Water Resour Manage (2010) 24:2817–2832
DOI 10.1007/s11269-010-9581-4

An Analytical Hierarchy Model for Assessing Global Water Productivity of Irrigation Networks in Iran

Aliasghar Montazar · E. Zadbagher

Received: 1 August 2009 / Accepted: 8 January 2010 /
Published online: 20 January 2010

Abstract Water management decisions in irrigation networks are often characterized by complexity, irreversibility and uncertainty. In the present study, an analytical hierarchy model is developed for assessing the Global Water Productivity (GWP) status of irrigation networks. For this purpose 14 criteria, affecting water productivity, and 14 major modern irrigation networks of Iran are analyzed. Dez and Saveh irrigation networks, with the relative weights of 0.112 and 0.045, show the highest and lowest GWP, respectively. The results obtained by the proposed model are evaluated using actual GWP of the irrigation networks from 5-year average field investigations. The results obtained by AHP model are in good agreement with the results determined from the field survey. However, in the proposed model, various mutual exclusive multivariate criteria are considered, offering high qualified final solution and enhancing the consistency of the decision-making process. As the proposed model can identify the effects of different parameters on the GWP of irrigation networks, it is applied as a comprehensive and practical decision-making tool with the aim of improving the performance of such systems.

Keywords Analytical hierarchy process · Decision-making · Iran · Irrigation network · Water productivity

1 Introduction

The water scarcity studies are mainly focused on the agricultural and food security. There, it is attempted to produce more food with less water by increasing water productivity (WP) through effective development of genotypes as well as offering

A. Montazar (✉) · E. Zadbagher
Department of Irrigation and Drainage Engineering, Campus of Aburaihan,
University of Tehran, P.O. Box 11365-4117, Pakdasht, Iran
e-mail: almontaz@ut.ac.ir

new technologies in the integrated crop management of irrigation networks (Kijne et al. 2003; Oki and Kanae 2006; Bouman 2007). The advantages of water use and the essential aspects of water management, such as producing in arid and semi-arid regions, are expressed by WP.

Large-scale irrigation networks, existed in the world, mostly show lower degrees of management performance—including recovery cost, water-use efficiencies induced by area-based water allocation and water delivery performance (Plusquellec et al. 1990; Postel 1992; Bottrall 1995). Recently, both internal and external indicators have been considered in some studies; however, in few of which (Hussain et al. 2003) the internal process measures are related to water productivity. Burt and Styles (2004) presented a rapid appraisal process for evaluating irrigation projects. The external performance indicators, provided there, were mostly those of Molden et al. (1998). They also provided a series of internal performance indicators and classified them in several groups. Some of these groups are: water delivery service, main canal characteristics, sub-main canal characteristics, budgetary, employees, water user associations, etc. Crop-scale irrigation uniformity can be examined in a project scale, considering the contribution of field, farm and project irrigation systems to non-uniformity, suggested by Clemmens and Molden (2007). They also studied the interrelation between project scale uniformity and relative irrigation water supply, and their sum effects on the project water productivity.

The global water productivity (GWP) status of irrigation networks, overall water productivity, can be improved by modernizing and optimizing such systems. In other words, the GWP of irrigation networks may be affected by many factors. An analytical framework and associated terms were proposed to cover the necessities of technical specialists in all water-using sectors, policy-makers and planners in achieving more water productivities and tracing the deficiencies in the irrigation networks (Perry 2007).

Over the past several decades, the environmental decision-making strategies have increasingly been evolved into more sophisticated, information-intensive, and complex approaches including expert judgment, cost–benefit analysis, toxicological risk assessment, comparative risk assessment as well as the methods of public and stakeholder values incorporation. This evolution led to improved array of decision-making tools such as Multi-Criteria Decision Analysis (MCDA) that offers a scientific decision analysis framework. Multi-criteria techniques are considered as promising frameworks for evaluation, in which the multi-dimensional, incommensurable and uncertain effects of decisions are explicitly taken into account (Munda 2000; Omann 2000). The MCDA is useful where different courses of action should be considered; they cannot be evaluated by measuring simple and single dimensions. In fact, the overall effects of different parameters on the performance of irrigation networks may be surveyed by a multiple criteria decision-making approaches, MCDM. Application of Data Envelopment Analysis (DEA) as a MCDM methodology was tested for Sri Ram Sagar Project, Andhra Pradesh, India to select the suitable irrigation planning alternative (Raju and Kumar 2006). It is found that DEA can be a useful methodology for ranking irrigation planning alternatives with mutually conflicting objectives, especially because this method evaluates each alternative independently, with independent set of weights.

Analytical hierarchy process (AHP), multi-attribute utility theory, outranking theory and goal programming are among the most ordinary used multi-criteria methods. AHP is widely applied in preference analysis of complex and multi-attribute problems (Varis 1989). Besides its flexibility in setting the objectives, AHP can commensurate the qualitative and quantitative decision attributes (Kangas 1993). According to Alphonce (1997), AHP can resolve certain decision problems in agriculture. Montazar and Behbahani (2007) developed an optimized irrigation method, using AHP, in which the criteria-physical, socio-economic, and environmental-affecting the irrigation efficiencies, were considered. Srdjevic and Medeiros (2008) presented a fuzzy AHP methodology for solving fully structured decision problems with criteria, sub-criteria and alternatives. The proposed methodology was used for the assessment of water management plans in part of the Paraguacu River Basin in Brazil.

