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Application of multi-criteria decision-making approach in catchment modeling and management

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ABSTRACT

Choosing the best scenario is very important to the implementation of integrated catchment assessment and management. Research suggests that Multi-Criteria Decision Making (MCDM) techniques can be applied to help in the best scenario selection process. As there are many MCDM techniques, the current research performed a comparative analysis of the use of Fuzzy TOPSIS and Fuzzy AHP approaches in selecting the best scenario decision making. The comparison was made based on the following factors: acceptance of changes in criteria; computational complication; quickness in the decision process; ability to support group decision making; number of optional scenarios and criteria; and uncertainty modeling. Both techniques were used to choose the best scenario. The results indicated that both techniques are appropriate for use in selecting the best scenario, especially for supporting group decision making and uncertainty modeling. However, the Fuzzy TOPSIS approach was found to be better suited for choosing the best scenario in regard to changes in criteria, quickness, and number of optional scenarios.

Keywords: Catchment assessment; Biological management; The best scenario; Fuzzy TOPSIS; Fuzzy AHP

1. Introduction

Watershed sources management is essentially a complex undertaking not only because of its wide scope, but also because of the broad range of characteristics that bear on its management. Operationally, the modeling and management of watershed sources must deal with characteristics that are hard to explain and components that may involve both qualitative and quantitative elements. In terms of scope, management may include geographic regions whose boundaries may not be simply recognizable and socioeconomic areas that influence different interest stakeholders, each with their own requests and socio-economic requirements [1,2].

Inherently, watershed management is a decision-making process with the purpose of choosing the best management scenario(s) from among possible alternatives. Decisions are based on the assessment of scenarios on both multiple quantitative and qualitative criteria. The assessment of qualitative or quantitative criteria by multiple decision makers lends a degree of uncertainty to the decision-making process [2–7].

In view of these difficulties, this research suggests the use of techniques based on fuzzy logic for undertaking such a complicated management process. Fuzzy techniques are deliberately developed for complex issues such as watershed assessment and management. Fuzzy set theory incorporated with multiple-criteria decision making (MCDM) techniques has been applied to deal with uncertainty in the watershed assessing and management process [6,8]; it helps in handling approximate criteria since it is able to integrate the analysis of quantitative and qualitative variables [9]. The current study compared Fuzzy AHP – the Fuzzy Analytic Hierarchy

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Process [6,10–16], and Fuzzy TOPSIS – Fuzzy Technique for Order Preference by Similarity to Ideal Solution [17–22].

In spite of numerous studies suggesting the application of Fuzzy AHP and Fuzzy TOPSIS, no comparative research on these two techniques when used for environment assessment and management has been done. Ertugrul and Karakasoglu [23] described a comparison of Fuzzy AHP and Fuzzy TOPSIS techniques used in facility location decision making. Also, Junior et al., [24] have studied on comparison between Fuzzy AHP and Fuzzy TOPSIS methods to supplier selection. Although, the authors believe there is still a need for a comparative assessment of both techniques in the context of watershed management, since the relative effectiveness of both techniques also depends on the attributes and aspects of the issue domain. Purposing to fill this gap, the current study is a comparative analysis of Fuzzy TOPSIS and Fuzzy AHP techniques used for choosing the best management scenario(s) in integrated catchment assessment and management.

2. Materials and methods

2.1. Study area

The Darenari catchment is located in the south of Iran, 30 km from Shiraz, center of Fars province and west of Maharlou salt lake. It has an area of about 554 ha and the geographic position lies between 52° 45′–52° 48′ E longitudes and 29° 21′–29° 22′ N latitudes. Elevation ranges from 1532 to 2620 m MSL.

Regarding the high flooding susceptibility of the catchment, flood mitigation actions are required to be implemented. Besides, due to the susceptible geological formations, water erosion, drought and land use changing from rangelands to agriculture, on-site soil degradation and off-site sedimentation in downstream have increased [25]. In order to prevention of catchment resources reduction such as water, soil and vegetation, in this research a scenario-based approach has been applied for consequences prediction of various management activities within an integrated catchment management framework.

2.2. Developing biologically-based management scenarios

First, the sources of surface runoff and sediment issues over the Darenari catchment were identified. Next, a list of all possible ways to reduce these problems was provided. Maintaining these conditions can sometimes allow a catchment to improve itself through natural evolution, particularly once there is no large-scale catchment disturbance [26]. Further, it can be used as a base case scenario to assess other scenarios.

After simultaneous management actions in the study area were ascertained, all feasible management actions were determined considering the restriction existing in the catchment. The three biological activities of sowing, seeding, and grazing management were identified for the Darenari catchment. These three activities were combined, which led to 8 (2^n) various management scenarios (Table 1).

Management scenarios must be exclusive. In fact, the acceptation of one scenario means the refusal of all others.

Table 1
Biological-based management scenarios for the Darenari catchment

Scenario	1	2	3	4	5	6	7	8
Activity								
Seeding	–	+	–	–	+	+	–	+
Sowing	–	–	+	–	+	–	+	+
Grazing management	–	–	–	+	–	+	+	+

2.3. Theory of fuzzy AHP technique (Chang's extended analysis)

The concept of fuzzy set theory, initially introduced by Zadeh [27], is the original basis of fuzzy AHP methodology. The fuzzy AHP technique can be considered an advanced analytical technique developed from the conventional AHP [6,13,14,28–31].

Chang's extent analysis [10,32] on fuzzy AHP depends on the degree of possibilities of each criterion. The pairwise comparison matrix is established based on triangular fuzzy numbers for the linguistic variables which are determined according to the answers on the question form. Chang's analysis phase's description may be found in Kahraman [33], Vahidnia et al. [29], Kayastha et al. [14], Mehendran et al. [15], Chatterjee et al. [31], Keshtkar et al., [34] and Eskandari and Miesel [35].

