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Full Length Research Paper

Deciding on the right area to set up damp for the purpose of sustainable development of water resources using TOPSIS method

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Nowadays, due to uncontrolled exploitation of ground water, the rate of water shortage has doubled. Accurate control and management of these water resources can alleviate the problem of drought inherently. Based on the statistics published by FAO (Food and Agriculture Organization), the need for fresh water is almost twice that experienced 21 years ago, while useful water resources have been reduced by half the number recorded 30 years ago. It seems that the number of fresh water resources that will be recorded in 2025 will be one-fourth of the number of useful water resources recorded in 1960. Meanwhile, danger of various pollutions for water resources frequently increased their value and importance. Taking into consideration the mentioned cases, if water resources are not managed in a better way, human lives will be threatened by the shortage of water. Thus, it is necessary to acquire the exact and up to date information about the condition of water resources and prediction of their situation in future in order to achieve optimum management for water resources. One of the management methods for water resources is Multi Criteria Decision Making. The results and findings of different studies show that in TOPSIS method, zone 3 with (0/755) point comes first among the 7 studied zones and thus it is the most appropriate zone to establish the proper damp. In contrast, zone 7 with (0/265) point comes last after zones 4, 2, 5, 6 and 1 with (0/668), (0/512), (0/492), (0/327) and (0/289) points respectively and so it is not suitable for establishing damp.

Key words: Damp, SHAHROUD-BASTAM, TOPSIS, zoning, sustainable development.

INTRODUCTION

Decision making problem is the process of finding the best option from all of the feasible alternatives. In almost all of such problems, the multiplicity of criteria for judging the alternatives is pervasive. That is, for many of such problems, the decision maker wants to solve a multiple criteria decision making (MCDM) problem. A survey of the MCDM methods was presented by Hwang and Yoon [Hwang, 1981]. Technique for Order Performance by Similarity to Ideal Solution (TOPSIS), one of the known classical MCDM methods, was also first developed by Hwang and Yoon. This technique is based on the concept that the chosen alternative should have the shortest distance from the Positive Ideal Solution (PIS), that is, the solution that maximizes the benefit criteria and minimizes the cost criteria, and the farthest distance from the nega-

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tive Ideal Solution (NIS), that is, the solution that maximizes the cost criteria and minimizes the benefit criteria. In classical MCMD methods, including classical TOPSIS, the ratings and weights of the criteria are known precisely. However, under many conditions, crisp data are inadequate to model real-life situations since human judgments including preferences are often vague and cannot estimate its preference with an exact numerical value. A more realistic approach may be to use linguistic assessments instead of numerical values, that is, to suppose that the ratings and weights of the criteria in the problem are assessed by means of linguistic variables. Lingual expressions, for example, low, medium, high, etc., are regarded as the natural representation of the judgment. These characteristics indicate the applicability of fuzzy set theory in capturing the decision makers‟ preference structure. Fuzzy set theory aids in measuring the ambiguity of concepts that are associated with human beings‟ subjective judgment.