According to Vermillion (1997), the management improvement effects on the irrigation performance has not been sufficiently confirmed because: (a) the irrigation projects are evaluated qualitatively; (b) the management and hardware are improved simultaneously. Therefore, the effects of management and hardware on the irrigation project improvement should be assessed separately. Furthermore, various aspects of irrigation projects (e.g., engineering, environment, local community, and financial affairs) should be considered in the evaluation in order to recommend the feasible measures and realize the improvement objectives. In this regard, AHP model was developed for evaluating the irrigation projects, using internal process indicators of the rapid appraisal process, Okada et al. (2008).

The evaluation of qualitative and quantitative factors are considered by AHP simultaneously and weighed scientifically. In this approach the tangible and intangible factors are organized systematically, and the structured and yet relatively simple solutions are provided for project evaluation. The effectiveness of AHP, the decision tool in the planning of irrigation networks, is focused in this research. More importantly, an analytical hierarchy model is developed here for assessing the GWP status of selected major modern irrigation networks in Iran.

2 Material and Methods

2.1 The Selected Irrigation Networks

Iran, with 1,648,000 km^2 area, is located between 25–40°N and 44–63°E. The altitude varies from −40 to 5,670 m, having a significant effect on the diversity of its climate. In general, Iran has a Mediterranean, semi-arid and arid climate with long and hot dry summers, and short, cool and rainy winters. The average annual precipitation is 252 mm year^{-1}. The northern and high altitude areas, in the west, receive about 1,600–2,000 mm year^{-1} (NCCO 2003), while the central and eastern parts of the country receive less than 120 mm year^{-1}. The availability of per capita freshwater was estimated about 2,000 m^3 capita^{-1} year^{-1} in the year 2000 for the country and expected to decrease below 1,500 m^3 capita^{-1} year^{-1} by 2030 due to the population growth (Yang et al. 2003). The recorded winter temperature is −20°C and lower in high-altitude regions in most parts of the country, and that of summer is over 50°C in the southern regions (NCCO 2003).

In this study, 14 modern irrigation networks, located in different areas of Iran, are selected, Fig. 1. In the irrigation networks, the cropping patterns, irrigation

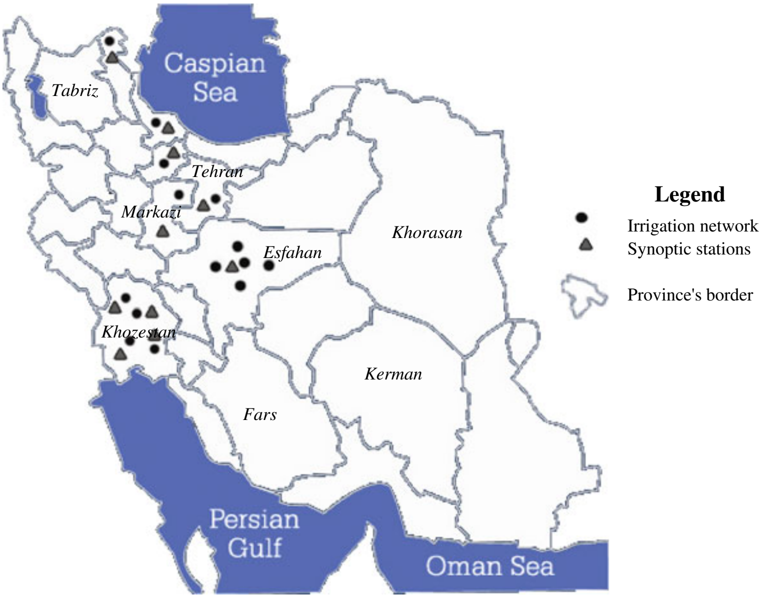

Fig. 1 Location of the selected irrigation networks in Iran

management, quantity scenarios and geographical situations are varied. There, the values of command areas are 2,300 and 284,180 ha for Saveh and Sefidroud irrigation systems, respectively. In these irrigation systems, the average annual rainfall, temperature and evaporation are 120–1,100 mm, 14–27°C and 773–1,101 mm, respectively (Table 1).

2.2 The Analytical Hierarchy Process

AHP is a mathematical method for analyzing complex decisions with multiple attributes (Saaty 1980). In this method separate performance indicators are aggregated into an integrated one (Bouma et al. 2000). By applying AHP, a hierarchical decision schema is constructed, decomposing the decision problem into its decision elements. Here, the attributes are compared in pair-wise manners for their preferences and the quantitative values are driven by using numerical techniques (Kurttila et al. 2000). In the comparisons, the more important one out of two attributes as well as its priority value is clarified. Where two criteria are of equal importance, the 1 value is given in the comparison; the 9 value shows absolute importance of one criterion out of all. In this study the preference values of pair-wise comparisons proposed by Saaty (1980) are used.

Three steps are taken in order to develop the required model using AHP as follows;

(a) defining a site-specific hierarchical structure;
(b) calculating weights;
(c) computing inconsistency ratios.