2.4. Fuzzy TOPSIS technique

The Fuzzy TOPSIS approach was extended from TOPSIS by Chen [17] to solve multiple criteria decision-making issues under uncertainty [19,21,36,37]. Linguistic numbers are applied by the decision makers, D_r ($r = 1, \ldots, k$), to evaluate the weights of the criteria and the ratings of the options. Therefore, $\tilde{w}_r^j$ explains the weight of the jth criterion, C_j ($j = 1, \ldots, m$), given by the rth decision maker. Also, $\tilde{x}_{ij}^r$ explains the rating of the ith option, A_i ($i = 1, \ldots, n$), in regard to criterion j, given by the *rth* decision maker. The framework and phases of Fuzzy TOPSIS method can be found in other studies [21].

3. Results and discussion

3.1. Application case in the catchment assessment and management

As mentioned in section of 2.2, a catchment assessment and management project requires determining management activities and choosing best scenario. In order to choose the best option, three biological activities and eight possible scenarios were assessed against four decision criteria. The possible scenario in each criterion was evaluated based on linguistic judgments given by the experts and decision makers, who had knowledge about study area. The four criteria were determined by the decision makers and experts (Table 2).

3.2. Fuzzy TOPSIS application

Assessments of the weight of the criteria and the priority of the options were carried out by the decision makers

Table 2
Applied criteria for catchment assessment and management

Criteria	Description
Ecological	The sum total measure of natural areas against improved landscapes (using the weighted land cover area index)
Physical	The effects of management activities on hydrological characteristics
Social	The acceptance level of management activities among the local community and stakeholders
Economic	The consequences of management activities affecting economic conditions (using gross margin and variable cost indices)

Table 3
Linguistic scale to assess criteria weight

Linguistic terms	Fuzzy triangular values
Very little importance (VLI)	(0.0, 0.0, 0.1)
Of little importance (LI)	(0.0, 0.10, 0.30)
Somewhat little importance (SLI)	(0.10, 0.30, 0.50)
Moderately important (MI)	(0.30, 0.50, 0.70)
Somewhat important (SI)	(0.50, 0.70, 0.90)
Important (I)	(0.70, 0.90, 1.0)
Very important (VI)	(0.9, 1.0, 1.0)

and experts based on the linguistic terms. The triangular fuzzy numbers (TFN) presented by Chen and Hwang [38] were applied to determine the linguistic values of these elements, as shown in Tables 3 and 4.

Tables 5 and 6 show the results of the linguistic judgments of the criteria weights and options priorities of the decision makers and experts involved in the evaluation process. The linguistic terms indicated in Tables 5 and 6 were changed into TFN.

Based on Chen [17], the Fuzzy Positive Ideal Solution (FPIS, A^+) and the Fuzzy Negative Ideal Solution (FNIS, A^-) were determined as

$$A^+ = [(1,1,1), (0,0,0), (1,1,1) , (1,1,1) , (1,1,1)] \quad (1)$$

$$A^- = [(0,0,0) (0,0,0), (0,0,0) (0,0,0) (0,0,0)] \quad (2)$$

The distances d_i^+ and d_i^- of the priority determination of each option from A^+ and A^-, are indicated in Tables 7 and 8, respectively.

The effectiveness and consequences of each scenario option are given by the closeness coefficient, CC_i, shown in Table 9. Finally, this estimation implies the prioritization indicated in Table 9, meaning that scenario A_8 is the best option, followed by A_7, A_5, A_6, A_3, A_2, A_4 and A_1, respectively.

3.3. Fuzzy AHP application

The linguistic terms and values were applied by decision makers and experts to comparatively assess the weight

Table 4
Linguistic scale to assess the priorities of the option scenarios

Linguistic terms	Fuzzy triangular values
Very low (VL)	(0.0, 0.0, 1.0)
Low (L)	(0.0, 1.0, 3.0)
Somewhat low (SL)	(1.0, 3.0, 5.0)
Good (G)	(3.0, 5.0, 7.0)
Somewhat high (SH)	(5.0, 7.0, 9.0)
High (H)	(7.0, 9.0, 10.0)
Very high (VH)	(9.0, 10.0, 10.0)

Table 5
Linguistic judgments of the weights of the criteria in the Darenari catchment management

Criteria	C_1 (Benefit)	C_2 (Cost)	C_3 (Ecologic)	C_4 (Social)	C_5 (Physical)
Weights	I	SI	I	VI	VI

Table 6
Linguistic ratings of the option scenarios in the Darenari catchment management

Criteria / Scenarios	C_1	C_2	C_3	C_4	C_5
A_1	VL	VH	VL	VL	VL
A_2	L	H	L	G	G
A_3	G	SH	SL	G	SL
A_4	SL	SH	SL	SL	SL
A_5	SH	G	G	H	SH
A_6	SH	G	G	G	SH
A_7	H	SL	H	SH	H
A_8	VH	VL	VH	VH	VH

Table 7
Distances of the priorities of each option from A^+ with respect to each criterion

Criteria / Scenarios	C_1	C_2	C_3	C_4	C_5	d_i+
$d(A_1, A^+)$	1.46	0.00	1.46	1.46	1.46	5.86
$d(A_2, A^+)$	0.31	0.00	0.31	0.87	0.87	2.37
$d(A_3, A^+)$	0.77	0.00	1.03	0.72	1.01	3.54
$d(A_4, A^+)$	1.03	0.00	1.03	1.01	1.01	4.09
$d(A_5, A^+)$	0.54	0.00	0.77	0.24	0.45	2.00
$d(A_6, A^+)$	0.54	0.00	0.77	0.72	0.45	2.48
$d(A_7, A^+)$	0.35	0.00	0.35	0.45	0.24	1.38
$d(A_8, A^+)$	0.24	0.00	0.24	0.11	0.11	0.69

of the criteria and the priority determining of the options. Based on Chang [10], TFN was applied to determine the linguistic values of these elements.

