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Water Scarcity Management in Arid Regions Based on an Extended Multiple Criteria Technique

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Abstract Relying on strategic multi-criteria techniques is an effective step for identifying the sources of water management problems, formulating strategies, and prioritizing the alternatives. In this study, a hybrid use of recently developed "Best Worst Method" (BWM) and strength-weakness-opportunity-threat (SWOT) matrix was presented as a novel strategic multiple criteria strategic technique called B'WOT. B'WOT simplifies decision-making by handling rank-reversal in pairwise comparisons. The methodology employed in this paper involves: (1) finding the effective strategic factors of the region with SWOT; (2) evaluating the relative significance of strategic factors through a comparative framework including B'WOT along with a conventional Analytic Hierarchy Process (AHP)-SWOT called A'WOT; (3) prioritizing the strategies with a risk-based multiple criteria technique, and (4) aggregation of divergent ranks of the strategies under different risk-attitudes. Comparison of the BWM vs. AHP in ranking SWOT factors according to consistency ratio (CR) and total deviation (TD) showed the superiority of BWM. Unlike AHP that some of its pairwise comparison matrices violated the acceptable CR's threshold, all the BWM's matrices provided consistent outcomes. Moreover, TD values of BWM's matrices were lower (better) than AHP ones. Employment of a risk-based technique was another merit of the study that provided a wide variety of prioritization lists with respect to pessimistic, neutral, and optimistic scenarios. Based on the aggregated results, "providing alternatives for low efficient and environmentally destructive agriculture by facilitating participation of private sector in industry and tourism sectors" was selected as the first priority to alleviate water scarcity in the Yazd province, Iran. In general, all the high-ranked strategies are -directly or indirectly- contributed to the seriously inefficient agricultural activities within the province.

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Keywords Best Worst Method · Multi-criteria decision making · Risk attitudes · Strategic framework · Water scarcity management

Abbreviations

AHP	Analytic Hierarchy Process
BWM	Best Worst Method
SWOT-TWOS	Strengths–Weaknesses–Opportunities–Threats
B’WOT	BWM-SWOT
A’WOT	AHP-SWOT
EFs	External factors
IFs	Internal factors
MCDM	Multi Criteria Decision-Making
QSPM	Quantitative strategic planning matrix
SMCF	Strategic multi-criteria framework
CR	Consistency ratio
CI	Consistency index
TD	Total Deviation
OWA	Ordered weighted averaging
IOWA	Induced ordered weighted averaging

1 Introduction

Due to widespread increase of population, economic growth, improper irrigation, insufficient infrastructure for water storage and constraints in water management; arid and semi-arid regions are faced with disastrous consequences of water scarcity such as land degradation, migration, biodiversity loss, declining the standard of living, etc. (Martin-Carrasco et al. 2013; Karandish et al. 2015; Azarnivand and Chitsaz 2015).

Approximately 65 % of Iran’s area includes arid and hyper arid climate, suffering from inappropriate spatial and temporal distribution of precipitation (Khalili 2004). Among the provinces of Iran, the lowest total precipitation belongs to Yazd located in central Iran. The water balance analysis of Yazd revealed a decline of 270 million cubic meters over the period of 1996–2004 (Abbaspour et al. 2009). Recently, Dastorani and Poormohammadi (2012) reported that the trend of water-budget in the case study is negative and is likely to grapple with a sticky situation of water scarcity in the foreseeable future. Therefore, the long-term water resources management vision of Yazd province should involve a wise water resources management to meet water demands for domestic, industry, and agriculture sectors. In other words, any proposed water resources analysis approach should boost sustainable development in the region. Due to divergent interests of stakeholders and multidimensionality of water resources projects, and existence of substantial complex socio-economic and bio-physical characteristics in the region; water resources should be governed based on a practical strategic multi-criteria framework (SMCF) (Azarnivand et al. 2014; Panagopoulos et al. 2012).

Throughout a system, the daunting tasks of strategic management/planning include formulating, implementing, and evaluating cross-functional decisions (David 2011). Among various strategic matrices, Strength-Weakness-Opportunity-Threat (SWOT) is considered as a well-known procedure for identifying the fundamental internal and external factors along with formulating the strategies. The quantitative strategic planning matrix (QSPM) also provides a mechanism for monitoring the factors' interactions through a vision by evaluating attractiveness scores of internal factors (IFs) against the external factors (EFs). Despite the aforementioned applications, SWOT-QSPM is not capable of determining the relative importance of factors. Therefore, combination of multi-criteria decision making (MCDM) methods with SWOT was adopted in some cases for complex strategic decision-making problems. MCDMs have been employed in such various fields as water shortage management (Tsakiris and Spiliotis 2011), GIS application (Panagopoulos et al. 2012), flood management (Chitsaz and Banihabib 2015), site selection (Ahmadisharaf et al. 2015), watershed prioritization (Malekian and Azarnivand 2016), conflict resolution (Bozorg-Haddad et al. 2016), etc. Kurttila et al. (2000) introduced the AHP-SWOT hybrid method (A'WOT) by merging a MCDM method called, analytic hierarchy process (AHP) into SWOT for strategic management. AHP is capable of obtaining the weights of tangible and intangible qualitative evaluation criteria by constructing judgment matrices of pairwise comparisons along with checking the consistency of decisions (Saaty 1980).

In line with combination of SWOT-MCDM, the two following approaches have been applied: (1) application of AHP instead of QSPM which is called A'WOT. A good example of A'WOT application in water management is related to reconstructing the water intake structures in Serbia (Srdjevic et al. 2012); (2) formulating the strategy by matching the SWOT factors in the first stage, and then, prioritization of the SWOT-based strategies with MCDMs according to different evaluation criteria. In this regard, prioritization of SWOT-based strategies for lake rehabilitation in Iran via AHP with respect to sustainable development criteria can be mentioned (Azarnivand et al. 2014).