Table 1 The summary statistics of the selected irrigation networks

Irrigation network	Altitude (m)	Main crops	Cultivated area (ha)	Average annual rainfall (mm)	Average annual temperature (°C)	Average annual evaporation (mm)
Abshar	1,550	Wheat, barely, alfalfa, sugar beet	26,000	120	14	939
Borkhar	1,550	Wheat, barely, alfalfa, sugar beet	7,600	120	14	939
Mahyar	1,550	Wheat, barely, maize, sugar beet, orchards	11,300	120	15	939
Nekooabad	1,550	Wheat, barely, rice	40,000	120	14	939
Roodasht	1,550	Wheat, barely, alfalfa, sugar beet	19,600	120	14	939
Dez	143	Wheat, barely, tomato, potato, onion, green house crops	93,750	370	27	943
Gotvand	67	Wheat, alfalfa, onion, green house crops, water melon, egg-plant	38,000	324	26	1,031
Karkheh	22	Wheat, cucumber, sesame, lettuce, green house crops	12,720	207	26	1,101
Maroom	313	Wheat, maize, water melon, sesame	16,402	356	25	959
Qazvin	1,278	Wheat, barely, alfalfa, maize, corn, orchards	30,621	478	14	903
Moghan	31	Wheat, barely, alfalfa, cotton, sugar beet	6,362	299	15	804
Saveh	1,108	Wheat, barely, cotton, melon, orchards	12,000	180	17	916
Sefidroud	36	Rice	169,800	1,100	14	773
Varamin	1,021	Wheat, barely, tomato, maize	60,000	145	16	929

The use of AHP involves developing a hierarchical decision model comprising decision attributes (criteria) and options. The model building process may take a top-down approach in which the researcher builds the model with available information. The decision problem was assessing GWP of irrigation networks in the semi-arid region of Iran. The model contains 3 levels (Fig. 2): the most general objective of assessing GWP of irrigation networks is considered as ranking overall utility at level 1. Level 2 consists of the 14 criteria or the parameters involved in the GWP of irrigation networks, which are: cover of the canals (CA_{co}), status of regulation and distribution structures (ST_{rd}), the water distribution approach (WD_{ap}), the potential evapotranspiration of the command area (ET_p), the annual average rainfall in the command area (R_{ai}), the yearly water regime (WY_{co}), the crops value (CR_{va}), crops water requirement (CW_{req}), cropping pattern (CR_{pa}), water price (W_{pr}), the available water for distribution (W_{av}), the water quality (W_{qa}), the cultural issues (CU_{is}), and status of the water user organizations (WU_{or}). On the third level, the alternatives or intended options were determined, which are the 14 selected

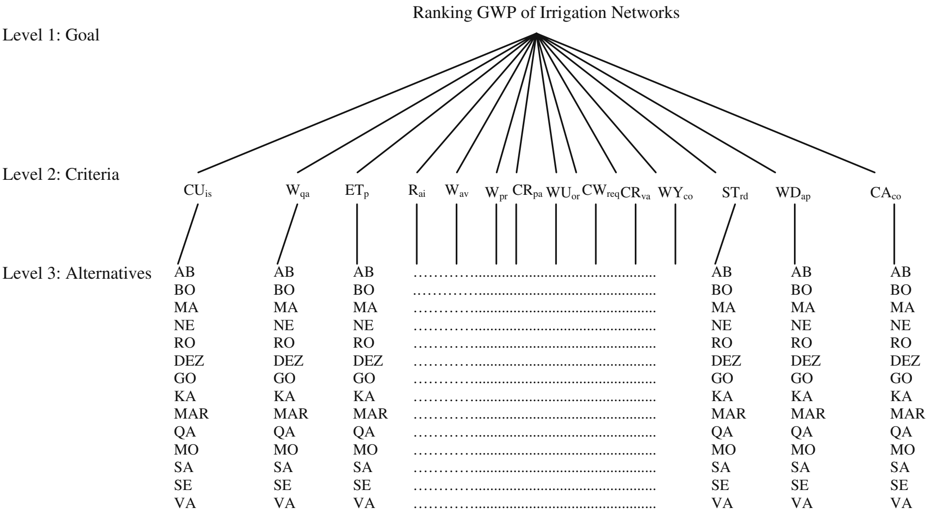

Fig. 2 Hierarchy of ranking GWP of irrigation networks

irrigation networks. Pair-wise comparison was used in weighting the criteria and alternatives.

At each level, the elements are compared in pair-wise with the corresponding elements at one level up to compute their relative weights. Then, the field investigation is conducted to determine the relative weights and matrixes of pair-wise comparisons. The prepared questionnaires were distributed in 48 local irrigation experts, out of which 40 completed ones were submitted and their results were used in the analysis. The questionnaires were designed in such a way that the respondents could select their priorities in the criteria and alternatives.

Here, the matrix of pair-wise comparisons alternatives is presented, as an example, with respect to the cultural issues, Table 2. According to the hypothetical values, used in this table, the AB irrigation network has the same importance as MA, RO, DEZ, KA, and SA ones (importance ratio 1:1). Its importance is half in comparison to QA, MO, and VA irrigation networks (importance ratio 1:1/2). Also, QA, MO, and VA irrigation networks are twice important to AB irrigation network. As mentioned earlier, pair-wise comparison was used for selecting alternatives. Besides, the same pair-wise comparison procedure was applied to set priorities in all 14 criteria regarding their contributing importance in the general objective. The matrix of pair-wise comparison is shown for 14 criteria in Table 3.