The comparative judgments of the criteria weights stated by decision makers involved were changed into TFN. The results of summation of these fuzzy numbers are illustrated in Table 10 and were calculated through the judgments arithmetic mean.

Furthermore, the fuzzy numbers of the summated comparative judgments of the alternative scenarios for each criterion stated by the decision makers and experts are indicated in Tables 11–15.

Table 8
Distances of the priorities of each option from A^- with respect to each criterion

Criteria / Scenarios	C_1	C_2	C_3	C_4	C_5	d_i-
$d(A_1, A^-)$	0.10	0.00	0.10	0.10	0.10	0.40
$d(A_2, A^-)$	0.31	0.00	0.31	0.31	0.31	1.25
$d(A_3, A^-)$	0.84	0.00	0.57	0.87	0.59	2.87
$d(A_4, A^-)$	0.57	0.00	0.57	0.59	0.59	2.31
$d(A_5, A^-)$	1.12	0.00	0.84	1.39	1.17	4.52
$d(A_6, A^-)$	1.12	0.00	0.84	0.87	1.17	4.00
$d(A_7, A$-)	1.32	0.00	1.32	1.17	1.39	5.20
$d(A_8, A^-)$	1.39	0.00	1.39	1.49	1.49	5.77

Table 9
Priority of option scenarios based on Fuzzy TOPSIS

Scenarios	CC_i	Priority
A_1	0.06	8th
A_2	0.33	6th
A_3	0.39	5th
A_4	0.31	7th
A_5	0.63	3rd
A_6	0.55	4th
A_7	0.72	2nd
A_8	0.84	1st

The consistency ratios (CR) for each comparative matrix were estimated based on Saaty [39] and Facchinetti et al. [40], and the results showed that all values of CR were below 0.2, which demonstrates the consistency of the comparative judgments.

The numbers of the fuzzy synthetic extent for the matrix of criteria were:

S_{C1} = (3.82, 5.0, 7.50) × (1/37, 1/25.48, 1/18.46)
= (0.10, 0.20, 0.40)
S_{C2} = (3.32, 4.32, 7.0) × (1/37, 1/25.48, 1/18.46)
= (0.09, 0.17, 0.38)
S_{C3} = (3.66, 5.5, 8.0) × (1/37, 1/25.48, 1/18.46)
= (0.10, 0.22, 0.43)
S_{C4} = (4.50, 6.0, 7.50) × (1/37, 1/25.48, 1/18.46)
= (0.12, 0.24, 0.41)
S_{C5} = (3.16, 4.66, 7.0) × (1/37, 1/25.48, 1/18.46)
= (0.09, 0.18, 0.38)

The levels of possibility of these fuzzy numbers were:

$V(S_{C1} \geq S_{C2}) = 0.91$, $V(S_{C1} \geq S_{C3}) = 1.0$, $V(S_{C1} \geq S_{C4})$
$= 1.0$, $V(S_{C1} \geq S_{C5}) = 0.89$
$V(S_{C2} \geq S_{C1}) = 1.0$, $V(S_{C2} \geq S_{C3}) = 1.0$, $V(S_{C2} \geq S_{C4})$
$= 1.0$, $V(S_{C2} \geq S_{C5}) = 1.0$
$V(S_{C3} \geq S_{C1}) = 0.94$, $V(S_{C3} \geq S_{C2}) = 0.86$, $V(S_{C3} \geq S_{C4})$
$= 1.0$, $V(S_{C3} \geq S_{C5}) = 0.89$
$V(S_{C4} \geq S_{C1}) = 0.88$, $V(S_{C4} \geq S_{C2}) = 0.80$, $V(S_{C4} \geq S_{C3})$
$= 0.94$, $V(S_{C4} \geq S_{C5}) = 0.83$
$V(S_{C5} \geq S_{C1}) = 1.0$, $V(S_{C5} \geq S_{C2}) = 0.96$, $V(S_{C5} \geq S_{C3})$
$= 1.0$, $V(S_{C5} \geq S_{C4}) = 1.0$

Thus, the weight vector W' was:

$d'(C_1) = V(S_{C1} \geq S_{C2}, S_{C3}, S_{C4}, S_{C5}) = \min(0.91, 1.0, 1.0, 0.89)$
$= 0.89$
$d'(C_2) = V(S_{C2} \geq S_{C1}, S_{C3}, S_{C4}, S_{C5}) = \min(1.0, 1.0, 1.0, 1.0)$
$= 1.0$
$d'(C_3) = V(S_{C3} \geq S_{C1}, S_{C2}, S_{C4}, S_{C5}) = \min(0.94, 0.86, 1.0, 0.89)$
$= 0.86$
$d'(C_4) = V(S_{C4} \geq S_{C1}, S_{C2}, S_{C3}, S_{C5}) = \min(0.88, 0.80, 0.94, 0.83)$
$= 0.80$
$d'(C_5) = V(S_{C5} \geq S_{C1}, S_{C2}, S_{C3}, S_{C4}) = \min(1.0, 0.96, 1.0, 1.0)$
$= 0.96$
$W' = (0.89, 1.0, 0.86, 0.80, 0.96)$

Table 10
Fuzzy numbers of the aggregated weights of the criteria in the Darenari catchment