Although AHP could overcome the drawbacks contributed to subjectivity of decision-making problems, it needs large comparison dataset that leads to more inconsistent comparisons (Forman and Selly 2001). Thus, Rezaei (2015) developed a new MCDM model that modifies the pairwise structure of AHP to eradicate its shortcomings. According to Rezaei (2015), the results derived from this recently introduced technique, called Best Worst Method (BWM), were more reliable and consistent than AHP. Hence, the present study applied BWM and AHP to derive the weights of SWOT factors. The next step of decision making is contributed to handling the view-points (risk-attitudes) of decision makers. The optimistic (risk-prone) and pessimistic (risk-averse) view-points of analysts have a considerable effect on the final decision (Zarghami et al. 2008). Thus, in addition to BWM, a risk-based technique called induced ordered weighted averaging (IOWA) was also used to prioritize the strategies against the criteria derived from the hybrid SWOT-MCDM model.

The successful practical water management frameworks have portrayed the present and future image of water resources in such different fields as urban water (Panagopoulos et al. 2012), water quality assessment (Alexakis et al. 2016), risk management (Martin-Carrasco et al. 2013), natural hazard alleviation (Azarnivand and Malekian 2016) for proper planning, development and management of water resources. Hence, the current research is conducted in line with the practical water management frameworks. The paper is aimed at obtaining the most conclusive strategy for water shortage mitigation in a hyper arid province of Iran with aids of different MCDMs and a practical strategic matrix. The evaluation process is consisted of SWOT, AHP, BWM, and IOWA as the main components of the methodology. The major objectives of this study are as follows: (1) from the methodological point of view, the paper introduces combination of BWM-SWOT (B'WOT) as a novel and robust SMCF. Unlike AHP, BWM technique has not been applied yet in water management projects which can be considered as one the merits of the current research. (2) from the technical point of view, the current research formulates four groups of strategies based on matching the internal strengths and weaknesses as against external opportunities and threats to address water shortage in the driest province of Iran. In the last step, the strategies are prioritized based on the high-ranked strategic factors via IOWA.

2 Material and Methods

2.1 Description of the Case-Study and Environmental Scanning Process

Located in central Iran, Yazd province has inhabitants of about 1,074,428, of which more than 80 % of residents are urban. Covering an area of 131,551 km^2, it is geographically bounded by 31°54′N latitude and 54 ° 17′E longitudes (Fig. 1, Abbaspour et al. 2009). The mean annual precipitation of Yazd province is about 55 mm, while its long term average minimum and maximum temperature varies between 11.8 and 26.6 °C (Ashraf et al. 2014). Although the

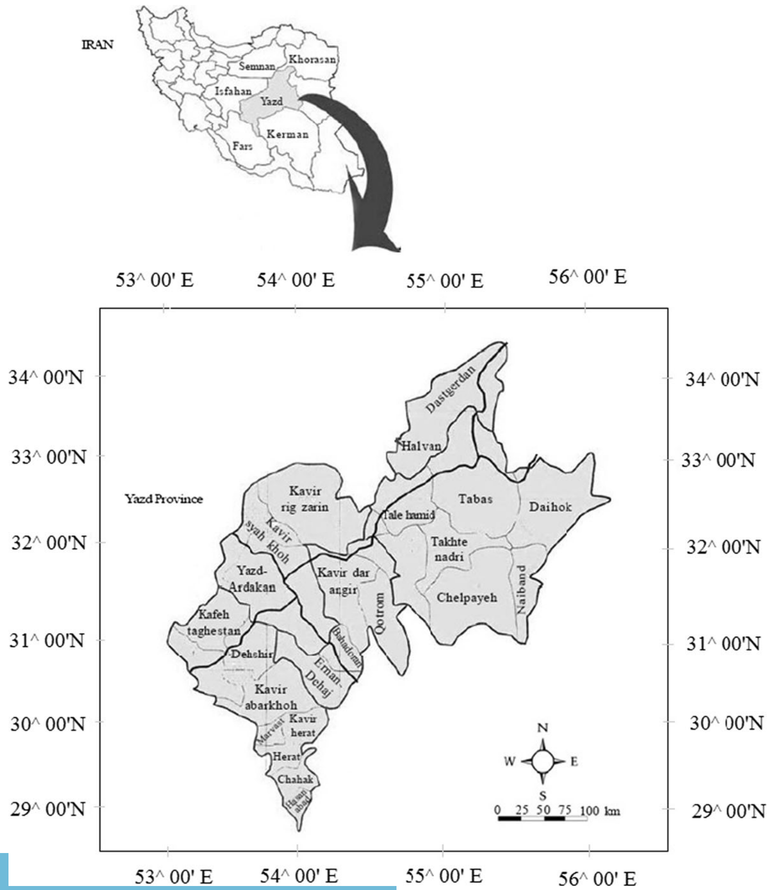

Fig. 1 Map of the study area

province has been beset with low irrigation efficiency of traditional farming systems, some 90 % of available water resources are allocated to the agricultural development. There are potentials of economic growth such as gardening, mining, and industry within the province that can act as the alternatives for agriculture. Groundwater resources such as qanats, springs, and wells are the principle suppliers of water in the study region, so that qanats supply 40 % of agricultural water in Yazd (Sadati et al. 2010).

