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Sustainability assessment of dams

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Abstract

Better management of water resources, by dam construction, is crucial for human survival due to climate change and water scarcity. With the growing demand for fresh water in modern societies, the movement of the large dams' construction started, and global river systems have been increasingly altered by dams for water and energy needs. Dams have played an important role for human development for centuries, but in recent decades dams projects have become mired in controversy. Critics of dams believe that benefits have been grossly overstated, while the social and environmental costs have been largely ignored. Therefore, the aim of this research is to conduct a sustainability assessment of dams' impacts to offer insights for construction of dams and their management. We used analytical hierarchy processing to address the question of socio-ecological sustainability impacts of an illustrative dam, Raees-Ali Delvari Dam (RADD), under climate change condition. The results showed that among the three pillars of sustainability, economic dimension of RADD was the most important. The criteria analysis indicated that experts perceived the negative factors (weakness and threats) to be relatively more important in sustainability of the dam than positive factors (strengths and opportunities). Environmental threats such as climate change can diminish the positive impacts and increase the environmental, social and economic weaknesses of the dam. Farmers in benefited and less-benefited regions had conflicting views regarding the strengths and weaknesses of the RADD. Unequal distribution of benefits among farmers of different regions is a major source of conflict and concern in sustainable management of dams. The results were used to develop a key dams' sustainability assessment checklist for management and building of new dams.

Keywords Dam's sustainability · AHP–SWOT · Key dams' sustainability assessment checklist · Raees-Ali Delvari Dam

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1 Introduction

The shortages of water, the most vital natural resource for human beings, are increasing in nature, and competition for its use is growing intensively (Karami et al. 2017). "Global water requirements would grow from 4500 billion to 6900 billion cubic meters until 2030" (WRG 2009). The amount of the water in the world will not decrease, but its distribution and demand for its use (food production or anything else) will change which will produce water scarcity. Per-capita water resources are expected to reduce due to climate change and population growth (Theodossiou 2016), especially in dry regions such as Iran, as shown in Fig. 1. By considering the rate of global per-capita water consumption which has increased threefold in the last century (Kahil et al. 2015), the future water problems for humanity will be more glaring. This problem will be more challenging under climate change conditions. Based on available predictions, Southeast Asia, Middle East, Australia, Southern Europe, and most of Africa and America will experience increased aridity in this century (Salinas et al. 2016). The climate change-related aridity will have enormous impacts on agriculture, industry, tourism, and ecosystems.

"The most essential cross-cutting Millennium Development Goals are poverty alleviation and securing environmental sustainability, both of which, in developing countries, are strongly linked to agricultural development" United Nations (2015). Agricultural production is the major source of livelihood for rural peoples, particularly the poor. Furthermore, it is a major contributor to GDP of developing countries (Keshavarz and Karami 2014). Water scarcity is expected to decrease agricultural productivity and consequently increase poverty in most of the Third World (Forouzani and Karami 2011).

In summary, fresh water was scarce in Iran, climate change and human activities intensify it, and for this reason, the better management of water resources is crucial for human survival. Humans in attempt to regulate water flow and reduce vulnerability have developed ways to preserve, store, and transfer water (Elston 2009). For this reason, human societies start to build dams. Dams have been built in the Middle East for centuries before BC, but the modern era of dam construction began in the 1940s (Wong 2013). Population growth increased dependence on dam to meet the growing water demand (Chen et al. 2016). Dams have played an important role in human development for thousands of years, allowing water to be stored for later use, diverted for

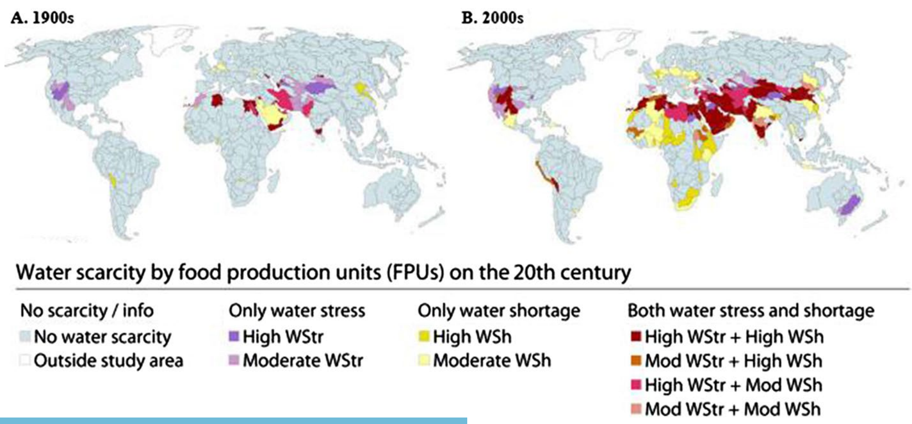

Fig. 1 Water scarcity by food production in the twentieth century

uses away from the stream, and converted to energy (Sun et al. 2012; Danner 2013). "In the latter half of the 19th century, the movement of large dams' construction started in the developed countries holding technical know-how and financial resources and later spread to the developing countries" (Shah and Kumar 2008). This resulted in construction of 50,000 large dams by the end of twentieth century. (Sparrow et al. 2011). By 2008, 60% of the world's large river systems were impacted by dams (Seto et al. 2008).

Based on the review of the available literature, dams' proponents claimed many benefits to them. The most important reason for building dams particularly in arid and semiarid regions is providing a reliable source of fresh water. This water then can be used for expansion and development of agriculture and domestic water consumption (Zhao et al. 2012). Electricity production is considered to be another significant benefit of dams. Although this is considered by some as green energy production, recently some have raised questions regarding the harmful environmental impacts of hydroelectric dams (Azari Dehkordi and Nakagoshi 2004; Kornijow 2009; Wasimi 2010; Özturk 2011). Even in dry regions flood is a serious problem. Flood control is often considered as major justification for building dams (Rodrigues et al. 2002; Lee 2003; Cheng et al. 2011; Xin et al. 2011). Other benefits of dams include recreation (Carmo and Carvalho 2011; Alrajoula et al. 2016), flourish of real estate (Akanmu et al. 2011), business activities (Santos et al. 2008), diversification of economy (Gyau-Boakye 2001), and economic growth (Cuthbertson 2008).