Criteria / Scenarios	C_1	C_2	C_3	C_4	C_5
C_1	(1.0, 1.0, 1.0)	(0.5, 1.0 , 1.5)	(0.66, 1.0 , 2.0)	(1.0, 1.0, 1.0)	(0.66, 1.0 , 2.0)
C_2	(0.66, 1.0 , 2.0)	(1.0, 1.0, 1.0)	(0.5, 0.66, 1.0)	(0.5, 0.66, 1.0)	(0.66, 1.0 , 2.0)
C_3	(0.5, 1.0 , 1.5)	(1.0 , 1.50 , 2.0)	(1.0, 1.0, 1.0)	(0.66, 1.0 , 2.0)	(0.5, 1.0 , 1.5)
C_4	(1.0, 1.0, 1.0)	(1.0 , 1.50 , 2.0)	(0.5, 1.0 , 1.5)	(1.0, 1.0, 1.0)	(1.0 , 1.50 , 2.0)
C_5	(0.5, 1.0 , 1.5)	(0.5, 1.0 , 1.5)	(0.66, 1.0 , 2.0)	(0.5, 0.66, 1.0)	(1.0, 1.0, 1.0)

Table 11
Fuzzy values of the scenario option ratings related to criterion C_1

Scenarios	A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8
A_1	(1.0, 1.0, 1.0)	(0.66, 1.0, 2.0)	(0.40, 0.50, 0.66)	(0.50, 0.66, 1.0)	(0.40, 0.50, 0.66)	(0.50, 0.66, 1.0)	(0.33, 0.40, 0.50)	(0.29, 0.33, 0.40)
A_2	(0.50, 1.0, 1.50)	(1.0, 1.0, 1.0)	(0.40, 0.50, 0.66)	(0.66, 1.0, 2.0)	(0.40, 0.50, 0.66)	(0.50, 0.66, 1.0)	(0.33, 0.40, 0.50)	(0.29, 0.33, 0.40)
A_3	(1.50, 2.0, 2.50)	(1.50, 2.0, 2.50)	(1.0, 1.0, 1.0)	(1.0, 1.50, 2.0)	(0.66, 1.0, 2.0)	(1.0, 1.50, 2.0)	(0.50, 0.66, 1.0)	(0.40, 0.50, 0.66)
A_4	(1.0, 1.50, 2.0)	(0.50, 1.0, 1.50)	(0.50, 0.66, 1.0)	(1.0, 1.0, 1.0)	(0.50, 0.66, 1.0)	(0.66, 1.0, 2.0)	(0.40, 0.50, 0.66)	(0.33, 0.40, 0.50)
A_5	(1.50, 2.0, 2.50)	(1.50, 2.0, 2.50)	(0.50, 1.0, 1.50)	(1.0, 1.50, 2.0)	(1.0, 1.0, 1.0)	(1.50, 2.0, 2.50)	(1.0, 1.50, 2.0)	(0.50, 0.66, 1.0)
A_6	(1.0, 1.50, 2.0)	(1.0, 1.50, 2.0)	(0.50, 0.66, 1.0)	(0.50, 1.0, 1.50)	(0.40, 0.50, 0.66)	(1.0, 1.0, 1.0)	(0.40, 0.50, 0.66)	(0.33, 0.40, 0.50)
A_7	(2.0, 2.50, 3.0)	(2.0, 2.50, 3.0)	(1.0, 1.50, 2.0)	(1.50, 2.0, 2.50)	(0.50, 0.66, 1.0)	(1.50, 2.0, 2.50)	(1.0, 1.0, 1.0)	(0.66, 1.0, 2.0)
A_8	(2.50, 3.0, 3.50)	(2.50, 3.0, 3.50)	(1.50, 2.0, 2.50)	(2.0, 2.50, 3.0)	(1.0, 1.50, 2.0)	(2.0, 2.50, 3.0)	(0.50, 1.0, 1.50)	(1.0, 1.0, 1.0)

Table 12
Fuzzy values of the scenario option ratings related to criterion C_2

Scenarios	A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8
A_1	(1.0, 1.0, 1.0)	(0.50, 1.0, 1.50)	(1.50, 2.0, 2.50)	(1.0, 1.50, 2.0)	(1.50, 2.0, 2.50)	(1.0, 1.50, 2.0)	(2.0, 2.50, 3.0)	(2.50, 3.0, 3.50)
A_2	(0.66, 1.0, 2.0)	(1.0, 1.0, 1.0)	(1.0, 1.50, 2.0)	(0.50, 1.0, 1.50)	(1.50, 2.0, 2.50)	(1.0, 1.50, 2.0)	(2.0, 2.50, 3.0)	(2.0, 2.50, 3.0)
A_3	(0.40, 0.50, 0.66)	(0.50, 0.66, 1.0)	(1.0, 1.0, 1.0)	(0.50, 0.66, 1.0)	(1.0, 1.50, 2.0)	(0.66, 1.0, 2.0)	(1.50, 2.0, 2.50)	(1.0, 1.50, 2.0)
A_4	(0.50, 0.66, 1.0)	(0.66, 1.0, 2.0)	(1.0, 1.50, 2.0)	(1.0, 1.0, 1.0)	(1.50, 2.0, 2.50)	(1.0, 1.50, 2.0)	(1.50, 2.0, 2.50)	(1.50, 2.0, 2.50)
A_5	(0.40, 0.50, 0.66)	(0.40, 0.50, 0.66)	(0.50, 0.66, 1.0)	(0.40, 0.50, 0.66)	(1.0, 1.0, 1.0)	(0.40, 0.50, 0.66)	(1.0, 1.50, 2.0)	(1.0, 1.50, 2.0)
A_6	(0.50, 0.66, 1.0)	(0.50, 0.66, 1.0)	(0.50, 1.0, 1.50)	(0.50, 0.66, 1.0)	(1.50, 2.0, 2.50)	(1.0, 1.0, 1.0)	(1.50, 2.0, 2.50)	(1.50, 2.0, 2.50)
A_7	(0.33, 0.40, 0.50)	(0.33, 0.40, 0.50)	(0.40, 0.50, 0.66)	(0.40, 0.50, 0.66)	(0.50, 0.66, 1.0)	(0.40, 0.50, 0.66)	(1.0, 1.0, 1.0)	(0.50, 1.0, 1.50)
A_8	(0.29, 0.33, 0.40)	(0.33, 0.40, 0.50)	(0.50, 0.66, 1.0)	(0.40, 0.50, 0.66)	(0.50, 0.66, 1.0)	(0.40, 0.50, 0.66)	(0.66, 1.0, 2.0)	(1.0, 1.0, 1.0)

