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Environmental policy and management of freshwater resources in the Haraz-Ghareh Su Basin in comparison to other Caspian sub basins

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ABSTRACT: Haraz-Ghareh Su is one of the seven sub-basins of the Caspian basin, located on the southern shores of the Caspian Sea, and as such, is in danger of water crisis due to absence of proper systematic policy and strategy. In this study, the pressure factors on the Haraz-Ghareh Su water resources were identified using DPSIR model. Then, the pressure parameters on the freshwater resources in the Caspian Basin were scored and prioritized into two categories: human and non-human criteria and eight sub-criteria with the help of questionnaires (the opinion of 36 specialists in environmental planning and management, as well as the use of FANP). Thereafter, the data layers were processed with the help of IDRISI software, and eventually, the data were overlaid in the ArcGIS and the final plan was made. The findings of the study shows that, among 8 effective sub-criteria on the environmental planning and management of the freshwater resources in the Haraz-Ghareh Su Basin, agricultural water consumption with 0.243 score points and dam-making with 0.039 score points are considered most and least important sub-criteria, respectively. Consequently, after the compilation and scoring of sub-basins of the Caspian basin, it appears that the sub-basin of Haraz-ghare Su with 0.158627 points had the worst situation in terms of the planning and management of freshwater resources in the Caspian basin. In order to decrease the pressure on the freshwater resources in the Haraz-Ghareh Su Basin, the formulation of long-term policy and strategy in this basin seems to be essential.

Keywords: DPSIR model, fuzzy analysis network process (FANP), fuzzy logic, Haraz-Ghareh Su Basin, water resource management.

INTRODUCTION

Water is precious and very scarce in many countries due to increase in municipal, industrial and agricultural demands (Zhang et al., 2014). Over the past decades, the conflict-laden issues of water resources allocation among competing municipal, industrial and agricultural interests have been of increasing concerns (Huang and Chang, 2003; Wang et al., 2003). The

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competition among water users has been intensified due to growing population shifts, shrinking water availabilities, varying natural conditions, and deteriorating quality of water resources (Li and Huang, 2008). The increased water demands and the inadequate water supplies have exacerbated the shortage of water resources (Wang and Huang, 2011), and as such, it has been considered as a major obstacle to sustainable water resources management. The constantly increasing demand for water in terms of both sufficient quantity and satisfied quality has forced planners to contemplate comprehensive, complex and ambitious strategy for water resources management systems (Li et al., 2010). When the essential demand cannot be satisfied due to insufficient resources, losses can hardly be avoided, resulting in a variety of adverse impacts on socio-economic development (Lu et al., 2010). Therefore, a sound strategy for water resources allocation is desired to help reduce such losses. However, the water resources management systems are complicated with a variety of uncertainties and their interactions, which may intensify the conflict laden issues of water allocation (Li et al., 2006). These complexities could become further compounded not only by interactions among the uncertain parameters, but also by additional economic implications.

To address the aforementioned concerns, a number of optimization techniques have been developed by several researchers (Slowinski, 1986; Wu et al., 1997; Huang, 1998; Jairaj and Vedula, 2000; Seifi and Hipel, 2001; Luo et al., 2003; Maqsood et al., 2005; Li et al., 2007; Wang et al., 2010).

For example, Slowinski (1986) proposed an interactive fuzzy multi objective linear programming method and applied it to water supply planning, while Huang (1996) proposed an interval-parameter programming (IPP) method for dealing with uncertainties expressed as interval numbers in a water resources management system. Bender and Simonovic (2000) proposed a fuzzy compromise approach to water resources planning under imprecision uncertainty. Further, Jairaj and Vedula (2000) optimized a multi-reservoir system through the use of fuzzy mathematical programming (FMP) technique, where uncertainties existing in reservoir inflows were treated as fuzzy sets. Faye et al. (2005) proposed a fuzzy approach for short term water resource systems under uncertainty. Lee and Chang (2005) proposed an interactive fuzzy approach for planning a stream water resources management system that involved vague and imprecise information. Edirisinghe et al. (2000) proposed a mathematical programming model for the planning of reservoir capacity under random stream flows, based on the chance constrained programming method with a special target-priority policy being considered according to the given system reliabilities. Moreover, Azaiez (2002) developed a multistage optimization model for supporting the conjunctive use of ground and surface water with an artificial recharge, where a certain supply and a random demand were assumed and opportunity costs for the unsatisfied demand were explicitly integrated. Pallottino et al. (2005) presented a scenario analysis approach for water system planning and management under conditions of climatic and hydrological uncertainty. Li et al. (2006) proposed an interval-parameter multistage stochastic programming method for supporting water resources decision making, where uncertainties were expressed as discrete random variables and interval values. While Nasiri et al. (2007) proposed a fuzzy multiple-attribute decision support expert system for dealing with the uncertainties surrounding water-resources management problems.

In the present study, the pressure factors on the Haraz-Ghareh Su water resources were first identified using the DPSIR model. Thereafter, the pressure parameters on the freshwater resources in the Caspian Basin were scored and prioritized into two categories: human and non-human criteria and eight sub-criteria with the help of questionnaires, the opinions of 36 specialists in environmental planning and management and also with the use of FANP. Thus, the designs of the data layers were prepared with the help of the IDRISI software, and eventually, the data layers were overlaid in the ArcGIS and the final plan was formulated.

MATERIALS AND METHODS

In most real-world problems, uncertainties may be expressed as random variables and therefore, the related under study systems would have some dynamics (Li et al., 2009). Thus, the relevant decisions must be taken at each time-stage under varying probability levels. Such a problem can be formulated as a scenario-based multistage stochastic programming (MSP) model.