However, in recent decades dam projects have become mired in controversy. Critics believe the negative environmental and sociocultural impacts are greatly ignored, while the benefits are exaggerated (Yuan et al. 2012; Fearnside 2016). The most common negative impact cited is mass displacement of local people (Jackson and Sleigh 2000). Resettled communities are frequently relatively disadvantage people whose voice has been often silence by existing power structure. In some extreme cases, resettlement resulted in extinction of indigenous culture (Scudder 2005; Habia 2009), and the social fabric and economy are torn apart (Steiger 2010). The issue of equity is also important. While deprived populations and minorities often excluded from sharing the benefits, they have received an unfair share of negative impacts of large dams (Abdul-Mohsen 2005). Loss of scarce water due to evaporation in dry regions is considered to be a foremost negative impact of dams (Tafangenyasha 1997). Environmental dangers of dams including drying of wetlands and lakes have been widely documented (Elston 2009). Aquatic ecosystems have been severely impacted by changes in the hydrological regime and water quality (Braatne et al. 2008; Hadj Salem et al. 2012). Modification of sediment transport can result in substantial reduction in nutrient supply downstream (Tukur and Mubi 2002). Finally, the World Health Organization (WHO) has reported that "the reservoirs created behind dams are often breeding grounds for water-borne illnesses (such as schistosomiasis, malaria, and cholera) and other potentially toxic bacteria" (Zhu et al. 2008).

Construction of dams is one of the most debatable issues in developing countries (Fearnside 2005). Therefore, understanding the impacts of dam construction is a crucial for environmental protection and water resource management (Ouyang et al. 2012). For these reasons, assessment of dams remains a necessity in facing the challenge of water scarcity under climate change. Therefore, the aim of this study is to conduct a sustainability assessment of dams' impacts and to provide recommendations for dam management and construction. More specifically, we used Raees-Ali Delvari Dam (RADD) as an illustrative case to address the question of socio-ecological sustainability impacts of dams under climate change.

1.1 Dams' construction and impacts in Iran

Historical background of Iran in hydraulic projects is brilliant. In Achaemenes era, many dams were built in Iran (Ardakanian 2006), which most of them had a military use. Historical evidence indicates that in 400 BC dams were used for irrigating agricultural lands in Arvand and Euphrates Rivers (Pashootan 1996). The historical Bahman Dam had a length and height of 100 and 20 m, respectively (Farshad 1983). The famous period of dam building in ancient Iran was in Sassanian era, which leads to urban development in Iran. The biggest dam in this era was Shadervan Dam with a length and height of 250 and 11 m, respectively (Taghavi-Nejad Deilami 1984). The most technical consideration in the dam building of Iran was location selection, material selection, making the foundation, design, towers pond, water delivering canals, and flood control (Farhangi 1993).

In modern era, as the population increased, there was a growing need to preserve water for year-round consumption. Currently, Iran has 1% of world population and 0.36% of world available fresh water (Mortazavi et al. 2009). In addition to the low rainfall (250 mm per year), distribution of precipitation in Iran is spatially problematic, as 75% of total precipitation befalls in 25% of the country (Ashofteh and Bozorg Haddad 2013); in addition, 90% of rainfall is in the autumn and winter. Due to this improper distribution, annually 61.8 km^3 of 400 km^3 total precipitation of Iran is released to the sea or run out of the country (Yousefi et al. 2014). From 118 km^3 annual available water, 92% (88.6 km^3) is consumed by agricultural sector (Yousefi et al. 2014). In Iran, per capita available water has decreased from 6800 m^3 in 1956 to less than 1300 m^3 in 2014 and it is predicted that the country will experience water scarcity as per capita available water approaches to less than 1000 m^3 by 2030 (Keshavarz and Karami 2013). Considering the magnitude of water scarcity in Iran, modern dam construction has been considered a legitimate policy to preserve reliable sources of water since the 1960s (Ashofteh and Bozorg Haddad 2013). The survey of dams indicates that 600 are constructed, 134 are under construction and plan for more than 300 dams are under study (Tartar et al. 2009). The reservoir capacity of Iran's under operation dams is 43,395 million cubic meters, but these dams regulate only 31,537 million cubic meters annually (Azari Dehkordi et al. 2003).

In the beginning, there was increasing enthusiasm for building modern dams. The advocates promoted the idea of building large dams by emphasizing flood control, clean energy, and water security. Building dams was a sign of development and national pride. However, in the past decade dams have come under numerous criticisms because of environmental, financial, and human rights issues.

2 Research method

2.1 Study area

The RADD which is used as an illustrative case in this study is one of Iran's largest hydro-project aimed at controlling and managing the Shapoor River. The Shapoor River Watershed is located in Bushehr Province in southern Iran. This river is 220 km long from north to south. Shapoor River drains a 21,274 km^2 low-gradient watershed consisting of non-agriculture and agricultural lands. The river discharges into Helleh wetland. The annual average air temperature in dam site is 26.2 °C. The annual average rainfall for last 10 years is 194.05 mm which shows 23% reduction from long-term annual rainfall.

Building a 102-m-high dam across the Shapoor River at Bushehr Province was infeasible in the 1950s, and politically and technically opposed to 1970. But in the middle of 1990s, the decision was taken to build the RADD. The dam is large sized with a storage capacity of 658,000,000 m^3. It was completed in 2008. The dam was formally operationalized in March 2009. Based on the access to water, the area under RADD can be classified into:

1. *Benefited region*: this area includes Shabankare region which has imparted the most from the dam; and
2. *Less-benefited region*: this area includes the Helleh Basin region which has imparted less from the dam (Fig. 2).

2.2 Stages of research

Analytical hierarchy processing (AHP) was used to assess the impact of RADD. AHP method is used to facilitate decision making by using both subjective judgment and empirical data (Rezaei-Moghadam and Karami 2008). Figure 3 illustrates the stages followed in this research. These stages include participation selection, SWOT analysis, building the decision tree, and finally conducting the AHP analysis.