Table 13
Fuzzy values of the scenario option ratings related to criterion C_3

Scenarios	A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8
A_1	(1.0, 1.0, 1.0)	(0.66, 1.0, 2.0)	(0.40, 0.50, 0.66)	(0.50, 0.66, 1.0)	(0.40, 0.50, 0.66)	(0.50, 0.66, 1.0)	(0.33, 0.40, 0.50)	(0.29, 0.33, 0.40)
A_2	(0.50, 1.0, 1.50)	(1.0, 1.0, 1.0)	(0.66, 1.0, 2.0)	(0.40, 0.50, 0.66)	(0.40, 0.50, 0.66)	(0.50, 0.66, 1.0)	(0.50, 0.66, 1.0)	(0.33, 0.40, 0.50)
A_3	(1.50, 2.0, 2.50)	(0.50, 1.0, 1.50)	(1.0, 1.0, 1.0)	(1.0, 1.50, 2.0)	(0.66, 1.0, 2.0)	(0.50, 1.0, 1.50)	(0.66, 1.0, 2.0)	(0.40, 0.50, 0.66)
A_4	(1.0, 1.50, 2.0)	(1.50, 2.0, 2.50)	(0.50, 0.66, 1.0)	(1.0, 1.0, 1.0)	(0.40, 0.50, 0.66)	(0.66, 1.0, 2.0)	(0.33, 0.40, 0.50)	(0.33, 0.40, 0.50)
A_5	(1.50, 2.0, 2.50)	(1.50, 2.0, 2.50)	(0.50, 1.0, 1.50)	(1.50, 2.0, 2.50)	(1.0, 1.0, 1.0)	(1.0, 1.50, 2.0)	(0.50, 0.66, 1.0)	(0.40, 0.50, 0.66)
A_6	(1.0, 1.50, 2.0)	(1.0, 1.50, 2.0)	(0.66, 1.0, 2.0)	(0.50, 1.0, 1.50)	(0.50, 0.66, 1.0)	(1.0, 1.0, 1.0)	(0.50, 0.66, 1.0)	(0.40, 0.50, 0.66)
A_7	(2.0, 2.50, 3.0)	(1.0, 1.50, 2.0)	(0.50, 1.0, 1.50)	(2.0, 2.50, 3.0)	(1.0, 1.50, 2.0)	(1.0, 1.50, 2.0)	(1.0, 1.0, 1.0)	(0.66, 1.0, 2.0)
A_8								

Table 14
Fuzzy values of the scenario option ratings related to criterion C_4

Scenarios	A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8
A_1	(1.0, 1.0, 1.0)	(0.50, 0.66, 1.0)	(0.40, 0.50, 0.66)	(0.66, 1.0, 2.0)	(0.33, 0.40, 0.50)	(0.40, 0.50, 0.66)	(0.33, 0.40, 0.50)	(0.29, 0.33, 0.40)
A_2	(1.0, 1.50, 2.0)	(1.0, 1.0, 1.0)	(0.50, 0.66, 1.0)	(0.50, 1.0, 1.50)	(0.50, 0.66, 1.0)	(0.66, 1.0, 2.0)	(0.50, 0.66, 1.0)	(0.40, 0.50, 0.66)
A_3	(1.50, 2.0, 2.50)	(1.0, 1.50, 2.0)	(1.0, 1.0, 1.0)	(2.0, 2.50, 3.0)	(0.66, 1.0, 2.0)	(0.40, 0.50, 0.66)	(0.66, 1.0, 2.0)	(0.50, 0.66, 1.0)
A_4	(0.50, 1.0, 1.50)	(0.66, 1.0, 2.0)	(0.33, 0.40, 0.50)	(1.0, 1.0, 1.0)	(0.33, 0.40, 0.50)	(0.50, 0.66, 1.0)	(0.40, 0.50, 0.66)	(0.33, 0.40, 0.50)
A_5	(2.0, 2.50, 3.0)	(1.0, 1.50, 2.0)	(0.50, 1.0, 1.50)	(2.0, 2.50, 3.0)	(1.0, 1.0, 1.0)	(0.40, 0.50, 0.66)	(1.0, 1.50, 2.0)	(0.66, 1.0, 2.0)
A_6	(1.50, 2.0, 2.50)	(0.50, 1.0, 1.50)	(1.50, 2.0, 2.50)	(1.0, 1.50, 2.0)	(1.50, 2.0, 2.50)	(1.0, 1.0, 1.0)	(0.50, 0.66, 1.0)	(0.40, 0.50, 0.66)
A_7	(2.0, 2.50, 3.0)	(1.0, 1.50, 2.0)	(0.50, 1.0, 1.50)	(1.50, 2.0, 2.50)	(0.50, 0.66, 1.0)	(1.0, 1.50, 2.0)	(1.0, 1.0, 1.0)	(0.50, 0.66, 1.0)
A_8	(2.50, 3.0, 3.50)	(1.50, 2.0, 2.50)	(1.0, 1.50, 2.0)	(2.0, 2.50, 3.0)	(0.50, 1.0, 1.50)	(1.50, 2.0, 2.50)	(1.0, 1.50, 2.0)	(1.0, 1.0, 1.0)