In order to implement the strategic management effectively, SWOT-TOWS matrix is capable of identifying the IFs and EFs of a system along with matching them. In general, IFs and EFs are derived from large numbers of responses in a brainstorming process. Here, the main sources of factor derivation (environmental scanning) were published papers (e.g. Sadati et al. 2010; Mostafaeipour 2010; Shahraki et al. 2011; Dastorani and Poormohammadi 2012; Ashraf et al. 2014) along with national regulations and documents. Throughout the brainstorming session, the coordinators defined different problems associated with Yazd's water resources and then recorded the experts' viewpoints. The factors that can be controlled by province management are taken into account as IFs while, those that can affect the Yazd's water management but management cannot affect them, are categorized as the EFs. The brainstorming participants are experts in the fields of hydrology, groundwater management, rangeland management, climatology, water resources engineering, urban planning, and watershed management. All of them have adequate academic and/or engineering knowledge and experience in the province's water resources issues.

2.2 BWM-SWOT (B'WOT)

According to Weihrich (1982), SWOT matrix identifies fundamental IFs and EFs while, TOWS formulates four groups of strategies by analysis of the feasible connections between IFs and EFs as follows: Maxi-Maxi (SO) strategies which use the internal strengths to take advantage of external opportunities; (2) Maxi-Mini (ST) strategies which avoid impact of the external threats by applying the internal strengths; (3) Mini-Maxi (WO) strategies which aim at eliminating internal weaknesses by an exploitation of the external opportunities; and (4) Mini-Mini (WT) strategies which are defensive tactics directed at minimizing the internal weaknesses, while avoiding the external threats. As stated earlier, throughout the conventional strategic management and planning approaches, weights/attractiveness scores of the SWOT factors were obtained via QSPM according to capability of the system to utilize or resist against EFs and IFs. To overcome the subjectivity of QSPM, pairwise comparisons of MCDMs have been proposed. The current research proposes a hybrid BWM-SWOT as a novel approach to provide a robust decision-making tool.

The BWM steps were defined as follows (Rezaei 2015):

(1) Considering $\{c_1, c_2, c_3, \ldots, c_n\}$ as a set of criteria/strategic factors, the best (most important) and the worst (least important) of them should be obtained. Provided that more than a criterion is considered to be the best or the worst, one can be selected arbitrary.

(2) The "Best-to-Others" vector should be determined on the basis of 1–9 preference scale. In other words, superiority of the best criterion over the others is obtained by applying a score between 1 and 9 scales.

(3) Similar to the previous stage, "Others-to-Worst" vector should be obtained. The Best-to-Others and Others-to-Worst vectors are presented as follows, respectively:

$$\begin{cases} A_B = (a_{B1}, a_{B2}, a_{B3}, \ldots, a_{Bn}), & where\ a_{BB} = 1 \\ A_W = (a_{1W}, a_{2W}, a_{3W}, \ldots, a_{nW})^T, & where\ a_{WW} = 1 \end{cases} \tag{1}$$

where a_{Bj} represents the preference of the best criterion B over criterion j while, a_{jW} displays the preference of the criterion j over the worst criterion W, respectively.

(4) Finding the optimal solutions through the following problem:

$$\begin{aligned} &\min \xi \\ &s.t. \\ &\left| \frac{W_B}{W_j} - a_{Bj} \right| \leq \xi, for\ all\ j \\ &\left| \frac{W_j}{W_W} - a_{jW} \right| \leq \xi, for\ all\ j \\ &\sum_j w_j = 1 \\ &w_j \geq 0, for\ all\ j \end{aligned} \tag{2}$$

By solving the problem (4), the optimal weights $\{w_1^*, w_2^*, w_3^*, \ldots, w_n^*\}$ and maximum ξ (ξ^*) are determined.

(5) Checking the consistency ratio (CR) of decision-making process with the following formula:

$$CR^* = \frac{\xi^*}{CI} \tag{3}$$

where CI which is called consistency index (Table 1). Unlike AHP in which the acceptable CR varies between 0 and 0.1, the acceptable CR range for BWM is 0–0.5. The supplementary information regarding the mechanism of BWM and computational process of AHP is presented in Rezaei (2015), and "*Appendix Section*", respectively.

In addition to consistency of the judgments, Total Deviation (TD) was also used to assess the performance of BWM vs. AHP based on measuring Euclidean distance. TD was evaluated as follows:

$$TD = \sum_i \sum_j \left(a_{ij} - \frac{w_i}{w_j} \right)^2 \tag{4}$$

Table 1 Values of consistency index

a_{BW}	1	2	3	4	5	6	7	8	9
ξ^*	0.00	0.44	1.00	1.63	2.30	3.00	3.73	4.47	5.23

where TD was calculated for the total number of pairwise comparisons of each method as follows:

$$\begin{cases} \text{BWM}\rightarrow \dfrac{TD_{\text{BWM}}}{2n} \\ \text{AHP}\rightarrow \dfrac{TD_{\text{AHP}}}{n^2} \end{cases} \tag{5}$$

The low values of *TD* represents that the weight ratios are closer. Therefore, the technique which has the lower *TD* is the best one.

2.3 IOWA

OWA as an aggregation operator was firstly introduced by Yager (1988) to quantify the optimism/pessimism level of analysts through the process of decision-making. Throughout this framework, the score of each strategy is calculated as follows:

$$F(x_1, x_2, \ldots, x_n) = \sum_{i=1}^{n} w_i b_i = w_1 b_1 + w_2 b_2 + \ldots + w_n b_n \quad \text{where;} \quad w_i \geq 0 \ \ and \sum w_i = 1 \tag{6}$$

where x_i is the score of a strategy according to a criterion i, n is the number of criteria, w_i is the ordered weights, $(x_1, \ldots, x_n)$ represents the input dataset of OWA operator in the descending order, and b_i is the ith largest element in the inputs dataset of the OWA operator.