The relative weights are then aggregated to obtain the final weight of each alternative. The special weight vector method was used to compute the weight of each element at one level relative to the corresponding element at one level up. One advantage of AHP is its capacity for controlling decision consistency that is always amenable to computation and evaluation. For each matrix, the quotient of consistency index to inconsistency index of a stochastic matrix of the same vector would be taken as the criterion to judge the decision inconsistency; this value is defined as the consistency ratio. In cases where this value is less than 0.1, the system has an acceptable consistency; if otherwise, then judgments must be repeated. In

Table 2 Pair-wise comparison matrix for cultural issues

Irrigation network	AB	BO	MA	NE	RO	DEZ	GO	KA	MAR	QA	MO	SA	SE	VA
AB	1	1	1	3	1	1	2	1	4	1/2	1/2	1	4	1/2
BO		3	1/3	1	1/3	1/3	1/2	1/3	2	1/4	1/4	1/3	2	1/4
MA			1	3	1	1	2	1	4	1/2	1/2	1	4	1/2
NE				1	1/3	1/3	1/2	1/3	2	1/4	1/4	1/3	2	1/4
RO					1	1	2	1	4	1/2	1/2	1	4	1/2
DEZ						1	2	1	4	1/2	1/2	1	4	1/2
GO							1	1/2	4	1/3	1/3	1/2	4	1/3
KA								1	4	1/2	1/2	1	4	1/3
MAR									1	1/5	1/5	1/4	1	1/5
QA										1	1	2	5	1
MO											1	2	5	1
SA												1	4	1/2
SE													1	1/5
VA														1

Consistency ratio = 0.01 < 0.1 OK

AB Abshar irrigation network, *BO* Borkhar irrigation network, *MA* Mahyar irrigation network, *NE* Nekooabad irrigation network, *RO* Roodasht irrigation network, *DEZ* Dez irrigation network, *GO* Gotvand irrigation network, *KA* Karkheh irrigation network, *MAR* Maroom irrigation network, *QA* Qazvin irrigation network, *MO* Moghan irrigation network, *SA* Saveh irrigation network, *SE* Sefidroud irrigation network, *VA* Varamin irrigation network

this work, evaluation of decision consistency was performed for each of the matrices developed.

2.3 Evaluating the AHP Model

The results obtained by the analytical hierarchy model, developed in this study, are evaluated using computed actual GWPs of the irrigation networks. Here only

Table 3 Pair-wise comparison matrix for 14 criteria

Criterion	CU_{is}	W_{qa}	R_{ai}	W_{av}	W_{pr}	CR_{pa}	WU_{or}	CW_{req}	CR_{va}	WY_{co}	ST_{rd}	WD_{ap}	CA_{co}	ET_p
CU_{is}	1	5	4	1	4	3	4	4	6	2	1	1	1	4
W_{qa}		1	1/2	1/5	1/2	1/3	1/2	1/2	2	1/4	1/5	1/5	1/5	1/2
R_{ai}			1	1/4	1	1/2	3	1	3	1/3	1/4	1/4	1/4	1
W_{av}				1	4	3	4	4	6	2	1	1	1	4
W_{pr}					1	1/2	1	1	3	1/3	1/4	1/4	1/4	1
CR_{pa}						1	2	2	4	1/2	1/3	1/3	1/3	2
WU_{or}							1	1	3	1/3	1/4	1/4	1/4	1
CW_{req}								1	3	1/3	1/4	1/4	1/4	1
CR_{va}									1	1/5	1/6	1/6	1/6	3
WY_{co}										1	1/2	1/2	1/2	3
ST_{rd}											1	1	1	4
WD_{ap}												1	1	4
CA_{co}													1	4
ET_p														1

Consistency ratio = 0.01 < 0.1 OK

agricultural commodities are investigated as they are concerned for main part of global water use. For this purpose, the delivered water, cultivated area and yield production rate of the irrigation networks, in 2002–2006, are considered (IWRMC 2006). Accordingly, 5-year average water productivity of each crop within cropping pattern is calculated as the ratio of water volume, used during the entire period of crop growth, to the corresponding crop, yielded in each irrigation network. Two effective components, rainfall (green water) and irrigation water (blue water), are considered to determine the volume of water used for crops growing in the field. The climate data are obtained from the most appropriate climatic stations, located in each irrigation networks (Fig. 1). The GWP of each irrigation network is calculated with respecting to the water productivity of its cropping pattern. The data are analyzed for pair-wise comparisons, using Expert Choice Professional Version Software (Expert Choice 2000). The pair-wise comparative matrices are developed, and the relative and absolute weights of each criteria and alternatives are calculated. Finally, the consistency ratio is determined for each pair-wise comparative matrix.

3 Analysis and Results

3.1 The Actual GWPs of Irrigation Networks

The annual average water volume, used by each irrigation network from water resources during 2002–2006, is shown in Table 4. According to the obtained results, DEZ shows the highest delivered water with the range use of 2,568.14 MCM year^{-1} and BO the lowest one with the range use of 47.2 MCM year^{-1}.

The actual GWPs of irrigation networks are determined based on their cropping patterns, crop yields and annual crop water-use. The lowest GWP, 0.24 kg m^{-3}, is correspondent to MA and BO irrigation networks, and the highest one, 0.81 kg m^{-3}, to DEZ. The differences between actual GWPs of irrigation networks are due to

Table 4 Volume of water-use of the irrigation networks

Irrigation network	Virtual water (MCM year^{-1})
AB	147.02
BO	47.20
MA	50.12
NE	227.32
RO	68.00
DEZ	2,568.14
GO	901.90
KA	111.64
MAR	258.02
QA	199.56
MO	244.53
SA	61.36
SE	526.80
VA	219.16

variations in the cropping pattern and the amount of crop productions, besides the factors effective in the efficiencies of water use in the irrigation areas.

