region, but at the same time it may waste economic resources. This study has shown that Karkheh reservoir's operation must provide an additional allocation of water for environmental receptors to stabilize and restore ecosystem conditions to natural levels.

Conclusions

This paper's climatic scenarios project the rise in average temperature, rainfall, and streamflow for the period 2010–2059 in Karkheh basin. On the other hand, future agricultural water use will impose excessive pressure on basin water resources. Therefore, despite the projected increase in water availability in the region, our projections demonstrate that future water demands cannot be met in the Karkheh basin. The calculated time-based reliability index indicates that available water resources under various climatic scenarios will meet future agricultural demand only 20–26% of the time. The water scarcity is reflected also in the volumetric reliability index, especially in the agriculture sector. This paper's results indicate that it is imperative to consider major modifications in water allocations to achieve sustainable use of water resources in the Karkheh basin.

References

Abbaspour KC, Faramarzi M, Seyed Ghasemi S, Hong Y (2009) Assessing the impact of climate change on water resources in Iran. J Water Resour Res. doi:10.1029/2008WR007615

Adgolign TB, Srinivasa Rao GVR, Abbula Y (2016) WEAP modeling of surface water resources allocation in Didessa sub-basin, west Ethiopia. J Sustain Water Resour Manag 2(1):55–70. doi:10.1007/s40899-015-0041-4

Ahmad S, Simonovic SP (2000) System dynamics modeling of reservoir operating for flood management. J Comput Civ Eng 14(3):190–198

Ashofteh P-S, Bozorg-haddad O, Akbari-Alashti H, Mariño MA (2015) Determination of irrigation allocation policy under climate change by genetic programming. J Irrig Drain Eng 141(4):04014059

Ashraf Vaghefi S, Mousavi SJ, Abbaspour KC, Srinivasan R, Yang H (2013a) Analyses of the impact of climate change on water resources components, drought and wheat yield in semiarid regions: Karkheh River Basin in Iran. J Hydrol Process 28(4):2018–2032. doi:10.1002/hyp.9747

Ashraf Vaghefi S, Mousavi SJ, Abbaspour KC, Srinivasan R, Arnold JR (2013b) Integration of hydrologic and water allocation models in basin-scale water resources management considering crop pattern and climate change: Karkheh river basin in Iran. J Reg Environ Change 15(3):475–484. doi:10.1007/s10113-013-0573-9

Bender MJ, Simonivic SP (1997) Consensus as the measure of sustainability. Hydrol Sci J 42(4):493–500

Bolouri-Yazdeli Y, Bozorg-Haddad O, Fallah-Mehdipour E, Mariño MA (2014) Evaluation of real-time operation rules in reservoir systems operation. Water Resour Manag 28(3):715–729. doi:10.1007/s11269-013-0510-1

Bozorg-Haddad O, Farhangi M, Fallah-Mehdipour E, Mariño MA (2014) Effects of inflow uncertainty on the performance of multireservoir systems. J Irrig Drain Eng 140(11):04014035. doi:10.1061/(ASCE)IR.1943-4774.0000756

Chenoweth J, Hadjinicolaou P, Bruggeman A, Levieveld J, Levin Z, Lange MA, Xoplaki E, Hadjikakou M (2011) Impacts of climate change on the water resources of the eastern Mediterranean and Middle East region: modeled 21st century and implication. J Water Resour Res. doi:10.1029/2010WR010269

Davtalab R, Madani K, Massah A, Farajzadeh M (2014) Evaluating the effects of climate change on water reliability in Iran's Karkheh river basin. In: Proceeding of world environmental and water resources congress, 1–5 June, Portland

Fanai N, Burn D (1997) Reversibility as a sustainability criterion for project selection. Int J Sustain Dev World Ecol 4(4):259–273

Fujino J, Nair R, Kainuma M, Masui T, Matsuoka Y (2006) Multi-gas mitigation analysis on stabilization scenarios using aim global model. Energy J 27(Special Issue: Multi-Greenhouse Gas Mitigation and Climate Policy):343–353

Gergel DR, Nijssen B, Abatzoglou JT, Lettenmaier DP, Stumbaugh MR (2017) Effects of climate change on snowpack and fire potential in the western USA. J Clim Change 141(2):287–299. doi:10.1007/s10584-017-1899-y

Harma KJ, Johnson MK, Cohen SJ (2012) Future water supply and demand in Okanagan basin, British Columbia: a scenario-based analysis of multiple, interacting stressors. J Water Resour Manag 26(3):667–689. doi:10.1007/s11269-011-9938-3