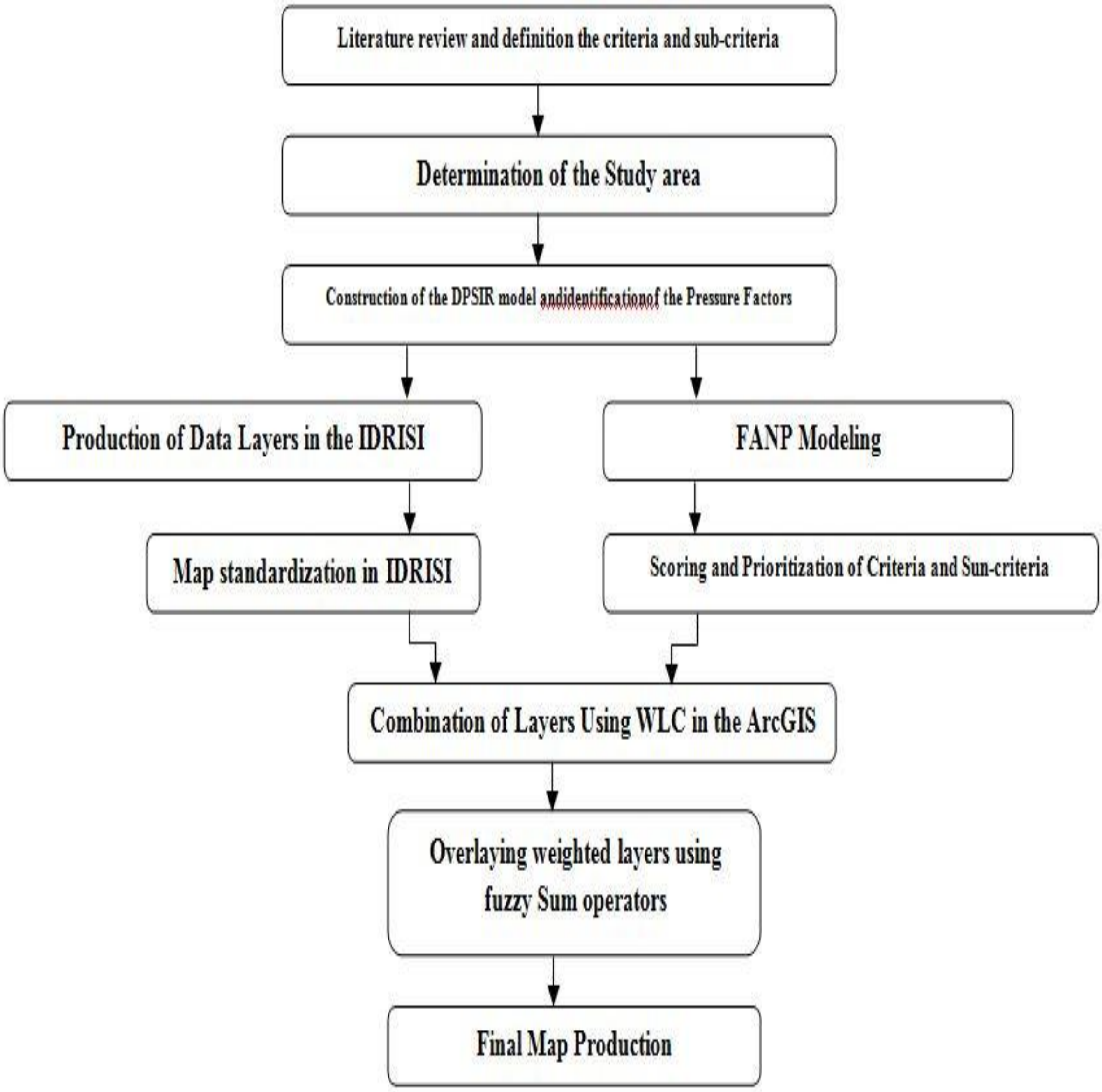


Fig. 1. Research method

THE STUDY AREA

Haraz-Ghareh Su Basin

Haraz River and other rivers between Haraz and Ghareh Su form a large basin known as the "Haraz-Ghareh Su". These rivers are located in the northern slopes of the Central Alborz and spread from Haraz (Mahmoud Abad) to Bandargaz. The geographical coordinates of this basin are from 26-51 to 44-54 of eastern length and from 35-44 to 36-55 of northern width, and its area is equivalent to 18272 km^2. This basin is located at the southern shores of the Caspian Sea and Gorgan Bay. It is the eastern neighbor of Sefidrud-Haraz basin, eastern-north neighbor to the salt lake basin and placed south to the central desert (Semnan Brine and Damghan Desert) and east to Ghareh Su and Gorgan. Based on the geographical divisions of mountains and plains, almost 73.7% of the lands of this basin is situated near mountains and the rest in plains.

However, the most important reason for the planning and management of freshwater resources in the Haraz-Ghareh Subasin is that, unlike other Caspian Su-basins, this sub-basin is in danger of water crisis, but not yet faced with it. As such, effective step need to be taken in terms of water resources management in this basin with the help of systematic, precautionary planning and policy.

Therefore, in order to decrease the pressures on freshwater resources of the Haraz-Ghareh Su basin, especially the pressures caused by human activities, the environmental management and policy of freshwater resources has immediate priority.