Later, Yager and Filev (1999) developed a more general operator, which is called IOWA. The Eq. (6) was changed for IOWA as follows (Eq. 7):

$$\text{IOWA}_w = \{(u_1, a_1), (u_2, a_2), \ldots, (u_n, a_n)\} = \sum_{i=1}^{n} w_i b_i \tag{7}$$

where u_i is the relative weight of criterion i, a_i is the score of each strategy according to a criterion, and b_i is the value of a_i from the couple (u_i, a_i) which has ith largest u_i value. Provided that among the ordering of the importance of criteria a tie like $u_2 = u_3$ exists, a_2 and a_3 should be replaced by their average values as $\frac{a_2+a_3}{2}$.

The second step in OWA methodology is calculating the order weights of operator with respect to the risk attitudes of the analyst. To do so, the order weighting vector was calculated on the basis of linguistic quantifiers using the following formula:

$$w_i = Q\left(\frac{i}{n}\right) - Q\left(\frac{i-1}{n}\right) \tag{8}$$

where $Q\left(\frac{i}{n}\right)$ = a linguistic quantifier, $i = 1,2,\ldots, n$, and $Q(0) = 0$.

To calculate $Q\left(\frac{i}{n}\right)$, the following formula can be used (Yager 1996):

$$Q\left(\frac{i}{n}\right) = \left(\frac{i}{n}\right)^{\alpha} \tag{9}$$

where α is the risk-attitude coefficient where $\alpha > 1$, $\alpha = 1$, and $\alpha < 1$ represents, pessimistic, neutral, and optimistic risk-attitudes, respectively. Owing to the fact that ranks of the strategies highly depend on the amount of α, more than one α should be used to perform the sensitivity analysis of the results (Rahmani and Zarghami 2013). In this regard, the set of {0.1, 0.5, 1, 2, 10} was used to indicate optimistic, fairly optimistic, neutral, fairly pessimistic, and pessimistic view-points, respectively.

In order to aggregate the divergent priorities, Copeland procedure should be applied to hold pairwise contests among the strategies regarding their ranks in each risk-attitude. The best strategy should have the highest number of victories while, the lowest number of losses in pairwise contests (Copeland 1951). Later, the IOWA method would be clarified by evaluating scores of a strategy.

3 Results and Discussion

The environmental scanning process revealed 26 strategic factors, of which 15 belongs to IFs while others are attributed to the EFs (Table 2). The most attractive strength of the case study was existence of industrial and mining potentials with high economic efficiency as an alternative for high water consuming agriculture sector. On the other hand, the cloud seeding

Table 2 Strategic factors of the study area

Internal (Strengths)	Internal (Weaknesses)
Industrial and mining potentials with high economic efficiency as an alternative for high water consuming agriculture (S1)	Failure to implement pressurized irrigation systems (W1)
Possibility of using solar energy because of substantial sunny days (S2)	High water loss along with low efficiency of urban water system networks (W2)
Ecotourism and cultural heritage potentials as a source of regional economic growth (S3)	Decline in groundwater resources, qanats, and seasonal rivers recharge (W3)
Existence of wastewater treatment networks in the province (S4)	High rate of migration from rural areas to the cities (W4)
Existence of cloud seeding center in Yazd (S5)	Salinity caused by rising incidence of fertilizer use (W5)
	Existence of the formations with high sensitivity to the wind erosion (W6)
	Existence of degraded pastures along with increasing desertification (W7)
	Lack of public awareness regarding new approaches and technologies of natural resources management (W8)
	Low economic efficiency while the high water consume of agriculture sector (W9)
	Lack of dialectic collaboration among stakeholders, NGOs, and the authorities (W10)
External (Opportunities)	External (Threats)
The possibility of allocating the budget from national plan of the elimination of subsidies to expand the eco-friendly industries (O1)	Arid climate plus low precipitation (T1)
Universities, Research and Engineering Institutes (O2)	Drought and global warming impacts (T2)
Funds and facilities by government for developing water resources engineering and management projects (O3)	High financial dependency of regional development plans (especially agricultural development) to the central government (T3)
Potentials of law, standards and regulations regarding water resources conservation and allocation (O4)	conflict on water resources in adjacent basins (T4)
Potentials of media, internet, and social networks to raise environmental awareness (O5)	Inexistence of birth control programs (T5)
	Lack of socio-economic development infrastructures in rural areas plus unfair distribution of job opportunities between urban and rural regions (T6)

center was not assessed as an important potential of the cases study. Among the opportunities, possibility of using social media and internet for raising environmental awareness outperformed others while, the decision makers did not assess potentials of rules and regulations as a golden opportunity. This fact had also been mentioned throughout a cause-effect analysis of water crisis management in central Iran (Azarnivand and Chitsaz 2015). The major weakness was the declining trend of groundwater resources in the province. The province is also highly threatened by consequences of drought and global warming impacts.

Matching IFs against EFs formulated 13 strategies in four strategic groups (Table 3). As stated earlier, the conventional structure of A'WOT was target of criticisms for its improper performance in providing consistent outcomes. Thus, comparison of AHP vs. BWM for determination of strategic factors' weights was taken into account in the next step. Two evaluation factors including *CR* and *TD* were used to choose the best technique based on pairwise comparison matrices of the two aforementioned techniques. The pairwise comparison matrices of B'WOT were summarized in Table 4. The results given in Table 5 demonstrated

Table 3 TOWS-based strategies in the four strategic groups involving Maxi-Maxi (SO), Maxi-Mini (ST), Mini-Maxi (WO), Mini-Mini (WT) strategies