Table 15
Fuzzy values of the scenario option ratings related to criterion C_5

Scenarios	A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8
A_1	(1.0, 1.0, 1.0)	(0.66, 1.0, 2.0)	(0.40, 0.50, 0.66)	(0.50, 0.66, 1.0)	(0.40, 0.50, 0.66)	(0.50, 0.66, 1.0)	(0.33, 0.40, 0.50)	(0.29, 0.33, 0.40)
A_2	(0.50, 1.0, 1.50)	(1.0, 1.0, 1.0)	(0.33, 0.40, 0.50)	(0.66, 1.0, 2.0)	(0.40, 0.50, 0.66)	(0.50, 0.66, 1.0)	(0.33, 0.40, 0.50)	(0.29, 0.33, 0.40)
A_3	(1.50, 2.0, 2.50)	(2.0, 2.50, 3.0)	(1.0, 1.0, 1.0)	(1.50, 2.0, 2.50)	(0.50, 0.66, 1.0)	(1.0, 1.50, 2.0)	(0.40, 0.50, 0.66)	(0.33, 0.40, 0.50)
A_4	(1.0, 1.50, 2.0)	(0.50, 1.0, 1.50)	(0.40, 0.50, 0.66)	(1.0, 1.0, 1.0)	(0.40, 0.50, 0.66)	(0.66, 1.0, 2.0)	(0.33, 0.40, 0.50)	(0.29, 0.33, 0.40)
A_5	(1.50, 2.0, 2.50)	(1.50, 2.0, 2.50)	(1.0, 1.50, 2.0)	(1.50, 2.0, 2.50)	(1.0, 1.0, 1.0)	(0.40, 0.50, 0.66)	(0.66, 1.0, 2.0)	(0.40, 0.50, 0.66)
A_6	(1.0, 1.50, 2.0)	(1.0, 1.50, 2.0)	(0.50, 0.66, 1.0)	(0.50, 1.0, 1.50)	(1.50, 2.0, 2.50)	(1.0, 1.0, 1.0)	(0.40, 0.50, 0.66)	(0.29, 0.33, 0.40)
A_7	(2.0, 2.50, 3.0)	(2.0, 2.50, 3.0)	(1.50, 2.0, 2.50)	(2.0, 2.50, 3.0)	(0.50, 1.0, 1.50)	(1.50, 2.0, 2.50)	(1.0, 1.0, 1.0)	(0.66, 1.0, 2.0)
A_8	(2.50, 3.0, 3.50)	(2.50, 3.0, 3.50)	(2.0, 2.50, 3.0)	(2.50, 3.0, 3.50)	(1.50, 2.0, 2.50)	(2.50, 3.0, 3.50)	(0.50, 1.0, 1.50)	(1.0, 1.0, 1.0)

Normalized weight vector was (0.20, 0.22, 0.19, 0.18, 0.21).

Computation of the weight vectors for the option assessment matrices followed a similar method. The weight vectors from Tables 11–15 were, respectively, (0.0, 0.04, 0.59, 0.25, 0.70, 0.21, 0.82, 1.0), (1.0, 0.90, 0.57, 0.81, 0.28, 0.66, 0.02, 0.11), (0.02, 0.03, 0.58, 0.37, 0.68, 0.44, 0.84, 1.0), (0.27, 0.61, 0.90, 0.38, 1.0, 0.93, 0.95, 1.0), and (0.0, 0.0, 0.40, 0.0, 0.44, 0.22, 0.75, 1.0). Table 16 summarizes the normalized weight vectors of the criteria and option scenarios.

For scenario option A_1, the consequences were calculated as:

$$D(A_1) = (d'(A_{1c1}) \times d'(C_1) + d'(A_{1c2}) \times d'(C_2) + d'(A_{1c3}) \times d'(C_3) + d'(A_{1c4}) \times d'(C_4) + d'(A_{1c5}) \times d'(C_5) = 0.058$$

The effectiveness and priority for the other option scenarios were calculated using same procedure. Table 17 indicates the consequences for all the options and their priorities. Thus, following this method, like with the application of Fuzzy TOPSIS, scenario A_8 was the best assessed option, and the lowest priority belonged to A_1. While in this technique some of the priorities changed, three of the top and the last priorities were similar to the results obtained using the Fuzzy TOPSIS technique.

3.4. Comparison of Fuzzy TOPSIS and Fuzzy AHP techniques

A number of necessary characteristics of Fuzzy TOPSIS and Fuzzy AHP techniques were applied to compare two techniques so as to suitably deal with the issues of management activity and scenario selection. The six main parameters were determined to be acceptance of changes in criteria; computational complication; quickness in decision making; suitability of supporting group decision making; number of scenarios and criteria; and uncertainty modeling.

Table 16
Weight vectors of the criteria and option scenarios in the Darenari catchment

Criteria Scenarios	C_1	C_2	C_3	C_4	C_5
A_1	0.00	0.23	0.00	0.04	0.00
A_2	0.01	0.21	0.01	0.10	0.00
A_3	0.16	0.13	0.15	0.15	0.14
A_4	0.07	0.19	0.09	0.06	0.00
A_5	0.19	0.06	0.17	0.17	0.16
A_6	0.06	0.15	0.11	0.15	0.08
A_7	0.23	0.00	0.21	0.16	0.27
A_8	0.28	0.03	0.25	0.17	0.36
Criteria weights	0.20	0.22	0.19	0.18	0.21

Table 17
Effectiveness and priority of options in the Darenari catchment

Scenarios	Effectiveness	Priority
A_1	0.060	8th
A_2	0.068	7th
A_3	0.146	4th
A_4	0.084	6th
A_5	0.148	3rd
A_6	0.110	5th
A_7	0.171	2nd
A_8	0.214	1st

3.4.1. Acceptance of changes in criteria

In certain catchment assessment and management conditions, some changes to the criteria applied to assess the scenarios may be necessary. Thus, in such cases, the order of importance of the criteria produced by the selection approach has to be consistent as well.