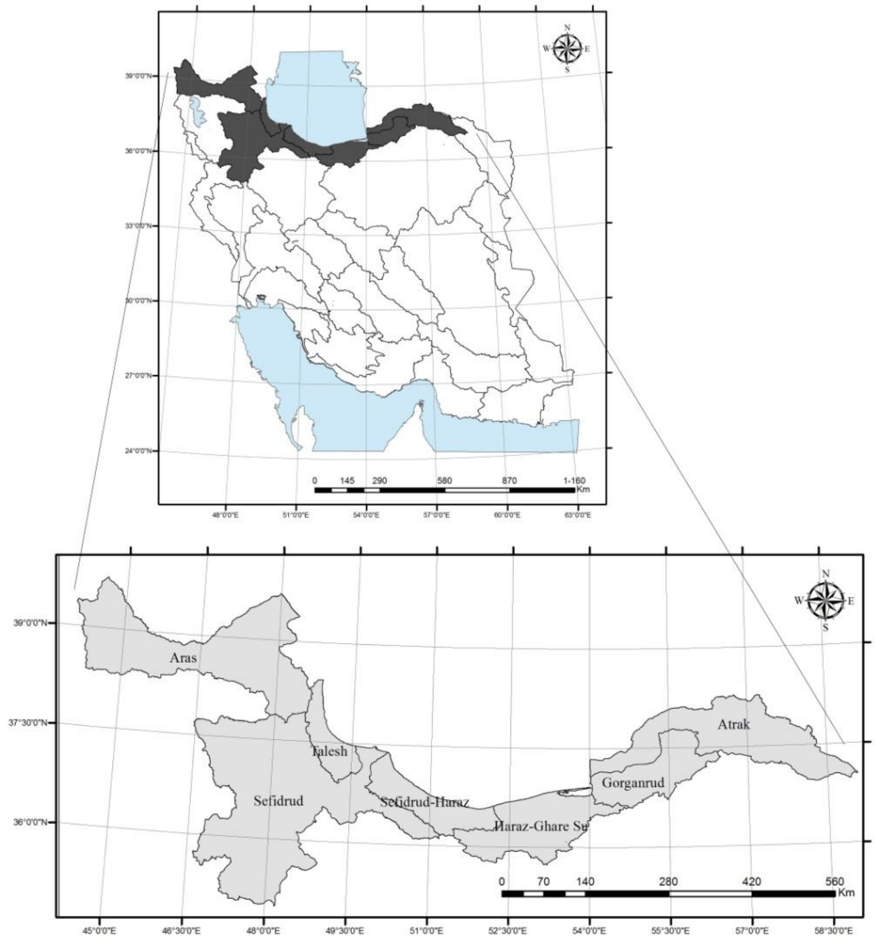


Fig. 2. Caspian basin and its sub-basins

METHODS

DPSIR Model

DPSIR stands for a system analysis view on environmental problems and the way the society deals with them. According to the DPSIR terminology, social and economic developments (Driving Forces, D) exert Pressures (P) on the environment and, consequently result to changes in the State (S) of the environment. This leads to Impacts (I) on ecosystems, human health, and society that may elicit a societal Response (R) that feeds back on Driving Forces, State or Impacts (Spangenberg et al., 2015; Smeets and Weterings, 1999; Gabrielsen and Bosch, 2003) (Fig. 3). Thus, the DPSIR scheme is described as a "causal framework for describing the interactions between society and the environment" (EEA, 2006).

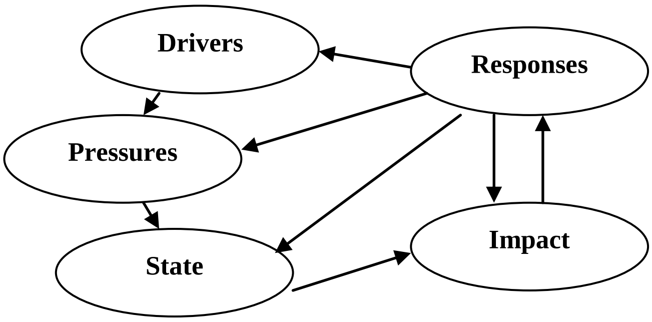


Fig. 3. The DPSIR model (Smeets and Weterings, 1999) assumes a causal chain from Driving Forces in the socio-economic system causing pressures on the environment. The pressures affect the State of the environment and cause impacts on the society and economy. These in turn trigger the responses intended to minimize the impacts by addressing either step of the causality chain.

Multi criteria evaluation method (MCE)

This method is required to evaluate several criteria by means of reaching a specific goal (Voogd, 1983; Carver, 1991; Eastman, 2012). The purpose of this multi-criteria evaluation is to select the best alternative (the best sub-basin), based on the ranking of reachable resources, acquired from the evaluation.

There are several methods used in multi criteria evaluation. The most important include a weighted linear combination method, Boolean methods, value approaches function desirability, AHP, ideal point method and agreement method (Malczewski, 1999). Multi criteria evaluation is often performed using one of these two methods: Boolean overlay or weighted linear combination. The fist process involves the overlap Boolean, whereby all criteria are reduced to the appropriate logic modes and then combined by one or more logical operators such as subscription (AND) and sum (OR). The second method is the weighted linear combination (WLC) in which continuous metrics (factors) are standardized to the normal numerical range and then combined with a weighted average. The result is a continuous raster map, which covers one or more Boolean constraints to match with the qualitative metrics and eventually leads the final decision (Eastman, 2012).

Weighted linear combination (WLC)

The weighted linear combination (WLC) method is the most common technique in the multi-criteria evaluation. This technique is also called the scoring method. This method is based on average weight. For the analyzer or decision maker, the weighting criteria are based on the relative importance of each criterion. Then by multiplying the relative weight in the attribute value, a final value is obtained for each alternative after specifying the final value of each alternative, thus the alternative that has the greatest value would be the most appropriate for the intended purpose. In this decision rule, the value of each alternative is calculated using the following formula (Shahabi and Niyazi, 2009):

$$V(X_i) = \sum_j w_j r_{ij} \quad (1)$$

Weighted Linear Combination (WLC) method can run with GIS and its overlap capabilities in the system. Overlap techniques in GIS allows the standard layer maps (input map) to be combined and integrated with each other, in order to produce a composite map (output map) (Burrough, 1990).

FANP method

The analytic hierarchy process (AHP), firstly proposed by Saaty (1980), is a popular method for solving the multi-criteria analysis problems involving qualitative data (Deng, 1999). Actually, it is a flexible, quantitative method for selecting among alternatives based on their relative performance with respect to one or more criteria (Boroushaki and Malczewski, 2008; Linkov et al., 2007).