2.2.1 Stage 1: participants selection

Four focus group interviews were conducted to explore the opinion of farmers from benefited and less-benefited regions, specialists of Bushehr Agricultural Organization (BAO)

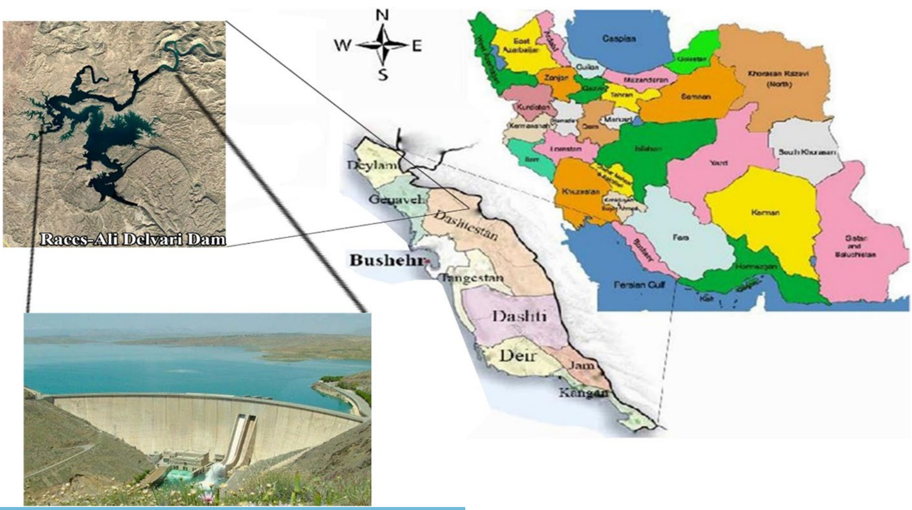

Fig. 2 Study area map

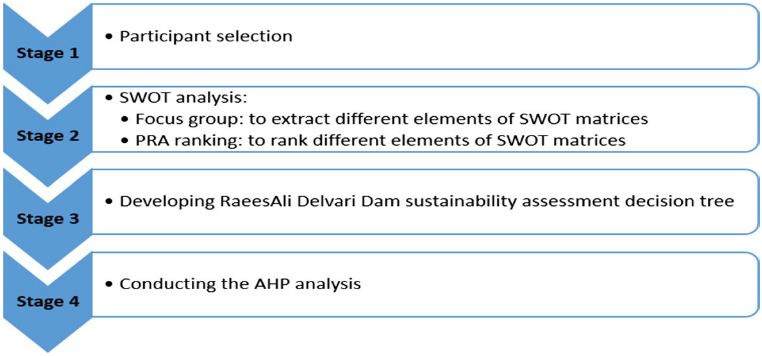

Fig. 3 Research stages

and water authorities about strengths, weaknesses, opportunities, and threats of RADD. Numbers of participants and reasons behind the selection of each group are presented in Table 1.

2.2.2 Stage 2: SWOT analysis

SWOT analysis was used to build the criteria section of the decision tree. To perform SWOT analysis, focus group method was used. Each focus group consisted of five members plus researchers, lasted 90 to 120 min, guided by six open questions about four dimensions of SWOT. The four focus groups interviews revealed a comprehensive list of strengths, weaknesses, opportunities, and threats. Numbers of items (sub-criteria) related to each dimension of SWOT were rather long. To select the six most central items, we returned to each focus group and conducted PRA ranking for each SWOT's aspects. The results of the mean ranks of four focus groups were used to select the final six items of each SWOT's dimension for use in AHP analysis.

3 Results

3.1 Developing decision's tree

Developing a model in three levels (main objective, criteria, and alternatives) is the first stage of each AHP analysis. In this study, the main objective was to evaluate the contribution of RADD to the sustainable development of the regions (Fig. 4). The hierarchical model for sustainability evaluation of RADD consists of level 1 and level 2 criteria. Level 1 criteria include social, environmental, and economic dimensions of sustainability. Level 2 criteria consist of SWOT dimension.

The six most central sub-criteria for level 2 criteria (SWOT's dimensions) were selected by mean rank of PRA analysis (Tables 2, 4 and 5). The most central sub-criteria for *strengths* dimension were increased water access, increased aquifer level, improved water quality, agricultural thrive, and increased income in the benefited region and flood control of Shapoor River (Table 2). The most central sub-criteria for *weaknesses* were increased canebrake development in water canals, inappropriate water delivering schedule, increased

Table 1 Descriptions of focus groups used in the study

Focus groups	Number of participants	Descriptions (reasons for selection)
Farmers from benefited region (FBR)	5	To represent the view of farmers from the benefited region Provide valuable emic views Key informant selected by other farmers
Farmers from less-benefited region (FLBR)	5	To represent the views of farmers from the less-benefited region Provide valuable emic views Key informant selected by other farmers
Bushehr Agricultural Organization (BAO)	5	To provide agricultural-related appraisal Provide valuable etic views Represent different agricultural disciplines Represent different managerial level Selected by higher-level supervisors
Bushehr Regional Water Authorities (BRWA)	5	To provide water-related appraisal Provide valuable etic views Represent different water-related specialties Represent different managerial level Selected from the list of specialists based on their area of expertise and length of services