Since in the group decision making, evaluation results from different evaluators‟ view of linguistic variables, its evaluation must be conducted in an uncertain, fuzzy environment. In recent years, the rate of water exploitation has become greater for many reasons such as population growth, industrial development, urbanization growth and consequently increased demand for food products. Hence the rate of exploitation and consumption of ground water has become greater than recharging them; in other words, input of ground water system is less than its output, though the system with negative balance sheet has positive feedback and is collapsing. Thus it is very significant to determine and assign the suitable position for this case. Due to continuous decline in per capita water and the importance of nutritious preparation for people, it is necessary to control the surface water using damp building or artificial recharge methods. Researchers of water sciences have studied the damp building and artificial recharge projects all over the world, drawn logarithm curve for cost against the amount of savable running water and concluded that it is frugal economically to accomplish artificial recharge projects especially flood distribution instead of damp building for the volume of less than 30 million cube meter (Bize et al., 1972). The experiences of under developed countries show that compressing the agriculture sector caused quick output resources but destroy the basic resources in the long term, which can be noticed in pasture destruction, forest resources reduction, deserts increase, reduction and destruction of surface water resources and ground water, and exponential compression of the basic resources. In our country, planning in agricultural, rural and natural resources development has always been founded at the level of political development. This traditional attitude towards planning and development caused instability in using basic resources. During two previous decades, Iran set up activities to develop agriculture and natural resources comprehensively. Although these activities were slow and sluggish, they can develop a new attitude among experts, connoisseurs and decision makers in the agriculture sector. Based on this attitude, casual, one-direction and one-dimensional activities can solve part of the short term problems and difficulties related to the agriculture sector and have pathetic effects on this sector in long term. Water resources management entails a set of various management activities aimed at the optimum utilization of water resources and reduction of economical, social and environmental damages and losses. The issue of decision making in water resources management is very complex and complicated because of several decision indicators and criteria. In achieving a determined purpose, there are lots of solutions with different priorities for various issues such as environmental, social, organizational and political problems. These necessities lead to the use of multiple criteria decision making aimed at selection of the best solution among different solutions.

There are many examples of different applications of fuzzy TOPSIS in literature. For instance: the evaluation of service quality (Tsuar et al., 2010), inter company comparison (Deng et al., 2012), the applications of inaggregate production planning (Wang and Liang, 2012), facility location selection (Chu, 2012) and large scale nonlinear programming. The modifications proposed in this paper can be implemented in all real world applications of Fuzzy TOPSIS. Krishnamurthy et al. (1996) used RS and GIS techniques to find a suitable position for artificial recharge of ground water in India. Also, they investigated the effects of geomorphologic and geological factors on the activities of ground water and stated that there is a special unevenness in each area for recharge of ground water. Saraf and Choudhury (1998) used remote sensing capabilities in extracting different layers like land usage, geomorphology, vegetation, and their integration in GIS environment to determine the most suitable area for artificial recharge of ground water. Mahdavi (1997: 16) investigated water management and artificial recharge of ground water in Jourm city and indicated that controlling usage and recharge of water tables by the watershed management is the main management technique.

Abdi and Ghayoumian (2012: 86) prioritized the suitable areas for storing surface water and reinforcing ground water based on the integration and analysis of geophysics data, land usage and topography, in the GIS environment. Kia Heyrati (2004) studied the function of flood distribution system in recharge of ground water in Moughar plain in Isfahan. Mahdavi et al. (2005) attempted to find the best position for artificial recharge of ground water by RS and GIS techniques in watershed Shahr Reza in Isfahan and introduced this tool for this case efficiently. Also, Noori et al. (2005: 635) tried to find the appropriate areas for artificial recharge of ground water by recharge pools and GIS technique in watershed

Gavbandi. Thus, alluvial fans and plain head (Dashtsar) were introduced as the best area for artificial recharge. Although Mousavi et al. (2010) found the potential appropriate areas for artificial recharge of ground water in the vicinity of Kamestan anticline by integration of remote sensing and GIS techniques, he introduced broken formations, alluviums and river canals as the best position for artificial recharge.

Mianabadi and Afshar (2008) investigated and ranked the project of water supply in Zahedan using three methods: Induced Ordered Weighted Averaging (IOWA), Linear Assignment and TOPSIS methods, and then compared the findings of these methods with the results of adaptable planning method (Mianabadi, 2008: 34-45). Limon and Martinez (2006: 313-336) used Multi Attribute Utility theory for optimum allocation of agricultural water in the north of Spain. Ahmadi et al. (2002: 339-352) used multiple criteria decision making to rank different projects aimed at refining agriculture water to reuse them. Also, Anand and Kumar (1996: 326-335) ranked management options of river basin by ELECTRE method. The purpose of this study is to explore the best area suitable for artificial recharge of underground basins in SHAHROUD-BASTAM watershed using effective factors in recharging underground water by TOPSIS and Linear Assignment technique. Put in another way, this study aimed at selecting the most appropriate area to establish soil damps for the purpose of sustainable development of water resources using Multi Criteria Decision Making methods and classifying the best areas in the considered watershed.