Since criteria in the real world are dependent on each other, the traditional approaches in this area are not properly measured. However, an analytical network process is proposed to develop analytic hierarchy process in order to obtain a set of suitable weights for criteria (Saaty, 1980; Alam and Bagherzade, 2009; Ghodsi, 2010). This method is used to recognize the purpose of decision-making; environment of decision and all elements of decision making. This Recognition is required for in decision makers to determine all affected criteria and their effect on each other and be able to draw the most realistic state of the network. Pairwise comparisons demonstrate the priority of elements to each other. But often, system recognition is not enough of and as such, decision maker cannot absolutely judge the pairwise comparison, thus a network analysis model is developed to resolve the problem. In the absence of uncertainty using fuzzy comparisons is the natural solution for modeling uncertainties (Razmi et al., 2008). In other words, Leung and Chavo (2000) pointed out that the individual opinions are the reason for low accuracy when the person is asked to give a precise number to the pairwise comparisons based on his perception. While the person's perception is not expressed in terms of absolute numbers and the range of numbers being better than the absolute number, reflects the person's perception of the importance of phenomenon than the other phenomena (Leung and Cao, 2000).

Fuzzy modeling method

In this method, all factors are combined with each other in one step and therefore, the purposeful pattern of integrating maps can then be used. Fuzzy logic idea considers Space objects as members of a set. In a fuzzy set theory, the values between 0 and 1 are characterized fuzzy member, which reflects the certain value of membership and thus there are no practical constrains on choosing a fuzzy membership values (Hansen, 2005; Lee, 2007; Kabir et al., 2014; Ghosh et al., 2012). Fuzzy logic method creates more flexible compounds of weighted maps and can be easily implemented with GIS modeling language (Lee, 2007). The values are chosen based on the subjective judgment to display the membership value of the set (Fig. 4).

The five fuzzy operators of; OR, AND, SUM, PRODUCT and GAMMA used for combining data sets in GIS are as follows:

1. Fuzzy AND; this is similar to the subscription in classic sets. The effect of this operator involves an output map handled with the smallest amount of fuzzy membership, which occurs in any situation (Dombi, 1990).

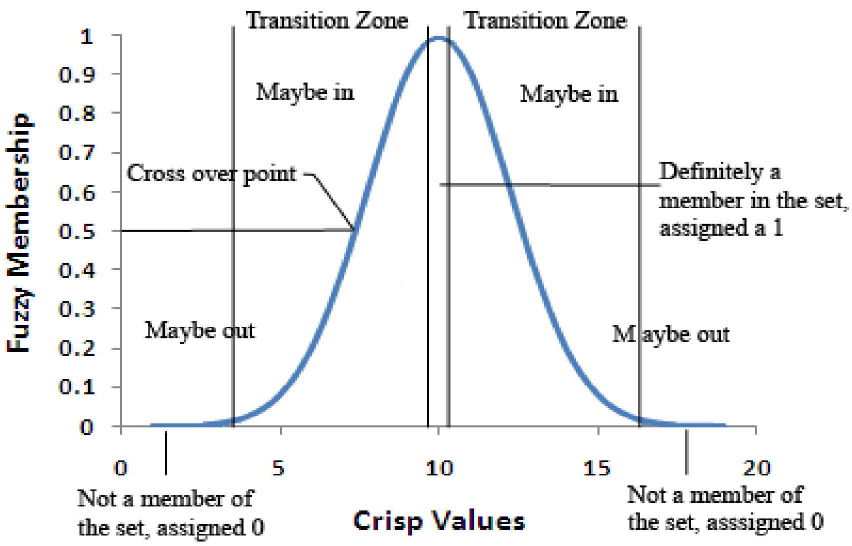


Fig. 4. Fuzzy function membership diagram (Dombi, 1990)

2. Fuzzy gamma operation: this involves the combination methodology of Fuzzy Algebraic product and Fuzzy Algebraic Sum and is obtained from the following equation:

$$\mu_{\text{combination}} = (\text{Fuzzy Sum})^{\gamma} \times (\text{Fuzzy Product})^{1-\gamma} \quad (2)$$

where γ parameter is selected in the range of (0, 1). If γ gets number 1, it shows (Fuzzy Sum) composition, but if it gets 0, it shows (Fuzzy Product) composition (Carter, 1994; Zimmerman and Zysno, 1980).

3. FUZZY OR; it is similar to the sum in the classic sets. The effect of this operator involves an output map handled with the largest amount of fuzzy membership and occurs in any situation (Dombi, 1990).

4. Fuzzy algebraic sum; is the supplemental fuzzy algebraic product, unlike fuzzy algebraic, fuzzy algebraic sum is always greater than or equal to the largest fuzzy membership (Atkinson et al., 2005).

5. Fuzzy algebraic product; it combines fuzzy membership by multiplication. This is a decreasing model in which the output value is always less than or equal to the smallest Fuzzy membership (Salari et al., 2011).

RESULTS

In the environmental management of freshwater resources in the Haraz-Ghareh Su basin, one must first identify and then score the pressure factors of the water resources. In the present study, these pressure points have been identified by utilizing the DPSIR model and the results are shown in Table 1.

Furthermore, after the preparation of the DPSIR data, Table 1, the weighting and prioritization of pressure factors on freshwater resources in the Haraz-Ghareh Su basin using FANP was carried out. In this study, pressure factors are identified by DPSIR and are used to provide data layers. Therefore, the following factors: agricultural water use, groundwater use, water pollution, dam building, population density, and changes in land cover as the human sub-criteria and changes in the wetlands and drought as the nonhuman sub-criteria, were used for policy-making, planning, and integration of management of freshwater resources. Thus, the mutual dependence of indicators and components are shown in Table 2 and Figure 5.