Strategic group	Strategies
WO	A1: Improving urban water distribution systems with the aids of the research and engineering capabilities plus funds by government (W2-O2,3)
	A2: Updating laws and regulations regarding water resources management to promote supervising on groundwater resources allocation along with imposing penalties for lawbreakers with establishment of a center consists of water resources and law experts (W3-O2,4)
	A3: Raising farmers' awareness regarding modern and innovative irrigation techniques to control water loss with employing research and engineering capabilities (W8-O2,5)
	A4: Implementation of optimal copping pattern and crop rotation along modernization and mechanization of agriculture to improve irrigation efficiency and economic growth with employing funds, and the research and engineering capabilities (W1,5,9-O2,3)
	A5: Prohibition on land use changes in erosion-prone zones and degraded pastures to combat desertification with the aids of land use regulations, funds, and the research and engineering capabilities (W6,7-O2,3,4)
SO	A6: Strengthening the eco-friendly industries that use alternative energies belongs to private sector to protect natural resources with allocating tax credits along with subsidies (S2-O1)
ST	A7: Providing alternatives for low efficient and environmentally destructive agriculture by facilitating participation of private sector in industry and tourism sectors (S1,3-T3)
	A8: Crisis management during period of drought occurrence by applying treated wastewater for agricultural and industrial consumptions to conserve freshwater resources (S4-T1,2)
	A9: Cloud seeding for emergency management during period of drought occurrence (S5-T1,2)
WT	A10: Establishment of a committee involving representatives of parliament, governmental authorities, stakeholders, and NGOs for providing water diplomacy in conflict resolution regarding water resources in adjacent basins (W10,T4)
	A11: Incorporating virtual water into water management for water saving in agriculture sector along with providing economic growth (W9-T1,3)
	A12: Implementation of family planning to provide equilibrium between human population and natural resources (W3-T5)
	A13: Strengthening socio-economic infrastructures and indigenous jobs to control high rate of migration to the cities that pose high pressure to water resources of dense populated areas (W4-T6)

Table 4 Pair-wise comparison vectors [(a): for the best factor (horizontal), and (b): for the worst factor (transpose); the ** and * refer to the best and worst factors of each group, respectively]

S	s1**	s2	s3	s4	s5					
	1	4.915	3.12	4.84	8.455					
O	o1	o2	o3	o4	o5**					
	4.72	1.965	3.06	7.205	1					
W	w1	w2	w3**	w4	w5	w6	w7	w8	w9	w10
	3.925	3.525	1	4.425	5.325	6	5.1	2.65	2.05	2
T	t1	t2**	t3	t4	t5	t6				
	3.605	1	4.105	6.975	3.315	4.36				

(a)

S	s1	8.455
	s2	3.825
	s3	6.715
	s4	4.885
	s5*	1
O	o1	3.725
	o2	6.115
	o3	5.09
	o4*	1
	o5	7.205
W	w1	3.6
	w2	3.95
	w3	6
	w4	3.45
	w5	2.95
	w6*	1
	w7	2.45
	w8	3.85
	w9	4.75
	w10	4.85
T	t1	3.975
	t2	6.975
	t3	3.345
	t4*	1
	t5	4.11
	t6	3.505

(b)

superiority of BWM over AHP where the CR^* values for all four strategic pairwise comparison matrices varied between the acceptable domain. On the other hand, according to pairwise comparison matrices of S and T, the *CR* values for were ≥ 0.1 and this superiority was also true for *TD* values. Despite the consistency ratio, the smaller values of *TD* are preferable. In this regard, evaluation of *TD* for all the four pairwise comparison matrices resulted in higher values of *TD* for AHP. As a result, the hybrid BWM-SWOT outperformed traditional combination of AHP and SWOT. Not only could B'WOT provide more consistent group decision-making

Table 5 Comparison between performances of BWM vs. AHP based on Total Deviation (*TD*) along with Consistency Ratio (*CR*, CR^*)

Factor	BWM					AHP			
	weights	Ranks	ξ^*	CR^*	*TD*	weights	Ranks	*CR*	*TD*
s1	0.441	1	1.679	0.343	0.676	0.543	1	0.100	0.742
s2	0.115	4				0.097	4		
s3	0.260	2				0.186	2		
s4	0.140	3				0.140	3		
s5	0.044	5				0.034	5		
o1	0.110	4	1.269	0.327	0.349	0.121	4	0.017	0.414
o2	0.271	2				0.220	2		
o3	0.192	3				0.175	3		
o4	0.045	5				0.041	5		
o5	0.382	1				0.443	1		
w1	0.078	6	1.209	0.495	0.710	0.071	6	0.040	1.571
w2	0.091	5				0.142	4		
w3	0.219	1				0.295	1		
w4	0.069	7				0.038	7		
w5	0.053	8				0.035	8		
w6	0.031	10				0.017	10		
w7	0.049	9				0.019	9		
w8	0.116	4				0.077	5		
w9	0.144	3				0.149	3		
w10	0.150	2				0.157	2		
t1	0.150	3	1.065	0.287	0.405	0.140	3	0.110	0.566
t2	0.396	1				0.471	1		
t3	0.121	4				0.098	4		
t4	0.049	6				0.034	6		
t5	0.163	2				0.198	2		
t6	0.121	4				0.060	5		

results, but also it represented smaller *TD* values. Considering the results, the rest of computational process relied on B'WOT rather than A'WOT. This study shows that, B'WOT can be an appropriate procedure for strategic multi criteria analysis because it provides more consistent and reliable results. Due to the fact that decision-makers are not beset with rank-reversal problem, computational process of B'WOT becomes simpler than A'WOT while its accuracy increases.

The next step was prioritization of TOWS-based strategies with respect to the key factors. Gallego-Ayala and Juízo (2011) highlighted the factors with an above average priority as the key factors throughout a study regarding strategic implementation of IWRM. Hence, 14 strategic factors with higher than average BWM's weight priority (0.120), were chosen as the evaluation criteria (Fig. 2).