MATERIALS AND METHODS

Mathematical situation of the studied area

Saveh province, being situated in the northern part of the central province, is bounded by 36°, 00‟ latitude to 37°, 00‟ north latitude and 54°, 15‟ to 57°, 15‟ longitude. It has access to GOLEATAN province in the north, ISFAHAN and KERMAN provinces in the south, KHORASAN province in the east and TEHRAN province in the west. Globally, SHAHROUD is located at 1250 m height above sea level and its extent is 7603/25 km^2 (Figure 1).

Procedure

The study area was investigated by the satellite images of Google Earth and its limitations were determined. Then digital elevation model of the area was separated from its digital elevation model in Iran in the environment of soft ware GlOBAL MAPER and the output was received. Required data layers for zoning in the environment of software Arc GIS 9.3 was prepared as follow:

First, the digital elevation model was classified into 7 elevation classes based on natural breaks in the heights of the area. The mentioned classes represent the studied zones in the area and subsequent calculations were done in each of these classes. The slope layer was prepared in the area by surface analysis tool in 3D analyses based on digital elevation model. Different processes were used to prepare the drainage density layer and habitual density layer such as: digitizing the main and minor waterways‟ layers on the topographical map (1:50000) of the area, digitizing the main and minor fault on the geological map (1:100000) of the area and digitizing the density tool in Spatial Analyses. However, iso-precipitation layer was prepared by interpolating method, which comprised cringing technique using interpolating tools in 3D analyses.

Secondly, the investigated criteria for each height zones were calculated (Tables 2 to 8) and their layers prepared separately. After achieving a few numbers in each layer, the numbers were analyzed by TOPSIS method. Then the considered watershed was ranked to select the best area for establishing the damp. These criteria were achieved from layers and then analyzed by the TOPSIS method.

Theoretical principles of TOPSIS method

In recent decades, several researchers have attempted to use Multi Criteria Decision Making (MCDM) in complex and complicated decisions. These decision methods are divided into two parts:

1. MODM = Multi Objective Decision Making
2. MADM = Multi Attribute Decision Making.

Multi Criteria Models are used to select the best options. Evaluative Models used for MADM are classified into two models:

1) Compensatory Model
2) Non-Compensatory Model.

Non-Compensatory Model includes methods which do not need to achieve data from DM and lead to objective answer. Exchange between indicators is permitted in Compensatory Model. It means that for example, a weakness in an indicator may be compensated by option of other indicators.

TOPSIS algorithm is a Multi Criteria Decision Making, a type of compensatory model and an adaptable subgroup with strong ability to solve multi alternative problems and overlap indicators in weak and power points (Kohansal and Rafiei, 2009: 93). In this model, if quantitative criteria can change into qualitative criteria, qualitative criteria can be used together with quantitative criteria. In the aforementioned model, it is supposed that each indicator and criterion has steady increasing and decreasing utility in decision making matrix; it means if criteria gain more positive amount, they will be more appropriate, while if it gain more negative amount, they will become less appropriate (Roy, 1991: 49-73).