3.2 Weighting for Decision Attributes

In the following sections, the pair-wise comparison data and the actual GWP of the irrigation networks are analyzed individually and aggregately, and the results are presented.

The relative weight of each criterion, describing the importance of a criterion in decision making, as well as the consistency ratio of its correspondent pair-wise comparative matrices are shown in Table 5. According to the results, obtained in this research, CU_{is}, W_{av}, CA_{co} and ST_{rd} criteria have the same importance in GWPs of irrigation networks. The estimated relative weight of these criteria is 0.129. Following the mentioned criteria, WD_{ap} with the relative weight of 0.114, is in the next level of importance. The criteria, WY_{co}, CR_{pa}, ET_{p}, R_{ai}, and CW_{req}, are of medium importance. The W_{qa} and CR_{va} criteria with relative weights of 0.021 and 0.015, respectively, are of low importance. The criteria weights are ranged between 0.033 and 0.129.

The compatibility of decisions with AHP model is evidently confirmed by less than 0.1 value of consistency ratio of pair-wise comparative matrices to all criteria. The highest level of consistency ratio is corresponded to the W_{av} criterion and the lowest one to the W_{pr} and WY_{co} criteria. The overall consistency ratio of the comparisons, 0.04, is acceptable for surveys administered to the general public.

The weights of alternatives are synthesized and their final results are presented in Fig. 3. Based on the compared relative weights of the irrigation networks, DEZ and SA, weighing 0.112 and 0.045, respectively, show the most and least GWPs, respectively.

Table 5 Criteria weights in the ranking model

Criterion	Weight in the ranking model
Cultural issues	0.129
Water quality	0.021
Annual average rainfall in the command area	0.033
Potential evapotranspiration of the command area	0.062
Available water for distribution	0.129
Water price	0.033
Cropping pattern	0.055
Status of the water user organizations	0.033
Crops water requirement	0.033
Crops value	0.015
Yearly water regime	0.062
Status of regulation and distribution structures	0.129
Water distribution approach	0.114
Cover of the canals	0.01

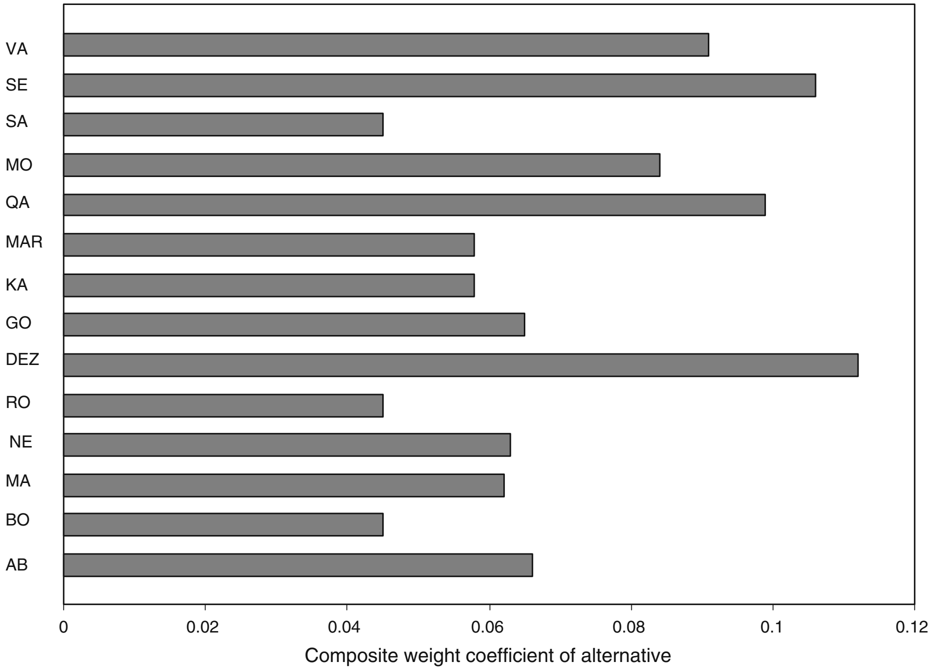

Fig. 3 Priority scores of each alternative in the AHP model

3.3 Sensitivity Analysis

Table 6 shows how the importance of each decision attribute is varied over the alternatives. The sensitivity analysis shows how the alternatives are prioritized over others with respect to each objective as well as the overall objective. According to the results, DEZ irrigation network has higher score in W_{av}, CW_{req}, and CA_{co} attributes and overall one. Also, SE irrigation network shows high score over W_{qa}, R_{ai}, ET_p, and ST_{rd} attributes. Moreover, no significant difference is observed between alternatives in the W_{pr} and WY_{co} attributes. The W_{av}, CU_{is}, CA_{co}, and ST_{rd} preferences show the highest priority over other criteria.