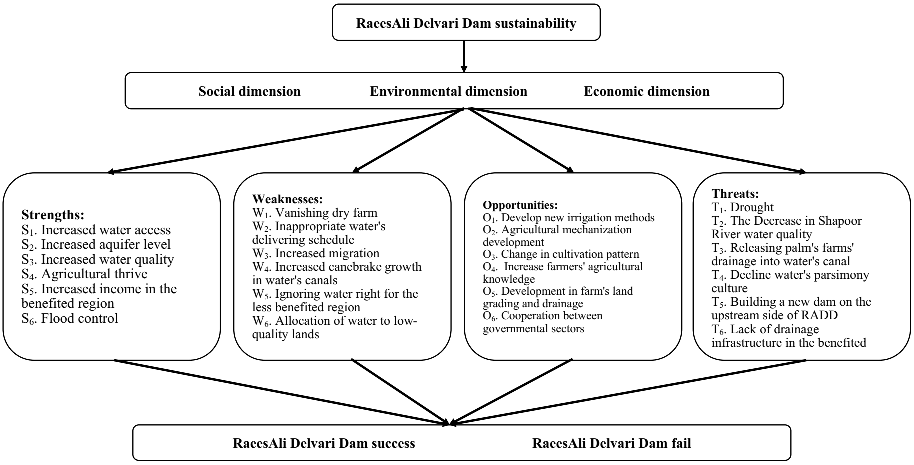

Fig. 4 Hierarchical model for sustainability evaluation of RADD

migration, allocation of water to low-quality lands, and in the less-benefited area, increased unemployment and ignoring water right (Table 3). As indicated in Table 4, the most central sub-criteria for *opportunities* were diffusion of new irrigation methods, agricultural mechanization, change in cropping pattern, improving agricultural knowledge, soil improvement, and intergovernmental cooperation (Table 4). Finally, with regard to *threat* dimension the most central sub-criteria based on mean rank were drought, decrease in Shapoor River water quality, releasing palm farms drainage into water canal, decline in water parsimony culture, building a new dam in the upstream side of dam, and lack of drainage infrastructure in benefited region (Table 5).

3.2 Raees-Ali Delvari Dam sustainability

The phase 1 of the study provided six sub-criteria for each dimension of SWOT were used to develop the AHP model of this study (Model 1). The inconsistency score for all parts of the model was within the acceptable range (less than 0.02). First, we will present the combined results of AHP analysis for the four focus groups, and we will discuss the difference between groups.

Considering the weight of the sustainability dimensions (Table 6) and the goal of the model, "Raees-Ali Delvari Dam sustainability," combined group analysis indicated that economic is the most important dimension (0.500), followed by social and environmental dimensions that are equally important (0.250). Further analysis indicated that BRWA (as the RADD administrator), BAO, and FBR groups, despite the slight differences, evaluated the economic as the most importance dimension of sustainability. However, FLBR attached equal weight to all three dimensions of sustainability (Table 6 and Fig. 5).

The integrated priorities of four focus groups for the SWOT criteria revealed (Table 6 and Fig. 8) that the most important criterion was *threats* dimension (0.277). *Weaknesses* appeared as the second most important factor in achieving sustainability (0.259). The dam *strengths* (0.236) and *opportunities* (0.228) were ranked third and fourth, respectively. Group analysis indicated that BRWA group believed threats is the most important dimension of SWOT, while BAO, and FBR groups point to strengths as the most importance.

Table 2 Selected criteria for strengths

	Increased aquifer level	More after cropping in benefited region	Increased in cash crop cultivation in benefited region	Increased water access	Increased land price in benefited region	Conserving Helleh wetland during drought	Agricultural thrive	Increased income in benefited region	Increased water quality	Improved social security in benefited region	Booming tourism in benefited region	Employment of local people during dam construction	Improved well-being in benefited region	Flood control	Increase in farm land economic value in benefited region
Mean of ranks	2.42	8.75	8.50	2.17	11.92	11.33	4.75	6.58	4	10.00	11.42	9.75	9.33	7.33	11.75
Variance	1.24	3.36	3.06	1.12	2.94	3.55	3.09	3.68	2.41	3.10	2.23	2.83	3.60	4.58	2.26
Min	1	5	5	1	8	5	1	2	1	4	8	6	4	1	6
Max	5	15	14	4	15	15	12	12	11	14	15	14	14	15	14
Number of Rank 1	3	0	0	4	0	0	2	3	1	0	0	0	0	2	0
Number of rank 2	4	0	0	4	0	0	1	0	0	0	0	0	0	0	0
Number of rank 3	3	0	0	2	0	0	1	0	5	0	0	0	0	1	0

Table 3 Selected criteria for weaknesses

	Inappropriate delivering schedule	Imbalance of water quality and water price	Ignoring water right for less-benefited region	Allocation of water to low-quality lands	Allocating water to lands with no water right	Invasion of Helleh wetland to farm lands	Decreased lands price in less-benefited region	Lack of establishment of water users' association	Increased unemployment in less-benefited region	Increased canebrake growth in water's canals	Vanishing dry-land farming	Inappropriate allocation water in practice	Increased migration	Decreased agricultural income in less-benefited region	Miss design of irrigation canals	Increased water conflict between farmers
Mean of ranks	7.42	9	8.08	11.25	10.50	11.83	8.58	10.25	8	3.8	9.42	8.58	7.75	10.58	9.08	10.25
Variance	4.66	5.56	6.10	5.79	3.66	3.09	5.88	2.98	5.10	4.23	5.73	5.93	4.07	2.27	5.48	3.36
Min	2	1	1	2	4	3	2	6	2	1	1	2	2	6	3	4
Max	16	17	16	17	16	16	17	14	16	11	17	17	13	13	17	15
Number of rank 1	0	1	2	0	0	0	0	0	0	8	1	0	0	0	0	0
Number of rank 2	1	1	1	1	0	0	1	0	1	0	2	3	1	0	0	0
Number of rank 3	1	0	1	0	0	1	1	0	1	0	0	2	3	0	2	0

Table 4 Selected criteria for opportunities

	Diffusion of new irrigation methods	Intergovernmental cooperation	Receiving budget to complete irrigation and drainage infrastructure	Improving agricultural knowledge	Agricultural mechanization	Building small dams for seasonal flood control	Soil improvement	Local participation in water management projects	Change in cropping pattern
Mean of ranks	1.83	5.75	6.08	4.75	2.75	7.25	5.33	7.25	4
Variance	1.27	1.60	2.15	2.38	1.66	2.52	1.44	2.45	1.76
Min	1	3	1	2	1	2	3	2	1
Max	5	8	9	8	7	9	8	9	7
Number of rank 1	7	0	1	0	3	0	0	0	1
Number of rank 2	2	0	0	3	2	2	0	1	2
Number of rank 3	2	1	0	2	5	0	1	0	1