Table 1. Results of the DPSIR model of freshwater resources in the Haraz-Ghareh Su Basin

Response	Impact	State	Pressure	Driving Force	Components of Model
• Increased costs of recycling, • Development of sewage networks, • Consume management of Fertilizers and pesticides, • Land cover management • Increased water quality monitoring programs, • Presenting long-term policy for management of water resources, • Programs to deal with drought, • Promote sustainable agriculture, • Learning the correct use of water.	• Adverse changes in land cover, • High pressure on water resources, • Increased mortality, • Low productivity of the agricultural sector, • Water resources pollution • Increased economic pressure, • Environmental degradation • Unemployment and emigration from the region.	• High levels of rainfall than the rest of the basin, • High density of population in the basin, • Many agricultural lands, • Sufficient water resources compared to other basins, • Lack of sewage collection network • Many consumption of fertilizers and pesticides and low efficiency of agricultural.	• Population density growth • Water Pollution • High water consumption by agriculture • High consumption of groundwater, • Dam building، • Drought، • Reduction the quantity and quality of water in wetlands • Land cover changes	• Population growth, • immigration to Basin, • Mismanagement, • Increasing consumerism and industrialization, • Lack of long-term goals and plans for water resources, • There are short-term goals and engineering approach to water resources	**Result**

Additionally, the preparation of tables and weighting of parameters were done using FANP and ASP programming language (Donuts et al., 2009). In this software, in order to calculate the compatibility of the data, the method of Gogos and Boucher (1998) was used. Further, data collection method for the weighting and prioritization of parameters was based on the distributed questionnaires among 36 specialists of environment and water resources.

The pair-wise comparisons of criteria and sub-criteria are shown in Table 2 and Figure 5, and were conducted using expert's opinions.

Table 2. Internal relationships of criteria.

Criteria	Human	Nonhuman
Human		*
Nonhuman	*	

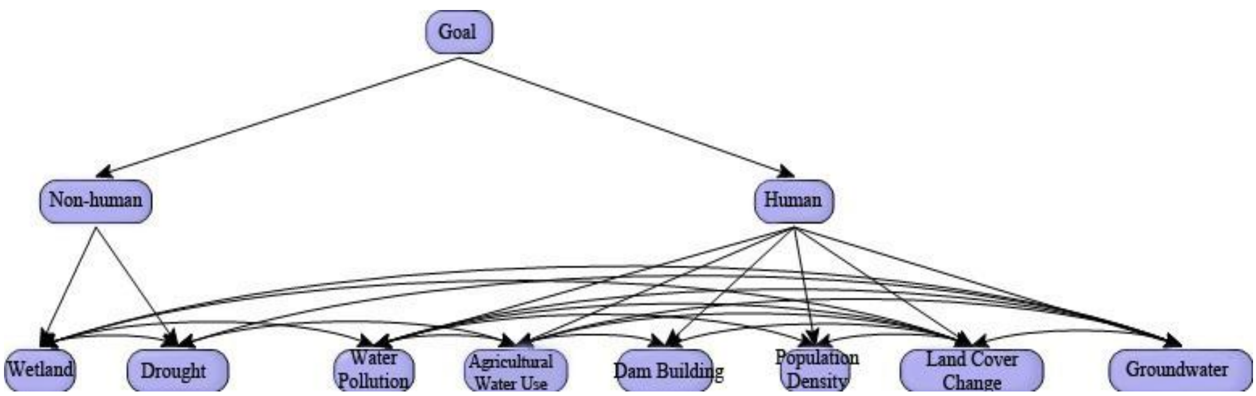


Fig. 5. Internal relationships of sub-criteria

Determination of the indicator weights and components using Fuzzy Analytic Network Process (FANP)

Based on expert's opinions and with the help of FANP technique, paired comparisons among indicators and components were done. Considering the paired comparisons, the weight of the indicators and components are shown in Figure 6.

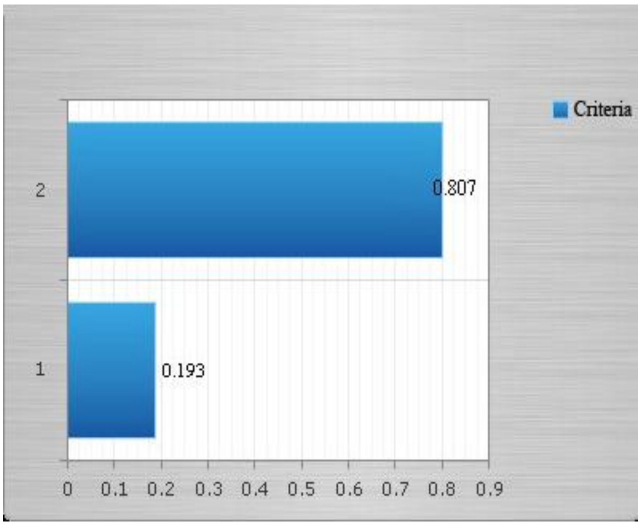


Fig. 6. Final weights of policycriteria and management of freshwater resources in the Haraz-Ghareh Su Basin

Table 3. Final weights matrix of criteria against goal

Criteria	The final fuzzy weight of Criteria	The final weight of Criteria
Nonhuman	(0.172, 0.182, 0.223)	0.193
Human	(0.668, 0.818, 0.862)	0.807

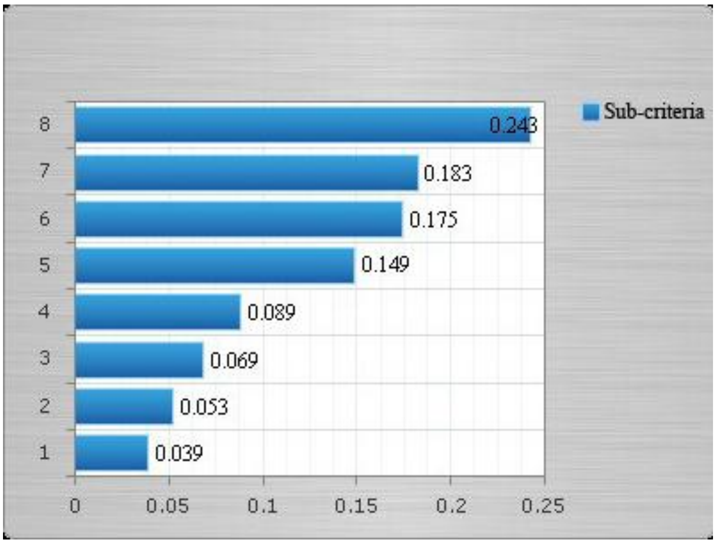


Fig. 7. Final weights of policy sub-criteria and management of freshwater resources in the Haraz-Ghareh Su Basin