The sensitivity analysis is carried out on the effects of local priorities, changing the weights of decision criteria. The weight assigned to cultural issues illustrated some sensitivity towards the final option, shown in Fig. 4. If the weight, given to the cultural issues, is less than 0.11, then DEZ irrigation network is the best alternative; the ratios of other weights are assumed constant (Fig. 4). According to the figure, if the weight, assigned to the cultural issues, is more than 0.29 (dotted vertical line in the figure), then the final outcome would change from DEZ to QA irrigation network. Similarly, by changing the weights of any decision criteria, one can determine how robust the choice of irrigation network is. The criterion weight, determined in the model (0.129), is shown by dash vertical line. The meeting points of this vertical line show the options' weights which are read on the scaled *y*-axis (the left *y*-axis). The choice sensitivity level towards criterion weight is shown by moving the dash vertical line to the left or right, regarding its initial position. The crossing points between the

Table 6 Variability in criterion importance across alternatives

Criterion	Alternative (irrigation network)
Cultural issues	MO=VA>KA=SA=AB=RO>QA=GO=DEZ>SE>MAR>NE=BO=MA
Water quality	SE>MO>KA=DEZ=MAR=GO>QA=VA>SA=NE>AB=BO>RO=MA
Annual average rainfall in the command area	SE>QA>DEZ>MAR>GO>MO>KA>SA>VA>NE=AB=BO=RO=MA
Potential evapotranspiration of the command area	SE>MO>QA>SA>VA>RO=NE=SA=BO>DEZ>MAR=GO>KA=MA
Available water for distribution	DEZ>SE>GO>MO>NE>MAR>VA>AB>KA>QA> AB=BO=RO=MA
Water price	SE=QA=DEZ=MAR=GO=MO=KA=SA=VA=NE=AB=BO=RO=MA
Cropping pattern	QA=MAR=VA=DEZ>SE=GO>MO>KA=SA>AB=NE=MA>BO=RO
Status of the water user organizations	QA>MAR=MA>KA=SA>BO>GO=MO=VA=NE>AB>DEZ=RO>SE
Crops water requirement	DEZ>SE=KA>QA=GO>RO>MO>MA=BO>VA>AB=SA=NE=MAR
Crops value	MA>DEZ>AB>GO=SA>KA>MO>AB=VA>MAR>NE=QA=RO=SE
Yearly water regime	SE=QA=DEZ=MAR=GO=MO=KA=SA=VA=NE=AB=BO=RO=MA
Status of regulation and distribution structures	SE>VA>NE>MA=RO>QA=SA>DEZ>MAR>MO=KA=GO=AB=BO
Water distribution approach	MA=NE=QA=BO>DEZ=KA=MAR=AB=MO=GO>VA=RO>SE>SA
Cover of the canals	DEZ>QA=SE>MA>MO=KA>GO=MAR=NE>RO>BO=AB>SA=VA
Overall	DEZ>SE>QA>VA>MO>AB=GO=NA=MA=MAR=KA=BO>SA=RO

The notations > and = symbolise the option preceding the sign is 'preferable to' and 'equal to' the one after the sign, respectively

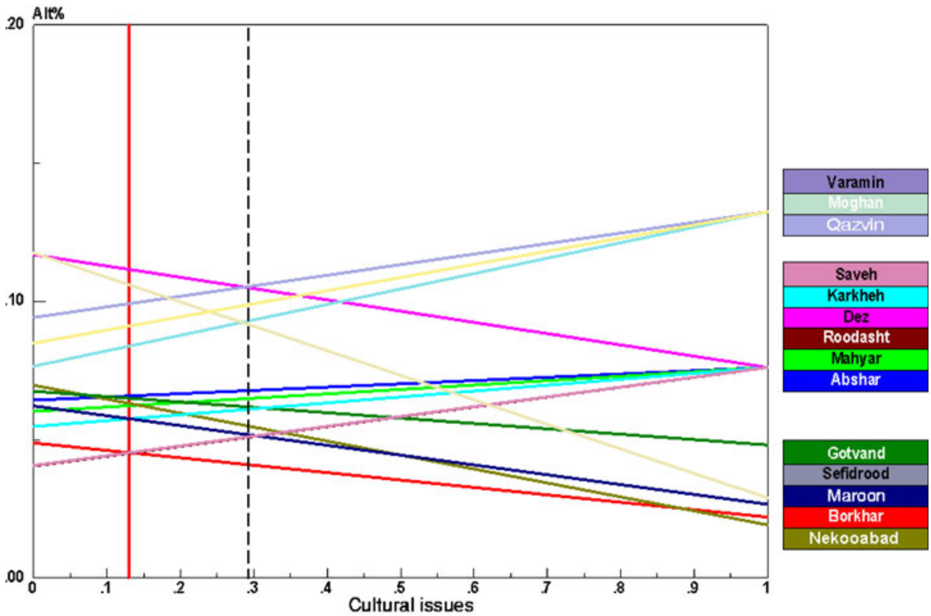

Fig. 4 Sensitivity of self-assessed weights for the cultural issues criterion

choices' lines and vertical line are called trade off points; at these points, the weight of choice variations is verified within the criteria. There are 25 trade-off points, which shows the high importance of cultural issues criterion in GWP ranking of irrigation network, observed in Fig. 4. The ranking of alternatives can be affected by marginal change in the criterion weight. Regarding the cultural issues criterion, the weights of alternatives are 0.03–0.14.