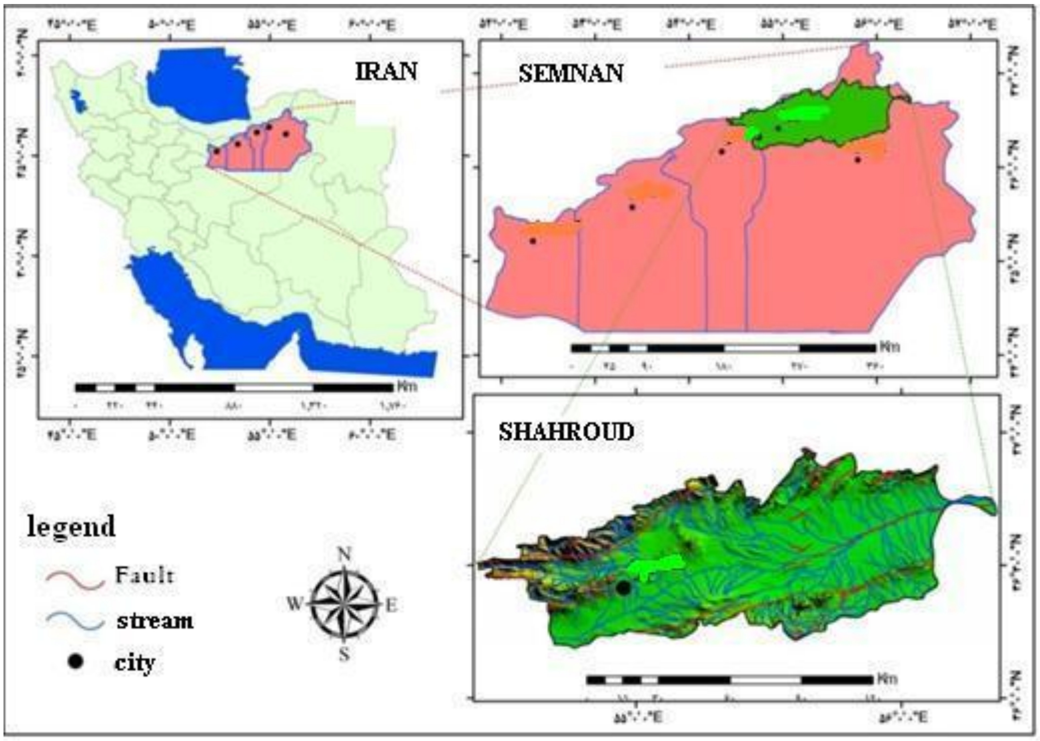

Figure 1. Mathematical situation of the studied area.

Problem solving process using TOPSIS method

TOPSIS model includes 8 processes which are described as follow (Olson, 2004: 2).

1. Establishing data matrix based on alternative n and indicator k: Generally, in TOPSIS model, matrix **n×m** with **m** alternative and **n** criteria is evaluated. In this algorithm, it is supposed that each indicator and criterion in Decision Making matrix has steady increasing and decreasing utility as shown hereunder:

$$A_{ij} = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \cdot & \cdot & & \cdot \\ \cdot & \cdot & & \cdot \\ a_{m1} & a_{m2} & \cdots & a_{mn} \end{bmatrix}$$

2. Standardizing data and preparing normalized matrix (matrix R) by Equation (1): Since it is possible that the quantitative amount of criteria and indicators do not have equal unit, the dimensions of their units should be omitted. Thus, all amounts of entries of Decision Making matrix should be changed into dimensionless amount with the following formula:

$$R_{IJ} = \frac{a_{ij}}{\sqrt{\sum_{i=1}^{m} a_{ij}^{\,2}}} \quad :)1($$

$$\begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1n} \\ r_{21} & r_{22} & \cdots & r_{2n} \\ \cdot & \cdot & & \cdot \\ \cdot & \cdot & & \cdot \\ r_{m1} & r_{m2} & \cdots & r_{mn} \end{bmatrix}$$