Table 4. Final weights matrix of sub-criteria against goal

Sub-criteria	The final fuzzy weight of Sub-criteria	The final weight of Sub-criteria
Changes in the Wetland	(0.039, 0.05, 0.077)	0.053
Drought	(0.099, 0.149, 0.194)	0.149
Water Pollution	(0.113, 0.174, 0.234)	0.175
Agricultural Water Use	(0.147, 0.252, 0.308)	0.243
Dam Building	(0.027, 0.038, 0.05)	0.039
Population Density	(0.042, 0.068, 0.091)	0.069
Land Cover Changes	(0.059, 0.087, 0.123)	0.089
Groundwater Use	(0.111, 0.184, 0.243)	0.183

Map standardization in fuzzy logic

In fuzzy logic, according to the value which follows the Intended criterion, each basin obtains a membership value that expresses the desirability of the corresponding region. It is unlike Boolean logic where each layer is rated to a scale of either 0 or 1, (Lin et al. 1996). Another influential factor in fuzzy map standardization is the determination of the Threshold boundaries called control points. Beside, in choosing a function, one should consider the type of intended criterion that is increasing or decreasing (Valizadeh et al., 2009). Table 5 shows the control points and type of fuzzy functions.

Table 5. Forms of fuzzy functions (Eastman, 2012)

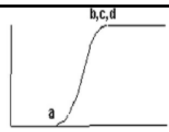
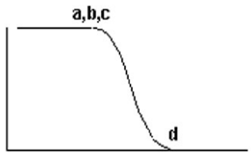
Fuzzy Function	Forms of Fuzzy Functions
Increasing Sigmoidal	
Decreasing Sigmoidal	

Table 6. Values of sub-criteria in sub-basins

Sub-basin	Groundwater Use[1]	Land Cover Changes[2]	Population Density[3]	Dam Building[4]	Agricultural Water Use[5]	Water Pollution[6]	Drought[7]	Changes in the Wetland[8]
Aras	8.8	12.86	55.2	4.14	1.24	6.7	0.1765	0.11
Talesh	0	28.91	126.1	4.22	0.44	69.3	0.0018	0.82
Sefidrud	11.3	8.18	45.9	66.9	0.79	17	0.0037	9.94
Sefirud-Haraz	8.9	21.11	101.1	5.69	0.99	51.3	-0.013	6.2
Haraz-Ghareh Su	33.5	19.44	135.1	47.83	1.15	41.3	-0.006	0.49
Gorganrud-Ghareh Su	35	18.90	66.9	51.81	1.65	0	-1.12	0.1
Atrak	9	14.09	38.6	19.09	0.91	0	-0.026	0.21

1.The Ratio of forbidden plains area to sub-basins area (percent)
2. The ratio of changes in land covers area (between 2001-2012) to sub-basins area (percent)
3. 2011 Population density of sub-basins (The number of people per square kilometer)
4. The ratio of accumulated water behind the dam to surface water (percent)
5. The Water efficiency in agricultural production (kg production/ m^3 Water)
6. The average percentage of high pollution area by N, P, BOD (percent)
7. The DIP indicator
8. The ratio of wetlands area in the 2012 to base level.

Table 7. Control points and fuzzy function for standardization of criteria maps in fuzzy logic

Criteria	Sub-criteria	Fuzzy Function	Control Points			
			a	b	c	d
Nonhuman	Changes in the Wetland	IncreasingSigmoidal	0.5	1	1	1
	Drought	IncreasingSigmoidal	2	-2	-2	-2
Human	Water Pollution	Decreasing Sigmoidal	5	5	5	50
	Agricultural Water Use	IncreasingSigmoidal	0.5	2.5	2.5	2.5
	Dam Building	Decreasing Sigmoidal	10	10	10	40
	Population Density	Decreasing Sigmoidal	20	20	20	160
	Land Cover Changes	Decreasing Sigmoidal	1	1	1	0
	Groundwater Use	Decreasing Sigmoidal	5	5	5	40

(Source: Authors)

Note that the data shown in Table 6 were obtained from "the water master-plan update and statistical yearbook of water" (Ministry of Energy, 2013), which encompasses a a case study of drought, water pollution, agricultural water use, dam building and groundwater use etc. Also, the information regarding the Iranian population was based on the Census of Population and Housing, 2011 (Statistical Center of Iran, 2012). The data on Wetlands and land cover changes were obtained using remote-sensing techniques and MODIS satellite images between 2001 and 2012.

Making Data Layer Maps

In this stage, data layer maps are made based on fuzzy logic. Each one of the effective data layers on environmental policy, planning, and management of freshwater in the Caspian basin was standardized and created by the IDRISI software. The results are illustrated in Figure 6.