4 Discussion

4.1 Aggregate Rankings of Irrigation Networks

Global water productivity may be considered for assessing the status of water-use efficiency and the performances of irrigation networks, Fig. 5. The variation margins of the proposed irrigation networks GWPs of may be divided into two groups, considering the error bar values shown in Fig. 5. Water-use efficiencies of irrigation networks within the above margins are defined as:

(a) Efficient (GWP ≥ 0.60)
(b) Semi-efficient (GWP < 0.60)

where, GWP is in kg m^{-3}.

Hence, water management status can be evaluated in the irrigation networks, shown in Table 7. According to the obtained findings, water management is efficient in SE and DEZ irrigation networks, while it is semi-efficient in other irrigation areas. Moreover, paying further attention to the cultural issues, cover of the canals,

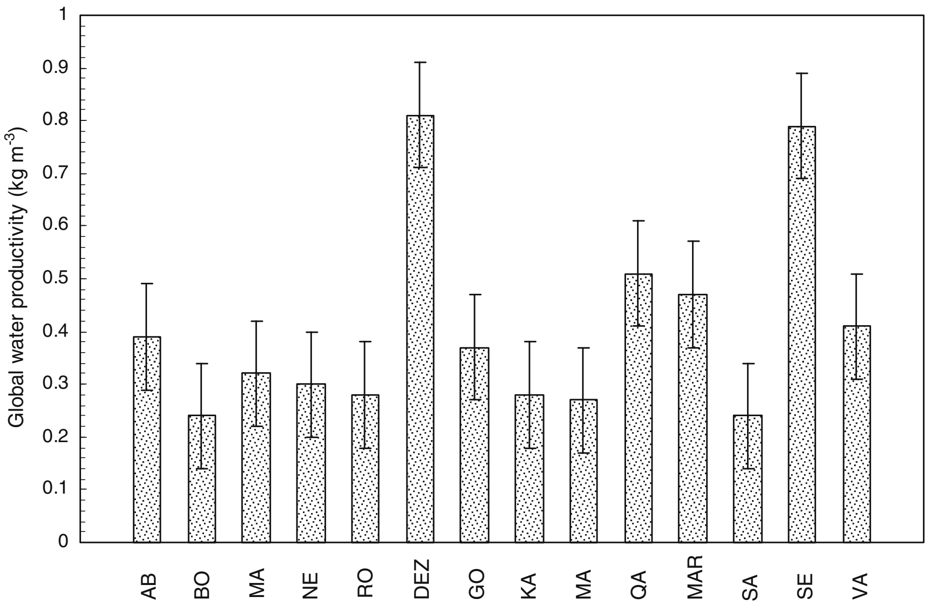

Fig. 5 Actual global water productivity of irrigation networks

regulation status, distributing structures, and available water for distribution could play significant role in the increasing of irrigation networks' GWPs. Herein, DEZ and SE irrigation systems achieve higher GWPs because of being relatively better in such factors. Therefore, in order to improve the current situation of global water productivity of irrigation networks, the approaches should focus on the management issues and criteria, which have the highest relative effects. In this way, only improving slightly the quality of these management criteria, the irrigation networks are more efficient and their water productivities are higher.

Table 7 Water management status of the selected irrigation networks

Management status	Irrigation network
SE	AB
SE	BO
SE	MA
SE	NE
SE	RO
E	DEZ
SE	GO
SE	KA
SE	MAR
SE	QA
SE	MO
SE	SA
E	SE
SE	VA

E efficient, *SE* semi-efficient

4.2 Predictive Validity of AHP Model

The results obtained by analytical hierarchy model are compared with those of actual irrigation networks' GWPs, Table 8. In this table, the actual and AHP-predicted rankings of different options are presented. The irrigation networks which have the same GWPs or relative weights are of the same ranks. According to the comparisons, the results obtained by analytical hierarchy model are in good agreement with those of actual GWPs. In most cases, evidently, the results acquired by the proposed model are in reasonable accordance with those of actual GWPs. In the ranks of AB, BO, GO, KA, MAR, QA, and SA, obtained by the model, are equivalent to the real ranking. Other irrigation networks have maximum variance of one rank (MA, NE, RO, DEZ, MO, SE and VA) in both methods.

However, different mutual exclusive multivariate criteria are considered in the proposed model which guarantees the high quality of final solution and enhances the consistency of decision-making process. Another advantage of AHP model is that the decision-maker can perform more exhaustive conceptual comparison of different decision components.

Concerning the wide series of factors involved in the ranking of irrigation systems, the proposed model, as a comprehensive and practical model, can be used in the evaluating of irrigation networks' GWPs. This model is effective in the improvement of soil and water resources exploitation and productivity. Hence, the model is an efficient decision-making tool for GWP and water management status of irrigation systems. Particularly, in the analytical hierarchy approach, the decision consistency can be measured too. This fact is of greater significance where the made decisions should be quantified and confirmed independently.

The findings show that the analytical hierarchy model can be used to aggregate preferences for obtaining a group decision, improve understanding of the choice problem, accommodate multiple objectives and increase transparency in decision making by considering effectively the relevant criteria in the decision making process. The model can also be applied to evaluate the distributive consequences of policy decisions.