Table 5 Selected criteria for threats

	Releasing palm farms drainage into water's canal	Decrease in Shapoor River water quality	Decline water's parsimony culture	Drought	Political decision about dam's water	Building new dam in the upstream side of RADD	Do not allocating enough water for Bushehr Province from Shapoor River water	Conflicts between farmers and governmental organizations	Lack of drainage infrastructures in benefited region	Increase in vegetables cultivation in benefited region	Lack of non-farm jobs and incomes
Mean of ranks	5.42	4.25	5.42	1.92	7.92	5.58	6.08	9.33	5.83	7.33	6.91
Variance	3.03	2.14	3.28	1.16	2.35	3.53	3.37	1.23	2.82	2.64	2.61
Min	1	1	1	1	4	1	2	7	1	4	3
Max	10	8	10	5	11	11	11	11	11	11	11
Number of rank 1	1	1	2	5	0	1	0	0	1	0	0
Number of rank 2	2	1	1	5	0	1	2	0	0	0	0
Number of rank 3	1	4	1	1	0	3	0	0	0	0	2

Table 6 Priorities for respondents determined through SWOT–AHP analysis

Factors	Total	BRWA	BAO	FBR	FLBR
SWOT analysis					
Strengths dimension	0.236	0.185	*0.292*	*0.367*	0.107
Weaknesses dimension	0.259	0.292	0.238	0.157	*0.363*
Opportunities dimension	0.228	0.170	0.215	0.256	0.263
Threats dimension	*0.277*	*0.353*	0.256	0.220	0.268
Sustainability dimensions					
Economic dimension	*0.500*	*0.443*	*0.500*	*0.661*	0.333
Social dimension	0.250	0.387	0.250	0.131	0.333
Environmental dimension	0.250	0.169	0.250	0.208	0.333
Alternatives					
RADD success	*0.596*	*0.624*	*0.656*	*0.626*	0.459
RADD fail	0.404	0.376	0.344	0.374	*0.541*

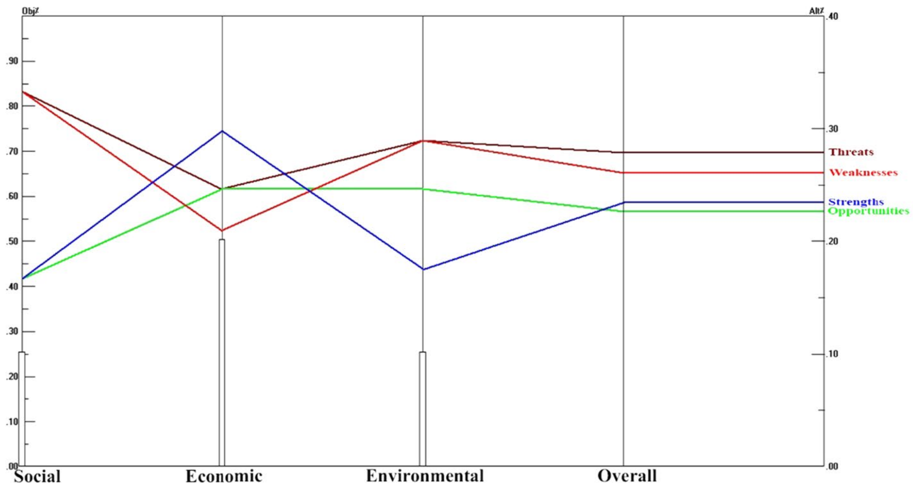

Fig. 5 Structural effects on criteria (all respondents)

The FLBR appraisal was in contradiction with the other three groups: They indicated *weaknesses* as the most important (Table 6 and Fig. 6).

SWOT sub-criteria showed that the *threat* of building a new dam in the upstream of RADD was the most important sub-criterion (0.121) which encompasses 12% of total weights of all sub-criteria (Table 7 and Fig. 7). For *strengths*, respondents gave equal weight to all sub-criteria (0.039) (Table 7 and Fig. 7). The results indicated that the absence of appropriate water delivering schedule was the most important *weakness* (0.074) (Table 7 and Fig. 7). Concerning *opportunities*, respondent thought that improving agricultural knowledge is the most important sub-criterion (0.079) (Table 7 and Fig. 7).

Sub-criteria analysis by the four groups was conducted (Table 7 and Fig. 8). The sub-criteria analysis of *strengths* indicated that BRWA, BAO, FBR, and FLBR respondents believed that the most important *strengths* of RADD were flood control (0.063), increased water quality (0.076), agricultural thrive (0.098), and increased water quality (0.022), respectively (Table 7 and Fig. 8) These results collaborate the findings of Zhou et al.

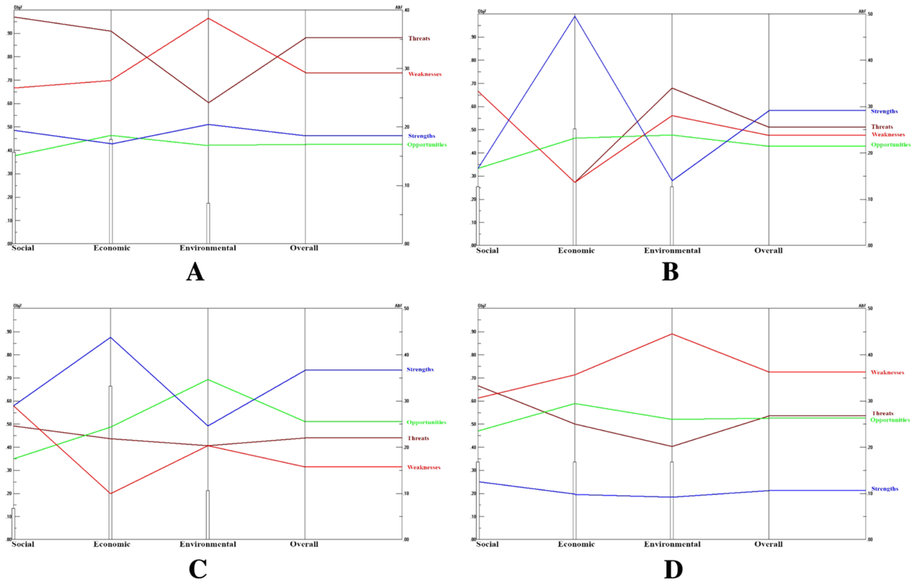

Fig. 6 **a** Structural effects on criteria by BRWA, **b** structural effects on criteria by BAO, **c** structural effects on criteria FBR, and **d** structural effects on criteria FLBR