Hong L, Chong-Yu X, Beldring S, Tallaksen L, Jain SK (2016) Water resources under climate change in Himalayan basins. J Water Resour Manag 30(2):843–859. doi:10.1007/s11269-015-1194-5

Intergovernmental Panel on Climate Change (2014) Climate change 2014: impacts, adaptation and vulnerability-regional aspects. Cambridge University Press, New York

Kamali B, Houshmand Kouchi D, Yang H, Abbaspour K (2017) Multilevel drought hazard assessment under climate change scenarios in semi-arid regions-a case study of the Karkheh river basin in iran. Water 9(4):241. doi:10.3390/w9040241

Lévite H, Sally H, Cour J (2003) Testing water demand scenarios in a water-stressed basin in South Africa: application of the WEAP model. J Phys Chem Earth 28:779–786

Loucks DP (1997) Quantifying trends in system sustainability. Hydrol Sci J 42(4):513–530

Loucks DP, Dorfman P (1975) An evolution of some linear decision rules for reservoir planning and operation. J Water Resour Res 11(6):777–782. doi:10.1029/WR011i006p00777

Marjanizadeh S (2008) Developing a “best case scenario” for Karkheh river basin management (2025 horizon); a case study from Karkheh river basin, Iran. PhD dissertation, Department of Water, Atmosphere and Environment, University of Natural Resources and Applied Life Sciences, Vienna

Masih I, Ahmad M, Uhlenbrook S, Turral H, Karimi P (2009) Analysing streamflow variability and water allocation for sustainable management of water resources in the semi-arid Karkheh river basin, Iran. J Phys Chem Earth 34(4):329–340

Ministry Energy of Iran (2012) Guideline for finding aquatic ecosystems environmental water requirement. Office of Deputy for Strategic Supervision, Tehran

Moeini R, Afshar A, Afshar MH (2011) Fuzzy rule-based model for hydropower reservoirs operation. J Electr Power Energy Syst 33(2):171–178

Mousavi SJ, Ponnambalam K, Karray F (2005) Reservoir operation using a dynamic programming fuzzy rule-based approach. Water Resour Manag 19(5):655–672. doi:10.1007/s11269-005-3275-3

Ngoc D, Geurbesville P, Minh T, Raghavan S, Shie Y (2016) A deterministic hydrological approach to estimate climate change impact on rivet flow: Vu Gia-Thu Bon catchment, Vietnam. J Hydro Environ Res 11:59–74

Raskin P, Hansen E, Zhu Z, Stavisky D (2009) Simulation of water supply and demand in Aral sea Region. J Water Int 17(2):55–67

Riahi K, Rao S, Krey V, Cho C, Chirkov V, Fischer G, Kindermann G, Nakicenovic N, Rafaj P (2011) RCP 8.5—a scenario of comparatively high greenhouse gas emissions. J Clim Change 109(1–2):33. doi:10.1007/s10584-011-0149-y

Sarzaeim P, Bozorg-Haddad O, Fallah-Mehdipor E, Loáiciga HA (2017) Environmental water demand assessment under climate-change conditions. Environ Monit Assess. doi:10.1007/s10661-017-6067-3

Simonovic SP (2009) Managing water resources: methods and tools for a system approach. UNESCO Publishing, London

Thomson AM, Calvin KV, Smith SJ, Page Kyle G, Volke A, Patel P, Delgado-Arias S, Bond-Lamberty B, Wise MA, Clarke LE, Edmonds JA (2011) RCP 4.5: a pathway for stabilization of radiative forcing by 2100. J Clim Change 109(1–2):77. doi:10.1007/s10584-011-0151-4

Van-Vuuren D, Edmonds J, Kainuma M, Riahi K, Thomson A, Hibbard K, Hurtt G, Kram T, Krey V, Lamarque JF, Masui T, Meinhausen M, Nakicenovic N, Smith S, Rose SK (2011) The representative concentration pathways: an overview. J Clim Change 109(1–2):5. doi:10.1007/s10584-011-0148-z

Wayne GP (2013) The beginner’s guide to representative concentration pathways. Skept Sci 25:1–24

Wilby RL, Dawson CW, Barrow EM (2002) SDSM—a decision support tool for the assessment of regional climate change impacts. Environ Model Softw 17(2):145–157

Zahmatkesh Z, Karamouz M, Goharian E, Burian SJ (2015) Analysis of the effects of climate change on urban storm water runoff using statistically downscaled precipitation data and a change factor approach. J Hydrol Eng 20(7):05014022