Then IOWA was employed to prioritize the strategies based on the standardized weights of the evaluation criteria and the score of each strategy according to a

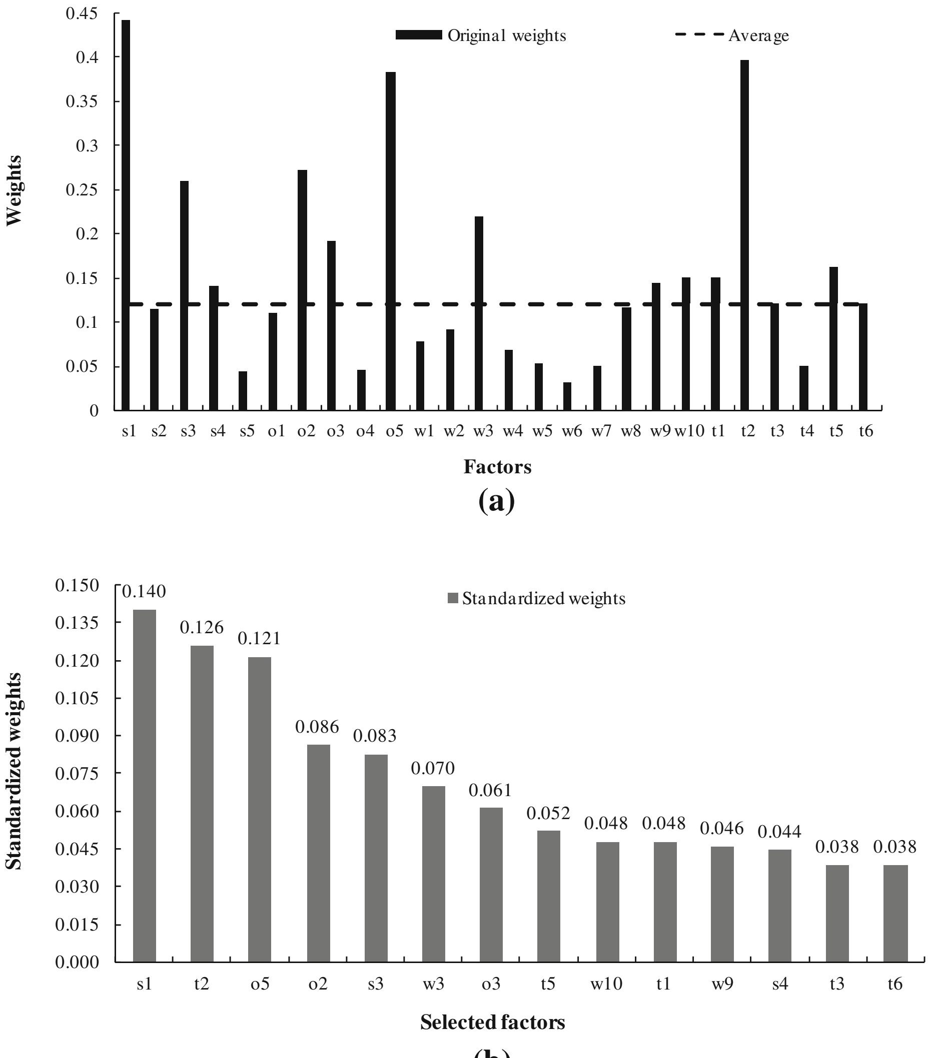

Fig. 2 The evaluation criteria and their relative weights [(**a**): selection of the criteria/factors on the basis of BWM weights, and (**b**): standardized weights of the selected criteria]

criterion within the aggregated decision matrix. Here, the computational process of A1 is presented as an example. Based on weights of BWM techniques, 14 OWA pairs are selected as follows: (u_1, a_1) = (1, 2.6), (2, 7.6), (3, 5.3), (4, 9.34), (5, 6.43), (6, 7.48), (7, 8.96), (8, 1.36), (9, 4.23), (9, 4.23), (10, 2.65), (11, 2.4), (12, 3.86), (12, 3.86). The criteria are ordered based on their priorities where 1 is the most important criterion while, 12 is the least significant one. Based on Eq. (9), the associated weight vector for $\alpha = 0.1$, was evaluated as w = (0.768, 0.055, 0.034, 0.025, 0.0199, 0.016, 0.0143, 0.0125, 0.011, 0.0101, 0.009, 0.008, 0.007, 0.007). To calculate the aggregated value, the IOWA pairs were reordered based on the u_i in the same order, as shown above. Hence, $b_i = (2.6, 7.6, 5.3, 9.34, 6.43, 7.48, 8.96, 1.36, 4.23, 4.23, 2.65, 2.4, 3.86, 3.86)$. The final values for A1 were determined as follows:

$$\begin{aligned} F_{\mathrm{IOWA}_1} = & (2.6)(0.768) + (7.6)(0.055) + (5.3)(0.034) + (9.34)(0.025) + \\ & (6.43)(0.020) + (7.48)(0.016) + (8.96)(0.014) + (1.36)(0.013) + (4.23)(0.011) + \\ & (4.23)(0.010) + (2.65)(0.009) + (2.4)(0.008) + (3.86)(0.007) + (3.86)(0.007) \\ = & \ 3.4 \end{aligned}$$

Table 6 reveals ranks of the strategies with respect to the five utilized risk-attitudes. Based on Mianabadi et al. (2014), the superiority of IOWA over OWA is attributed to the fact that, u_i values can be demonstrated by linguistic/fuzzy values; hence, the relative weights of criteria do not required to be quantified. IOWA provided a mechanism to consider different risk attitudes that would also lead to providing a sensitivity analysis. Based on the mentioned capability of OWA, five prioritization lists are available for policy-makers that would provide a wide variety of ranking lists with respect to the expected and unexpected scenarios of water shortages in the foreseeable future.