(2018), Zammoran-Mieza et al. (2017), and Chezgi et al. (2016), with regard to dams' benefits. The analysis of *weakness* indicated that respondents believed that the most important *weaknesses* of RADD were increased migration (BRWA), ignoring water right for FLBR (BAO and FLBR), and inappropriate water delivering schedule (FBR). The sub-criteria analysis of *opportunities* showed that respondents believed that the most important *opportunities* of RADD were improving agricultural knowledge (BRWA, BAO, and FLBR), change in cropping pattern (BAO), and diffusion of irrigation methods (FBR). By considering the FBR group access to water, they believe that diffusion of new irrigation method could be a noble opportunity which contributes to development. But in FLBR due to low access to water, improving agricultural knowledge could be a good opportunity for farmers to leading development. The sub-criteria analysis of *threats* dimension indicated that all groups believed that the most important *threats* of RADD were building a new dam in the upstream of RADD (Table 7 and Fig. 8).

One of the aims of this study was to determine the priority of the two alternatives of "success" and "failure" of RADD in contributing to sustainable development of the region. The results of the overall synthesis of judgment in the network (Table 6 and Fig. 9) indicated that the alternative "RADD success" received the highest priority (0.596) and has a considerably larger value than the "failure" alternative (0.404). All the respondent groups had a similar opinion regarding the priority of alternatives except FLBR who gave a higher priority to "failure" alternative to RADD (0.541). The most important reason for this kind of dam's alternative assessment could be a direct and indirect beneficiary of RADD's water. In FBR and the governmental body, this beneficiary is more than FLBR, and due to this they gave the higher priority to "success" alternative.

Based on the findings of the comparison of RADD sustainability model alternatives (Fig. 4), we tested the degree of structural features influence on assessment result. For this reason, all preference information based on pairwise comparisons in the AHP models was

Table 7 Priorities for respondents determined through SWOT–AHP analysis

Factors	Total	BRWA	BAO	Benefited region	Less-benefited region
Increased water access	0.039	0.027	0.060	0.043	0.014
Increased aquifer level	0.039	0.027	0.066	0.066	0.013
Increased water quality	0.039	0.021	*0.076*	0.041	*0.022*
Agricultural thrive	0.039	0.032	0.035	*0.098*	0.021
Increased income in FBR	0.039	0.015	0.035	0.066	0.021
Flood control	0.039	*0.063*	0.020	0.052	0.015
Vanishing dry farm	0.029	0.047	0.024	0.017	0.033
Inappropriate water delivering schedule	*0.074*	0.054	0.065	*0.083*	0.049
Increased migration	0.027	*0.079*	0.014	0.009	0.019
Increased canebrake growth in water's canal	0.021	0.030	0.015	0.010	0.015
Ignoring water right for FLBR	0.062	0.046	*0.088*	0.009	*0.214*
Allocation of water to low-quality lands	0.047	0.035	0.033	0.029	0.033
Diffusion of irrigation methods	0.047	0.030	0.026	*0.081*	0.043
Agricultural mechanization	0.022	0.011	0.018	0.030	0.022
Change in cropping pattern	0.043	0.036	*0.072*	0.022	0.060
Improving agricultural knowledge	*0.079*	*0.054*	*0.072*	0.077	*0.092*
Soil improvement	0.023	0.023	0.015	0.022	0.028
Intergovernmental cooperation	0.015	0.016	0.012	0.023	0.019
Drought	0.069	0.040	0.072	0.043	0.064
Decrease in Shapoor River water quality	0.023	0.028	0.024	0.025	0.019
Releasing palm's farms' drainage into water canal	0.019	0.023	0.013	0.007	0.032
Decline water parsimony culture	0.025	0.111	0.030	0.007	0.021
Building new dam in the upstream side of RADD	*0.121*	*0.120*	*0.099*	*0.119*	*0.119*
Lack of drainage infrastructures in FBR	0.019	0.030	0.018	0.012	0.013

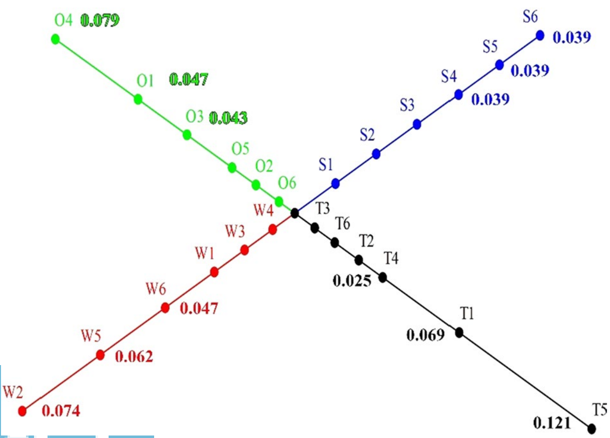

Fig. 7 Structural effects on sub-criteria (all respondents)