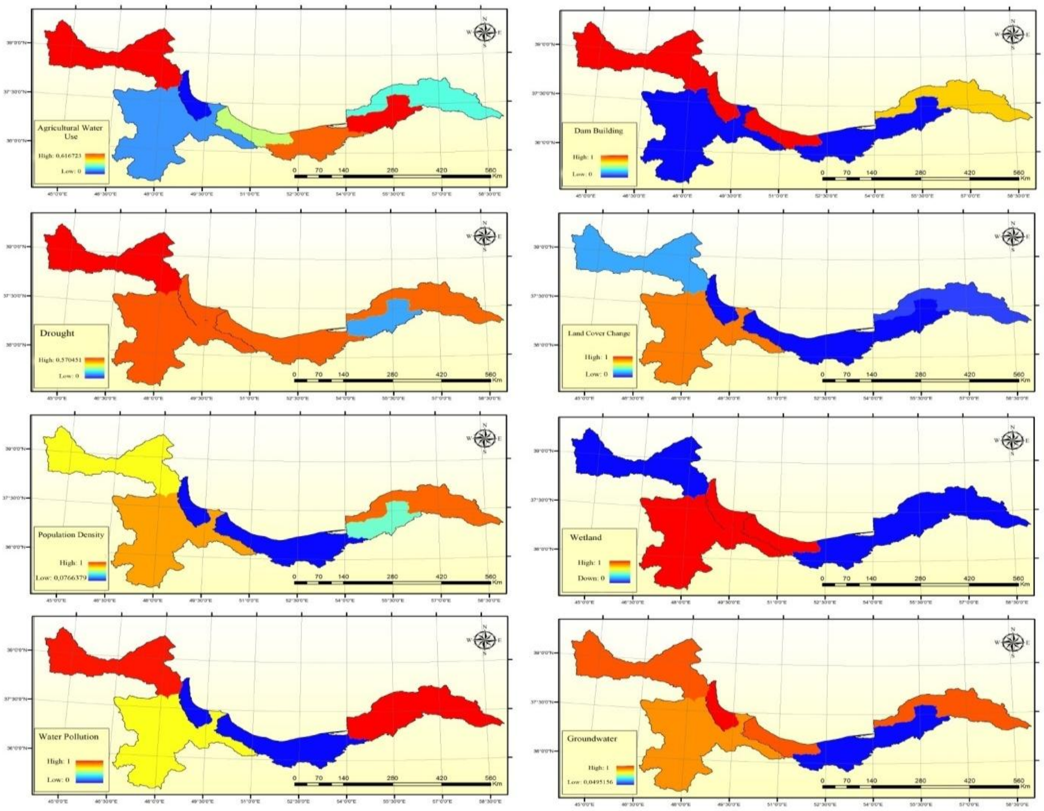


Fig. 8. Data layers maps of environmental policy and management of freshwater resources in the Caspian Sub-basin

Overlay of data layers and making the final map

The designed maps by IDRISI were overlaid in GIS with fuzzy SUM method for environmental policy and management of freshwater resources in the Caspian Basin as shown in Figure 9.

The scoring and combination of data layers in the Caspian Sub-basins show that the sub-basin of Haraz-Ghareh Su with 0.158627 score points had the lowest ranking and worst situation compared to others.

Figure 11 shows a number of environmental policies and strategies of freshwater resources in the Haraz-Ghareh Su basin.

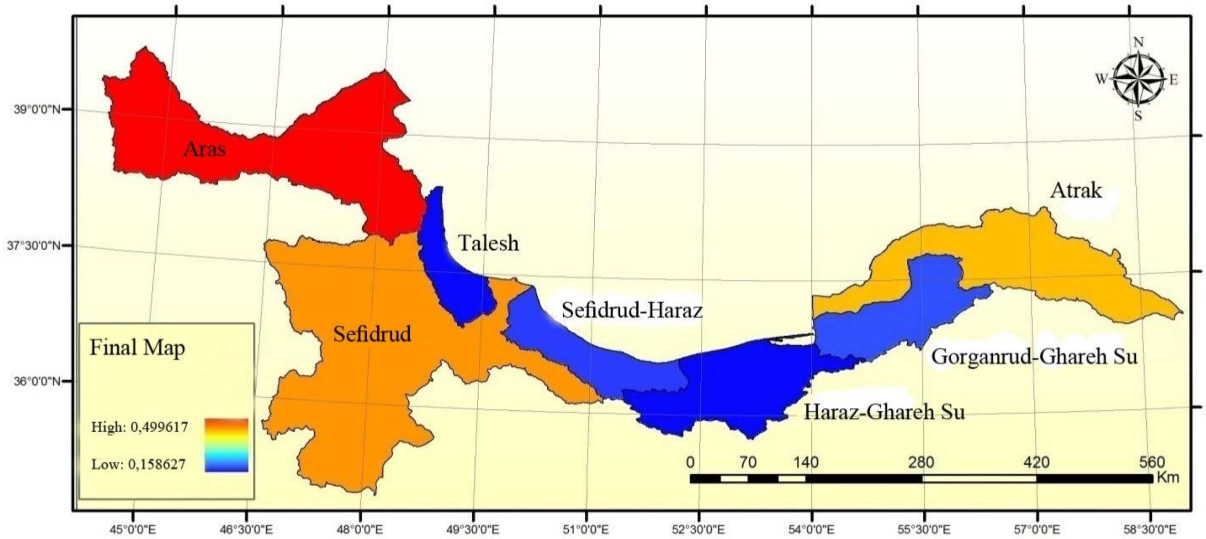


Fig. 9. Overlaying maps of environmental policy and management of freshwater resources in the Caspian Sub-basin