Table 8 Comparing actual and AHP-predicted ranking

Irrigation network	AHP model	Actual GWP
AB	6	6
BO	11	11
MA	9	8
NE	8	9
RO	11	10
DEZ	1	2
GO	7	7
KA	10	10
MAR	10	10
QA	3	3
MO	5	4
SA	11	11
SE	2	3
VA	4	5

5 Conclusions

According to the results obtained in this study, the proposed model can precisely analyze the global water productivity of irrigation networks and determine the sensitivity of GWP towards each parameter. Moreover, in this method various management, climatic, social–cultural and structural parameters are taken into account. Based on the results, water management is efficient in Sefidroud and Dez irrigation networks, while in Moghan, Qazvin and Varamin is semi-efficient, and in the other irrigation areas it is relatively inefficient. Such findings in the irrigation networks could be effective in better planning and management of limited water resources in the studied regions. The effects of different parameters on water use efficiencies in the irrigation networks can be identified applying analytical hierarchy model, presented in this research. Therefore, the proposed model may be considered as a comprehensive and practical decision-making tool focusing on the performance improvement of irrigation systems.

Acknowledgment Support for this study was provided by the deputy of Research and Technology, University of Tehran (Project No. 7305002-01-P).

References

Alphonce CB (1997) Application of the analytical hierarchy process in agriculture in developing countries. Agric Syst 53(1):97–112

Bouma J, Brouwer R, van Ek R (2000) The use of integrated assessment methods in Dutch water management: a comparison of cost–benefit and multi-criteria analysis. In: Third international conference of the European society for ecological economics, Vienna, 3–6 May

Bouman BAM (2007) A conceptual framework for the improvement of crop water productivity at different spatial scales. Agric Syst 9(1):43–60

Bottrall AF (1995) Overview: irrigation management research—old themes, new contexts. Water Resour Dev 11(1):5–10

Burt CM, Styles SW (2004) Conceptualizing irrigation project modernization through benchmarking and the rapid appraisal process. Irrig Drain 25(2):145–154

Clemmens AJ, Molden DJ (2007) Water uses and productivity of irrigation systems. Irrig Sci 25: 247–261

Expert Choice (2000) Expert Choice software and manual. Expert Choice Inc., 4922 Elsworth Ave., Pittsburgh, PA 15213, USA

Hussain I, Sakthivadivel R, Amarasinghe U, Mudasser M, Molden D (2003) Land and water productivity of wheat in the Western Indo-Gangetic Plains of India and Pakistan: a comparative analysis. IWMI, Colombo, vol VI, 50 p. IWMI Research Report 65

Iranian Water Resources Management Company—IWRMC (2006) Annual information and data on performance assessment of modern irrigation networks (annual report 2002–2006). Ministry of Energy of Iran, Tehran

Kangas J (1993) A multi-attribute preference model for evaluating the re-forestation chain alternatives of a forest stand. For Ecol Manag 59:271–288

Kijne JW, Barker R, Molden D (2003) Water productivity in agriculture: limits and opportunities for improvement. Comprehensive assessment of water management in agriculture series 1. CAB7IWMI. Colombo, Wallingford

Kurttila M, Pesonen M, Kangas J, Kajanus M (2000) Utilizing the analytic hierarchy process (AHP) in SWOT analysis—a hybrid method and its applications to a forest certification case. Forest Pol Econ 1:41–52

Molden DJ, Sakthivadivel R, Perry CJ, de Fraiture C, Kloezen W (1998) Indicators for comparing performance of irrigated agricultural systems. Research report no 20. International Water Management Institute, Colombo

Montazar A, Behbahani SM (2007) Development of an optimized irrigation system selection model using analytical hierarchy process. Biosystems Eng 98:155–165
Munda G (2000) Conceptualising and responding to complexity. In: Spash C, Carter C (eds) Environmental valuation in Europe. Policy research brief, vol 2. Cambridge Research for the Environment, Cambridge
NCCO (2003) Initial national communication to united nations framework convention on climate change. Iranian National Climate Change Office at Department of Environment, Tehran
Okada H, Styles SW, Grismer ME (2008) Application of the analytic hierarchy process to irrigation project improvement. Agric Water Manag 95:199–204
Oki T, Kanae S (2006) Global hydrological cycles and world water resources. Science 313:1068–1072
Omann I (2000) How can multi-criteria decision analysis contribute to environmental policy making? A case study on macro-sustainability in Germany. In: Third international conference of the European society for ecological economics, Vienna, Austria, May 3–6
Perry C (2007) Efficient irrigation; inefficient communication; flawed recommendations. Irrig Drain 56:367–378
Postel S (1992) The last oasis, facing water scarcity. Earthscan, London
Plusquellec HL, McPhail K, Polti C (1990) Review of irrigation system performance with respect to initial objectives. Irrig Drain Syst 4(4):313–327
Raju KS, Kumar DN (2006) Ranking irrigation planning alternatives using data envelopment analysis. Water Resour Manag 20:553–566
Saaty TL (1980) The analytic hierarchy process. McGraw-Hill, New York
Srdjevic B, Medeiros YDP (2008) Fuzzy AHP assessment of water management plans. Water Resour Manage 22:877–894
Varis O (1989) The analysis of preferences in complex environmental judgements, a focus on the analytic hierarchy process. Environ Manage 28:283–294
Vermillion DL (1997) Impacts of irrigation management transfer: a review of the evidence. IIMI research report no 11. IIMI, Colombo
Yang H, Reichert P, Abbaspour KC, Zehnder AJB (2003) A water resources threshold and its implications for food security. Environ Sci Technol 37:3048–3054