As indicated in Fig. 1a, in applying Fuzzy AHP with five criteria and related weights, the criteria importance order given by the method was (C_2>C_5>C_1>C_3>C_4), as indicated in Fig. 1a. To assess the impact of adding a new criterion, five tests were done, each with an additional criterion with a weight equal to one of the five existing criteria. (Fig. 1b).

The results showed no significant changes in the order of importance in most of the tests; yet, when the additional criterion had a weight equal to that of C_3, an inversion in importance order was observed, indicating that the ranking reversal may also happen when there is a change in criteria. When Fuzzy TOPSIS was applied, adding a new criterion did not appear to cause changes in the criteria importance order.

To assess the impact of excluding a criterion, another test was carried out. At first, the importance order of the criteria as identified in the Fuzzy AHP was (C_2>C_5>C_1>C_3>C_4), as indicated in Fig. 3a. The importance order remained the same as before the criterion C_3 was removed and showed no change when it was excluded.

3.4.2. Computational complication analysis

The time complication was applied to assess the computational complications of both techniques. Based on the results of Chang [10], the number of times multiplications were performed within the algorithms was considered as the time complication, T. In the current research, exponentiation and logical operations were also applied as a time complication assessment. Given there were n optional scenarios and m criteria, the Fuzzy TOPSIS technique needed $3nm$ actions to calculate the normalized decision matrix, $3nm$ actions to calculate the weighted decision matrix, and $14nm$ actions to calculate the distances d_i^+ and d_i^-. The time complication $T_{n,m}$ of the Fuzzy TOPSIS technique is followed in Eq. (3).

$$T_{n,m} = 3nm + 3nm + 7nm + 7nm = 20nm \quad (3)$$

Using a similar method, the Fuzzy AHP technique required $6m(n + 1)$ actions to calculate the fuzzy synthetic extent of all matrices of decision, $nm(n - 1) + n(n - 1)$ to calculate the levels of possibility, $n(m+1)$ to normalize vector W', and, ultimately, nm actions to calculate effectiveness. The time complication $T'_{n,m}$ of the Fuzzy AHP technique is followed in Eq. (4).

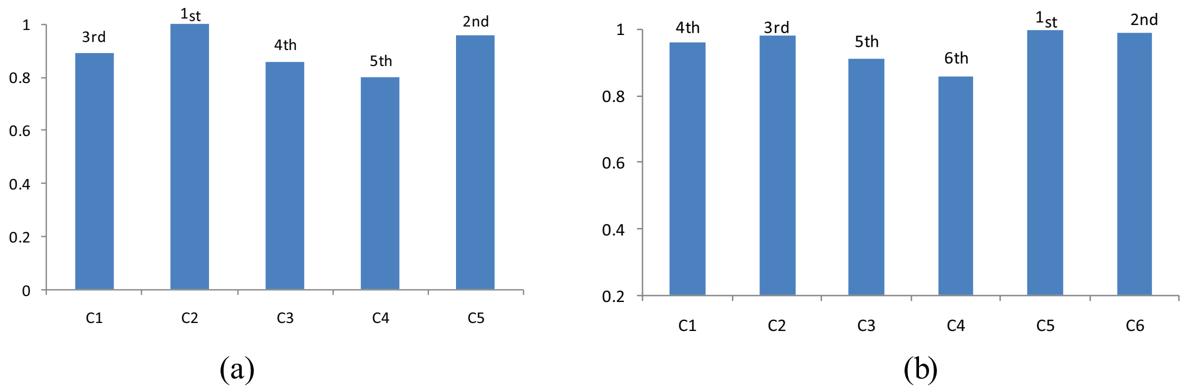

Fig. 1. Results of change tests of criteria for Fuzzy AHP technique.

$$T'_{n,m} = 6m(n + 1) + nm(n - 1) + n(n - 1) + n(m+1) + nm = n^2(m + 1) + m(7n + 6) \quad (4)$$

Results showed that Fuzzy AHP is generally better implemented than Fuzzy TOPSIS. Results further indicated that the Fuzzy TOPSIS and Fuzzy AHP techniques needed 800 and 451 actions, respectively. However, the results of the consistency tests of the judgment matrices indicated that the time complication of the Fuzzy AHP technique, $T_{n,m}$, rose by a parameter of $4n(m+1)$. Also based on the results, the Fuzzy TOPSIS technique implemented was more suitable than the Fuzzy AHP as it increased the number of options; however, Fuzzy AHP is still generally more suitably implemented.

3.4.3. Quickness in the decision making

The number of expert judgments was applied to assess quickness in both approaches. Given n, the numbers of scenarios, and m, the number of criteria in the Fuzzy TOPSIS technique, m judgments for each of the n options were needed in addition to the m judgments related to the weight of the criteria. This may be demonstrated as in Eq. (5).

$$J_{n,m}^{TOPSIS}\ m + nm = m(n + 1) \quad (5)$$

The number of judgments required for a decision matrix of the Fuzzy AHP technique A_{ixi} was:

$$JA_{i,i} = i\,(i - 1/2) \quad (6)$$

Considering there are m matrices of size $n \times n$ in addition to the decision matrix of size $m \times m$ related to the weight of the criteria, the total number of judgments needed was

$$J_{n,m}^{AHP} = m(m - 1/2) + m[n.n - 1/2] \quad (7)$$

Based on Eqs. (5) and (7), the results indicated that as the number of criteria and options rose, 45 and 150 judgments were required by Fuzzy TOPSIS and Fuzzy AHP, respectively. In other words, Fuzzy AHP needs four times more judgments than Fuzzy TOPSIS when there are 9 options and 9 criteria. On the other hand, when there are few criteria and options ($J_{2\times2}$, $J_{2\times3}$, $J_{2\times4}$, $J_{3\times2}$), more judgments are necessary when applying Fuzzy TOPSIS compared to Fuzzy AHP. Thus, considering to interesting degree of experts to data gathering, it may be stated that the Fuzzy TOPSIS technique operates more suitably than the Fuzzy AHP. In other words, Fuzzy TOPSIS allows for more quickness in the decision-making process than Fuzzy AHP.