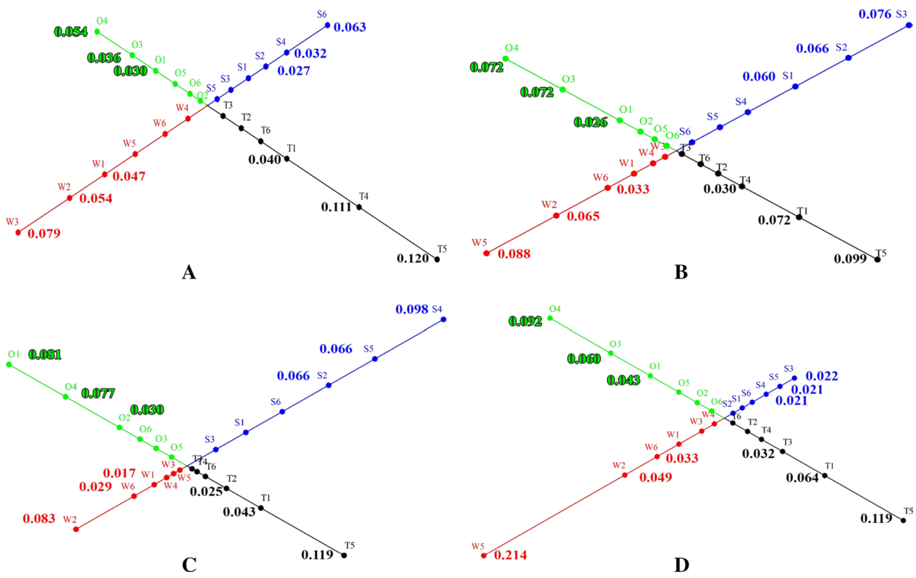

Fig. 8 **a** Structural effects on sub-criteria by BRWA, **b** structural effects on sub-criteria by BAO, **c** structural effects on sub-criteria by FBR, and **d** structural effects on sub-criteria by FLBR

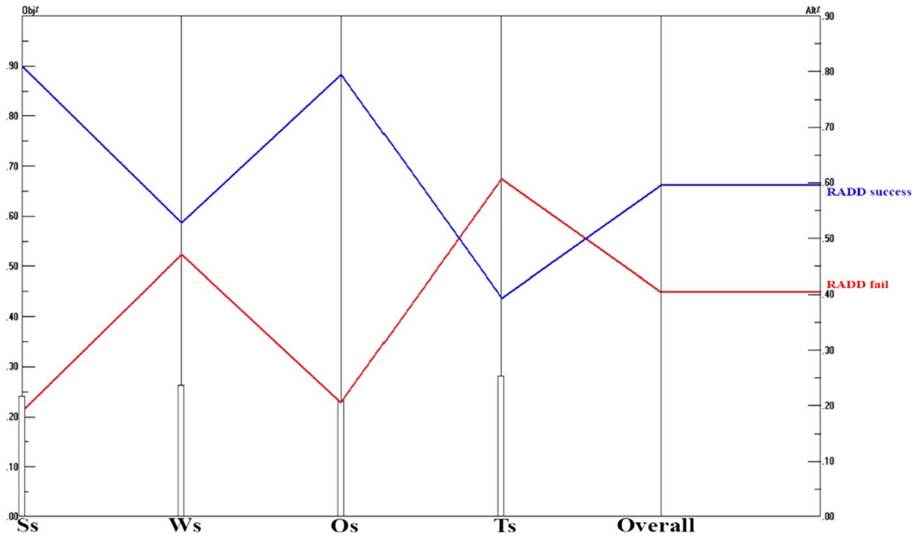

Fig. 9 Structural effects on alternatives (all respondents)

considered. “This transformation assumes that a difference of 100% between two indicator values is equivalent to a comparison value of 9, the endpoint of Saaty’s 1–9 scale” (Saaty and Vargas 2013).

The four groups have an agreement regarding the priority of *strengths* and *opportunities* on the “success” alternatives of the dam (Fig. 10). However, there were differences

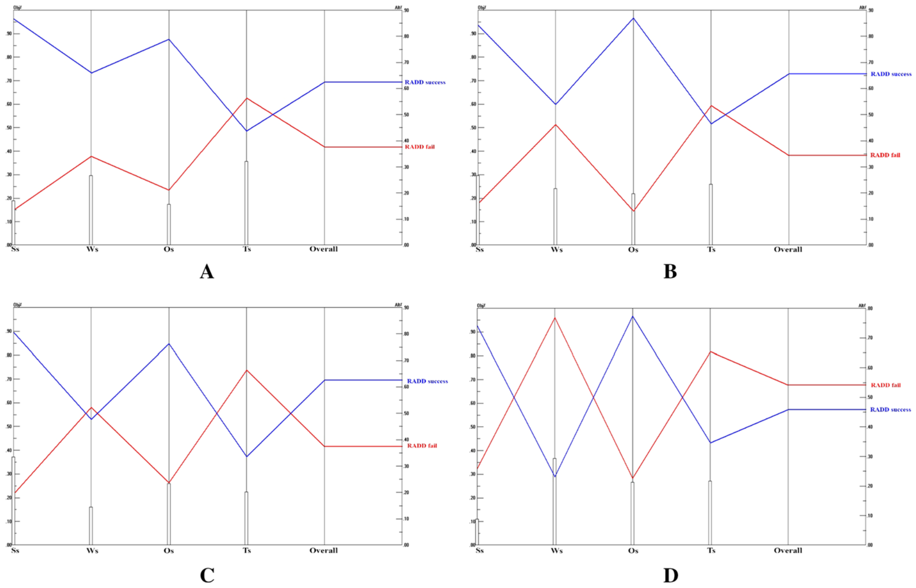

Fig. 10 **a** Structural effects on alternatives by BRWA, **b** structural effects on alternatives by BAO, **c** structural effects on alternatives by FBR, and **d** structural effects on alternatives by FLBR

in priorities they gave to *weaknesses* and *threats*. FLBR respondents evaluated the *weaknesses* to have a high impact to "failure" alternative (Fig. 9), while BRWA respondents believed despite the *weaknesses* "success" alternatives had a higher priority (Fig. 10).