In some cases, policy-makers preferred to have only one aggregated ranking list on the basis of different risk attitudes. Due to the fact that, aggregation of various risk-attitudes may be a challenging issue for policy-makers, an aggregation technique was used by the researchers. To aggregate divergent priorities, Copeland procedure was used which is a simple yet practical technique to successfully aggregate the results. Based on Table 7, the first rank belonged to A7 which is a Maxi-Mini (ST) strategy. A7 emphasized on encouraging private sector to strengthen industry and tourism sectors rather than low efficient and environmentally destructive agriculture. All the

Table 6 Different ranking lists of the strategies

Risk attitude	optimistic ($\alpha = 0.1$)		Fairly optimistic ($\alpha = 0.5$)		Neutral ($\alpha = 1$)		Fairly pessimistic ($\alpha = 2$)		Pessimistic ($\alpha = 10$)	
Strategies	score	rank	score	rank	score	rank	score	rank	score	rank
A1	3.430	10	4.912	9	5.028	10	4.379	11	4.186	10
A2	5.762	5	10.901	7	5.538	7	4.767	9	4.762	8
A3	3.906	9	8.558	5	6.356	2	6.272	1	7.003	1
A4	4.257	8	9.371	4	6.255	3	6.071	3	6.354	3
A5	4.938	7	9.782	8	5.396	8	4.823	8	5.020	7
A6	7.057	2	9.301	3	5.885	5	5.460	5	6.096	5
A7	8.796	1	7.814	1	6.676	1	6.145	2	6.274	4
A8	7.035	3	8.927	2	6.014	4	5.043	7	3.206	11
A9	2.679	13	7.756	13	2.985	13	2.294	13	1.198	13
A10	3.409	11	9.206	11	5.029	9	4.758	10	4.360	9
A11	6.120	4	9.502	6	5.870	6	5.679	4	5.433	6
A12	3.089	12	6.341	12	4.118	12	3.426	12	1.579	12
A13	5.190	6	7.568	10	5.026	11	5.202	6	6.931	2

Table 7 The aggregated ranks of the strategies

Strategies	Victory (V)	Loss (L)	V-L	Copeland rank
A1	2	10	−8	11
A2	6	6	0	7
A3	11	1	10	2
A4	9	3	6	4
A5	4	8	−4	9
A6	10	2	8	3
A7	12	0	12	1
A8	8	4	4	5
A9	0	12	−12	13
A10	3	9	−6	10
A11	7	5	2	6
A12	1	11	−10	12
A13	5	7	−2	8

five top-ranked strategies of Table 7 are -directly or indirectly- contributed to agricultural activities within the province. The first priority recommended alternative economic activities rather than currently destructive agriculture. The second one emphasized on the modern irrigation to save available water resources. The third one highlighted using alternative sources of energy to protect the environment. The fourth priority belonged to adopting optimal cropping pattern. Finally the fifth rank was attributed to relying on treated wastewater rather than fresh water in agriculture and industry sector.

Due to the fact that transformation of socio-economic activities of a province from agriculture to industry is a challenging issue, future studies in the realm of spatial planning, development, hydro-politics, and economics should focus on operational and managerial aspects of the aforementioned issue. Moreover, updating the water resources laws and regulations must be taken more seriously by the responsible authorities. The process of water reallocation from agriculture to industry might be associated with various problems. For instance, conflicts among the stakeholders on the new reallocated water resources would be increased. Another challenge might be related to educating stakeholders to learn new skills for industrial purposes. Therefore, social learning must be taken seriously by interest groups, public agencies, NGOs, universities, and responsible authorities. Ignoring democratized decision-making processes has adversely impacted sustainable water resources management in many regions (Hernández-Mora et al. 2015). To sum up, such recommendations by Giupponi and Sgobbi (2013) as improving the effectiveness and applicability of legislative and planning frameworks, training and capacity building, networking and cooperation, harmonization of transnational data infrastructures and, learning from past experiences would be useful for successful implementation of the selected strategies.

Throughout the last step, the similarity between each ranking list (according to different α values) and Copeland ranks was investigated. In so doing, coefficient of determination (R^2) was applied to reveal the similarity of rankings to the aggregated ranking. Based on Fig. 3, the highest similarity was observed among neutral view-point and Copeland ranking where the R^2 was equal to 0.903. Thus, it would be possible to rely on neutral ranks instead of aggregated list in some cases. However, the pessimistic and optimistic attitudes bore low similarity to the Copeland results.