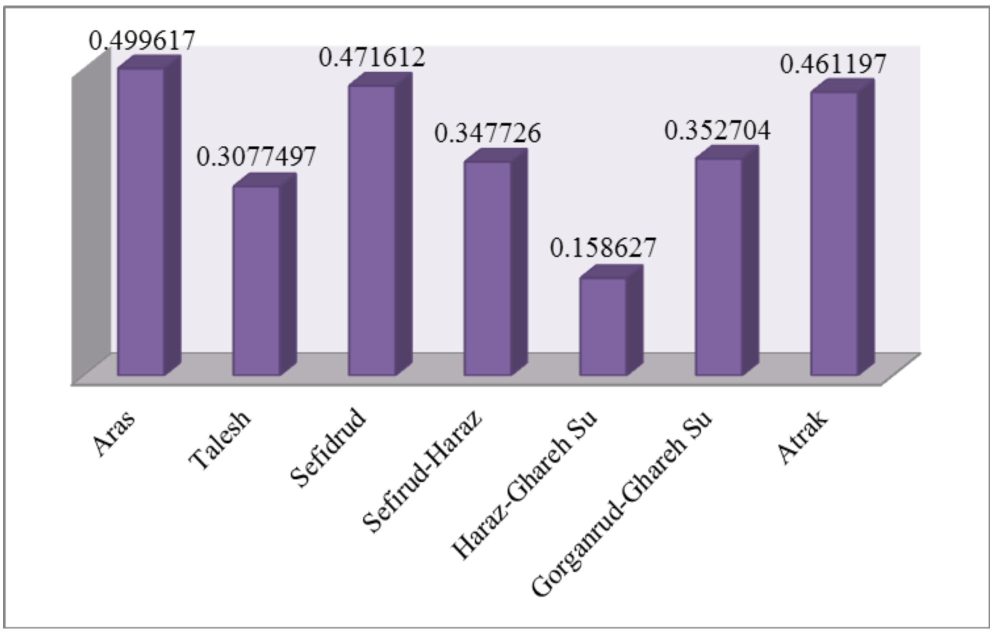


Fig. 10. Final scoring of the policy and management of water resources in the Caspian sub-basins based on fuzzy SUM logic

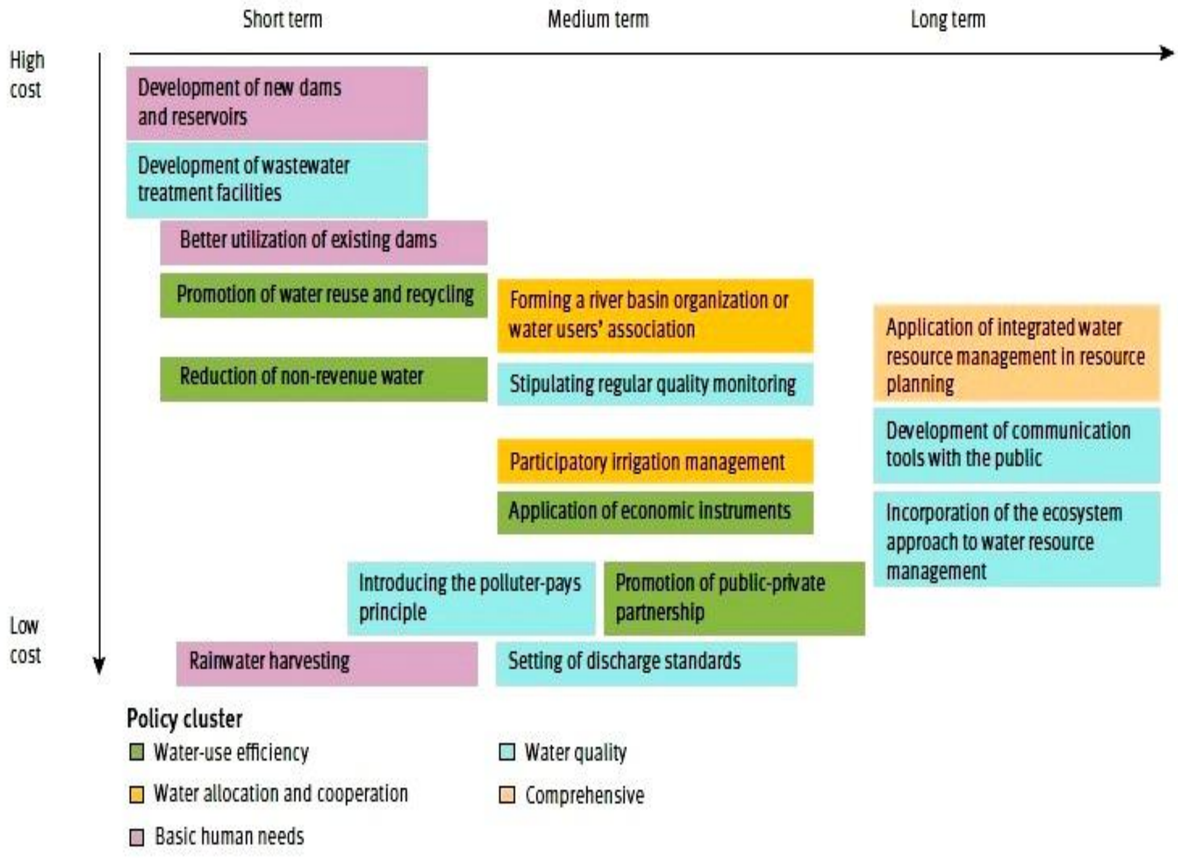


Fig. 11. Selected freshwater policies in the management of freshwater in the Haraz-Ghareh Su basin

CONCLUSION

In the study of pressure parameters in the Haraz-Ghareh Su Basin, it was found that the management of agricultural water usage, among all other parameters, is the most important. Besides, following the combination and processing of data layers relative to water resource management in the Caspian Basin, it was discovered that the sub-basin of Haraz-Ghareh Su is currently in the worst situation, while the sub-basin of Aras has the best condition among others.

Therefore, the application of result-oriented systems for policy-making and management of water resources could be useful and effective in the identification of risks and threatening of pressures on water resources, evaluation and improvement of needed activities, reduction of unnecessary costs, and integration of resource management along with development in this basin.

To help select the most appropriate alternative policy options or programs, policy analysts categorize the water sector into supply-side and demand-side components. The supply-side approach is structure-oriented, that is, investments in water projects are combined with engineering and technical expertise in order to capture, store and deliver water and to enable systems operate effectively. The supply-side focuses on providing water and related services.

However, the supply or demand-driven approaches cannot be successful alone in the Haraz-Ghareh Su basin, and as such, the combination of supply and demand-driven approach must be used for management of freshwater resources.

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