3.4.4. Suitability of supporting group decision making

Both approaches make the summation of judgments of more than one expert or decision-maker possible. With the Fuzzy AHP technique, however, summation is not clearly considered in the approach suggested by Chang [10]. In fact, Chang proposes that summation be calculated by applying the arithmetic means of the judgments.

Because Fuzzy AHP requires a greater volume of data than the Fuzzy TOPSIS technique, the time complication of Fuzzy AHP compared with that of the TOPSIS technique will increase when the number of decision-makers and experts increases. Even though both approaches provide group decision making, because of the effect on time complication, the Fuzzy TOPSIS technique is more suitable and better. In addition to fuzzy arithmetic means, an optional method for both approaches would be to weight the judgments of the various decision-makers and sum the data by calculating a weighted mean.

3.4.5. Number of optional scenarios and criteria

With the Fuzzy TOPSIS technique, there are no limitations in the number of options or criteria applied in the selection process; however, the comparative evaluation of the Fuzzy AHP technique does include some restrictions. Saaty [39] proposed that the number of comparative criteria or options applying AHP be restricted to nine rather than condemning human judgment and its consistency. This proposal is equally used with the Fuzzy AHP technique. With five criteria and eight options, applying the Fuzzy AHP technique is completely feasible; however, to reduce the criteria number restriction, the criteria can be deployed into the Fuzzy AHP hierarchy structure, where the number of options causes a real restriction. Thus, the particularities of the conditions at hand determine the selection of the technique.

3.4.6. Uncertainty modeling

Both approaches apply the fuzzy set theory to deal with the inherent loss of data accuracy in the decision-making process of the best scenario. In both approaches, the main source for estimating uncertainty is the number of fuzzy morphologies. Because of the imprecision of judgments of qualitative variables and in order to better illustrate the linguistic terms applied by each decision-maker and expert to assess the options regarding various decision criteria, the elements of the triangular membership functions may be selected.

Pairwise comparisons are applied for the Fuzzy AHP technique by means of comparative linguistic variables in order to deal with vagueness. The characteristic of pairwise comparisons by means of comparative linguistic variables of the Fuzzy AHP technique makes this technique more suitable than Fuzzy TOPSIS in dealing with vagueness when the aim is to choose the best scenario.

4. Conclusion

The current research compared the Fuzzy AHP and the Fuzzy TOPSIS approaches in regard to six factors that were especially relevant to the issue of selecting the best scenario and indicated the utilization of both approaches in scenario selection, explaining the purpose, and clarifying the application of these methods for the issue of scenario selection. The comparative assessment of the methods in respect to changes in criteria weight, quickness and computational complication was based on computational tests considering eight scenarios. The implementation of the techniques concerning changes in criteria was assessed through five tests of criteria. As for quickness and computational complication, the methods were evaluated using 150 tests concerning scenario selection. Suitability for supporting group decision making was compared by applying the analysis of equations of both techniques. Other parameters were compared using qualitative analyses of the algorithms of both techniques.

This comparative analysis of Fuzzy AHP and Fuzzy TOPSIS identified noticeable consequences that must be considered so as to better set the method to the characteristics of the current issue. The outcomes of the analyses of the six parameters are valid for the context of selecting the best scenario(s) in catchment management. For other decision-making issues, changes to criteria, quickness, and computational complication can also be relevant; thus, the conclusions are also appropriate to them.

It can be seen that under some conditions, Fuzzy AHP causes a change to the preference priority of the criteria. On the other hand, the outcomes of the Fuzzy TOPSIS technique were very consistent. Fuzzy TOPSIS operates better in quickness of decision making than Fuzzy AHP in most cases, except those for which there are few criteria and scenarios. Increasing the number of scenario options causes some restrictions to Fuzzy AHP; however, it is not a limitation to the application of Fuzzy TOPSIS. In the case of the number of criteria, the intrinsic restriction caused by the Fuzzy AHP technique may be overcome by deploying the criteria into the Fuzzy AHP hierarchy framework. At the same time in which Fuzzy TOPSIS shows no restriction to the number of criteria, it also does not allow the deployment of the criteria into related indices. This may be considered a disadvantage of the technique when utilized in scenario selection.

The time complication of Fuzzy AHP is lower than that of Fuzzy TOPSIS. However, if the Fuzzy AHP decision matrix consistency test is implemented, which is frequently required, than the advantage of the Fuzzy AHP technique is not very noticeable. This consequence differs from the results of Ertugrul and Karakasoglu [23] who stated that Fuzzy AHP needs more complicated calculations than Fuzzy TOPSIS.

Both approaches suitability support group decision making. It is useful to state which weighted mean could be applied to summation judgments despite the arithmetic means being often applied. Applying the weighted means, one could give various importance to various decision makers and experts. However, both approaches are equally suitable for dealing with a lack of accuracy in scores of options as well as the relative importance of various criteria. It is useful to mention that Fuzzy AHP is more suitable than Fuzzy TOPSIS when the aim is to choose the best scenario from among several scenarios.

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