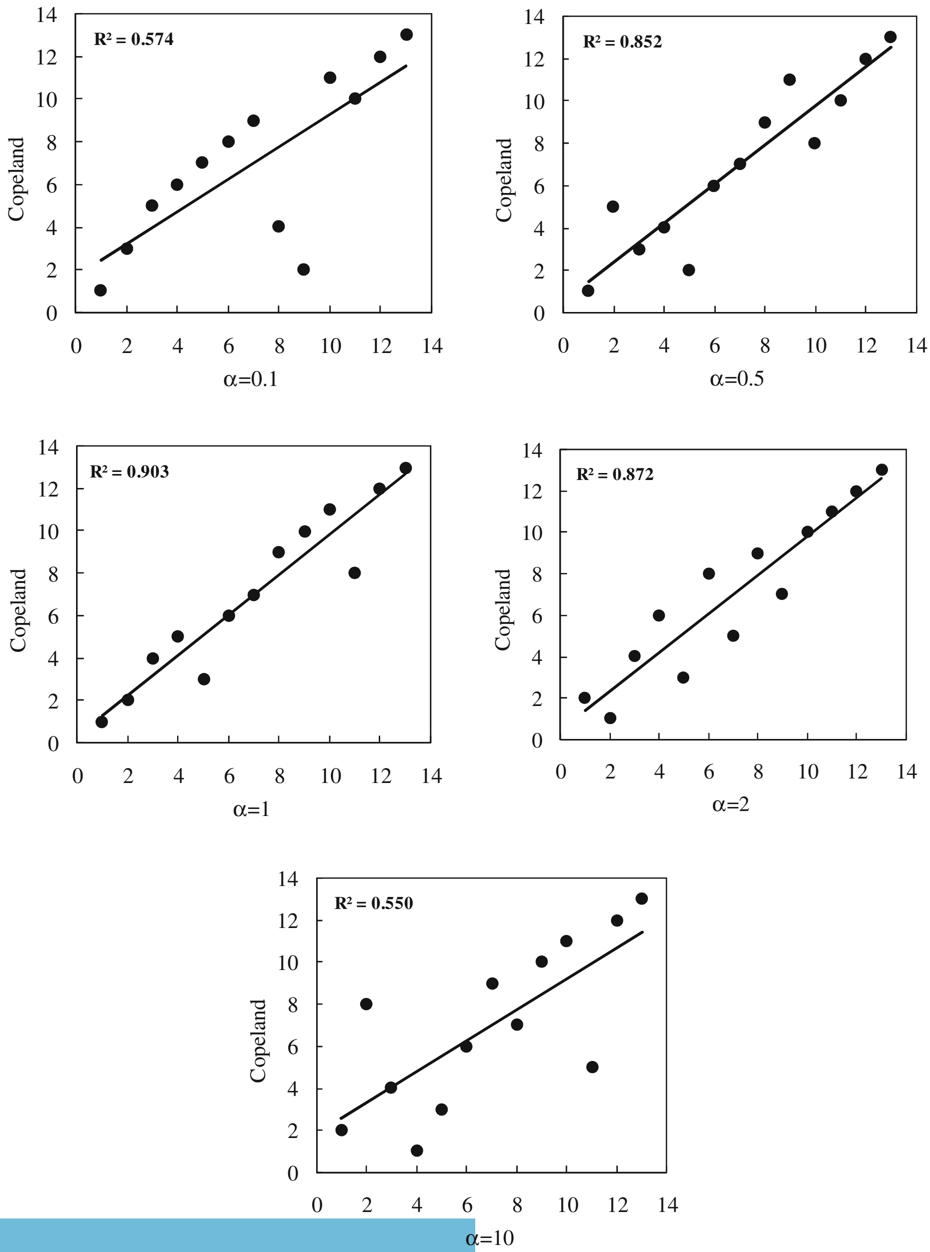

Fig. 3 Similarity of each ranking list to the Copeland ranking based on R^2

Owing to construction of a strategic framework as a formal criteria selection, and strategy formulation procedure, the current research tried to present a different methodological framework in comparison to similar researches about arid regions. For instance, Sadeghi Ravesh et al. (2011) did not apply any formal criteria selection method in de-desertification analysis of an arid region. Jozi et al. (2012) conducted an environmental risk analysis without consideration of relative importance of evaluation criteria. Yazdanpanah et al. (2014) focused on statistical analysis on social behaviors of farmers within a semi-arid and drought-prone area of Iran. Yet, they could have provided more reliable results by analyzing key strategic factors in the case study through a strategic or cause-effect context. Nasrabadi and Shamsai (2014) benefited from a participatory process to derive solutions for improve water resources management in the northeast of Iran. However, they only relied on brainstorming techniques. In other words, their assessment was adversely influenced by inexistence of multiple criteria.

4 Conclusion

Throughout the present study, a new hierarchical, risk-based, strategic MCDM framework was developed to formulate and prioritize water shortage alleviation strategies in an arid region. Each component of the proposed framework involving SWOT, TOWS, BWM, IOWA, and Copeland brought effective merits to the study. SWOT identified 15 IFs and 11 EFs. The majority of strategic factors belonged to the internal weaknesses. The destructive cropping pattern, ineffective social learning, lack of stakeholder collaboration, and decline of groundwater resources constitute the major weaknesses of the province. TWOS matched the IFs vs. EFs to formulate 13 strategies in four groups. WO and WT strategies respectively with five and four formulated strategies constituted 70 % of the strategies. Two hierarchical MCDMs namely, AHP and BWM were tested to evaluate the strategic factors' weights. In this regard, not only can BWM provide more consistent results, but it also facilitated completing the questionnaires for the decision-makers. The consistency ratio for all four strategic pairwise comparison matrices of BWM varied between the acceptable thresholds. On the other hand, for AHP, the consistency ratios of pairwise comparison matrices for strengths and threats were not smaller than acceptable limitation. Evaluation of total deviation for all the four pairwise comparison matrices resulted in higher values of TD for AHP. As a result, the recently-introduced hybrid BWM-SWOT outperformed traditional combination of AHP and SWOT. IOWA generated five different ranking lists that would be strongly recommended for the researches that require consideration of various risk attitudes. In four out of five considered risk attitudes, A7, a ST (Maxi-Mini) strategy, outperformed others. Finally, Copeland performed successfully in aggregating the divergent rankings. A7 with 12 victories in pairwise contests of Copeland stood superior to the others. The 2nd rank belonged to A3 which was a WO (Mini-Maxi) strategy. The high-ranked strategies focused on substituting the destructive agricultural activities with high-efficiency, eco-friendly industries with respect to the existing potentials. Considering the fact that the proposed framework performed appropriately in different phases of strategic decision making, it can be recommended to other strategic issues in the future studies.

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