4 Conclusion and recommendation

The AHP–SWOT analyses were conducted to assess RADD sustainability. Based on the results of the present study, the following conclusion and recommendations are offered:

Dams have benefits, but with a high cost. On the benefit side, reliable water supply, flood control, and high water quality have resulted in agricultural thrive, increased aquifer level, and increased income in the benefited region. On the other hand, RADD is facing important threats and weaknesses. We used PRA ranking to prioritize the strength and weakness of RADD by using three pillars—environmental, social, and economics—of sustainability theory. The findings revealed that economic dimension was perceived by respondents to be the most important sustainability concern. Experts perceived the negative aspects (threats and weakness) of the RADD dam to be relatively more important than positive aspects (opportunities and strengths). Due to uncertainty caused by climate change, "threats" were the most important negative aspect. AHP analysis showed that building a new dam in the upstream of RADD was the most important sub-criteria. We concluded that RADD's strengths could diminish by climate change. Furthermore, the environmental, social, and economic weaknesses will increase by water scarcity. Such impacts can make the construction of new dams unjustifiable and sustainable management of existing dams a challenge.

Farmers in benefited and less-benefited region had conflicting views regarding the strengths and weaknesses of the RADD. Considering the increasing water conflict among regions, dams could be a major source of social and political instability in the regions that are disproportionally affected by dams. Finally, the experts and farmers from benefited region believed that the RADD was relatively successful in achieving sustainability of the region, while farmers from less-benefited region evaluated the dam to have relatively failed to achieve sustainability.

Although our study is based on the illustrative case of RADD, we speculate that our findings have far-reaching implication for management and building of new dams in most arid regions affected by climate change. Based on the results, a Key Dam Sustainability Assessment Checklist (KDSAC) was developed (Table 8). This checklist could be used as a decision supporting device for assessment of sustainability of building and management of dams. The intensity and importance of each element in the checklist could be determined, by locally applying AHP–SWOT analysis. Then, the sustainability score can be calculated by Formula 1. Sustainability score is scaled to range between –9 and +9. For interpretation of the score, see Fig. 11. It is important to notice that others have also provided useful frameworks and guidelines for dams' assessment. Two of the most famous of these works

Table 8 Key dams' sustainability assessment checklist

Check list's elements	Intensity[a]									Importance[b]					
	Unsustainable				Sustainable					None			Very high		
1. Water access	−9	−7	−5	−3	1	3	5	7	9	0	1	2	3	4	5
2. Water quality	−9	−7	−5	−3	1	3	5	7	9	0	1	2	3	4	5
3. Agricultural development	−9	−7	−5	−3	1	3	5	7	9	0	1	2	3	4	5
4. Income generation	−9	−7	−5	−3	1	3	5	7	9	0	1	2	3	4	5
5. Flood control	−9	−7	−5	−3	1	3	5	7	9	0	1	2	3	4	5
6. Reliable water supply	−9	−7	−5	−3	1	3	5	7	9	0	1	2	3	4	5
7. Appropriate settlements	−9	−7	−5	−3	1	3	5	7	9	0	1	2	3	4	5
8. Improving water right	−9	−7	−5	−3	1	3	5	7	9	0	1	2	3	4	5
9. Diffusion of agricultural innovation	−9	−7	−5	−3	1	3	5	7	9	0	1	2	3	4	5
10. Improving cropping pattern	−9	−7	−5	−3	1	3	5	7	9	0	1	2	3	4	5
11. Increasing agricultural knowledge	−9	−7	−5	−3	1	3	5	7	9	0	1	2	3	4	5
12. Soil improvement	−9	−7	−5	−3	1	3	5	7	9	0	1	2	3	4	5
13. Drought mitigation	−9	−7	−5	−3	1	3	5	7	9	0	1	2	3	4	5
14. Improving water saving culture	−9	−7	−5	−3	1	3	5	7	9	0	1	2	3	4	5
15. Decreasing threats	−9	−7	−5	−3	1	3	5	7	9	0	1	2	3	4	5
16. Increasing opportunities	−9	−7	−5	−3	1	3	5	7	9	0	1	2	3	4	5
17. Equitable development of the region	−9	−7	−5	−3	1	3	5	7	9	0	1	2	3	4	5
18. Overall economic benefits	−9	−7	−5	−3	1	3	5	7	9	0	1	2	3	4	5
19. Overall environmental benefits	−9	−7	−5	−3	1	3	5	7	9	0	1	2	3	4	5
20. Overall social benefits	−9	−7	−5	−3	1	3	5	7	9	0	1	2	3	4	5

[a]The intensity of sustainability/un-sustainability impacts of building dam on each element

1: no intensity, +3: moderate positive intensity, +5: strong positive intensity, +7: very strong positive intensity, +9: extreme positive intensity, −3: moderate negative intensity, −5: strong negative intensity, −7: very strong negative intensity, −9: extreme negative intensity

[b]The sustainability importance of the elements

0: none, 1: very low importance, 2: low importance, 3: moderate importance, 4: high importance, and 5: very high importance

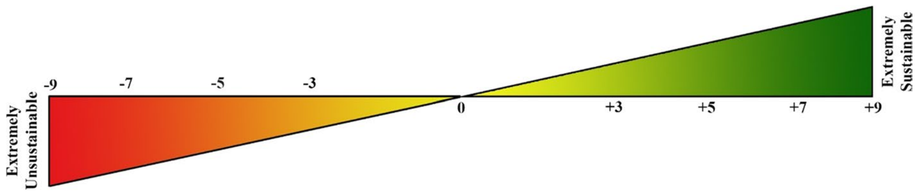

Fig. 11 Dams' sustainability assessment spectrum

are provided by World Commission on Dams (2000) and World Bank (2009). The guideline provided by this study in comparison with previous frameworks has the following advantages: (1) this is a rapid appraisal tool; (2) both etic and emic view of stakeholders can be assessed; (3) it provides post-dam operation assessment guidelines; and (4) based on dimension and intensity recommendation for improving sustainability of the dam can be provided.

Formula 1: Dam's sustainability score

$$\mathrm{DS} = \frac{\sum_{i:1}^{20} \mathrm{IN}_i * \mathrm{IM}_i}{100},$$

where i is the number of elements; DS is the dam sustainability score; IN_i is the intensity of ith element; and IM_i is the importance of ith element.

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