3. Determining weights for whole indicators (w_j) by Equation (2) and modifying calculated weights (w_j) by Equation (3): In this process, the weights of all indicators are calculated by expertise theories and approaches such as: Linmap method, AHP model, and Antropi model, based on the importance of the criteria. It is expected that the sum of criteria weights should be equal to 1. In this study, AHP model was used to calculate the amount of (w_j) (Table 3):

$$\sum_{j=1}^{n} w_j = 1 \quad (2)$$

$$W'_j == \frac{\lambda_j . w_j}{\sum_{j=1}^{n} \lambda_j . w_j} \quad (3)$$

4. Creating dimensionless weighted matrix (V) to implement vector W as an input for algorithm: In order for the amounts of entries in matrix R to gain equal value,

the sum of weights of parameter (w_j) are multiplied to the values in the column of this matrix one by one. The acquired matrix is normalized and the weighted matrix is shown by sign (V) (Table 4):

$$V_{ij} = R_{ij}.W_{n\times n} = \begin{bmatrix} V_{11,...} & V_{1j,...} & V_{1n} \\ . & . & . \\ . & . & . \\ V_{m1,...} & V_{mj,...} & V_{mn} \end{bmatrix}$$

Subsequently, a description of the determination of positive ideal (A^+) and negative ideal (A^-) is shown in Equations (4) and (5) respectively:

5. $$d_{i+} = \sqrt{\sum_{j=1}^{n}\left(V_{ij} - V^{+}{}_{j}\right)^2}\ ;\ i = 1,2,\ldots,m \qquad (4)$$

6 $$d_{i-} = \sqrt{\sum_{j=1}^{n}\left(V_{ij} - V^{-}{}_{j}\right)^2}\ ;\ i = 1,2,\ldots,m \qquad (5)$$

7. Calculating distance size of i-alternative with ideals and using Euclidean method by Equations (6) and (7):

$$d_{i+} = \text{dictance of i} - \text{alternative from positive ideal} = \sqrt{\sum_{j=1}^{n}\left(V_{ij} - V^{+}{}_{j}\right)^2}\ ;\ i = 1,2,\ldots,m \qquad (6)$$

$$d_{i-} = \text{distance of i} - \text{alternative from negative ideal} = \sqrt{\sum_{j=1}^{n}\left(V_{ij} - V^{-}{}_{j}\right)^2}\ ;\ i = 1,2,\ldots,m \qquad (7)$$

Calculating relative closeness for i-alternative (A_i) i to ideal solution using Equation (8):

$$cl_{i+} = \frac{d_{i-}}{d_{i+} + d_{i-}}\ ;\ 0 \leq cl_{i+} \leq 1\ ;\ i = 1,2,\ldots,m \qquad (8)$$

As can be observed from the equations, if A_i=A^+, then d_{i+}=1 and cl_{i-}=0. On the contrary, if A_i=A^-, then d_{i+}=1 and cl_{i-}=0. In summary, the more alternative A_i is closer to ideal solution, the more the value of cl_{i+} is closer to the unit.

8. Ranking alternatives based on descending order of cl_{i+}: This amount is fluctuating between 0 and 1. Thus, cl_{i+} = 1 represents the highest rank and cl_{i+} = 0 represents the lowest rank.

RESEARCH FINDINGS

The results of the TOPSIS method used to find out the most suitable area for artificial recharge of groundwater aquifers of SHAHROUD-BASTAM watershed are shown in Tables 1 to 8. Therefore, a matrix is formed with rank (49) for data matrix, with 7 alternatives (height zones) and 7 related indicators (rainfall, stream density, habitual density, extent, land area facies, slope, and height) (Table 1).

Problem solving matrixes in TOPSIS method

The different problem solving matrixes used in the TOPSIS method are shown in Tables 1 to 8.

DISCUSSION AND CONCLUSION

In recent decades, researchers have used Multi Criteria Decision Making in complex and complicated decisions (Hekmat and Mousavi, 2007: 29). In these models, several criteria are used to measure instead of a desirable criterion (Taherkhani, 2008: 62). Nowadays, prioritizing and selecting appropriate substitutions out of different elements and deciding about them is significant in environmental planning and management. In other words, it is necessary to use suitable methods which are combined with different indicators in order to achieve better results and to do the best job for environmental planning and management (Shakoeei, 1999: 43).

In previous decades, decision making in water management problems and selection of better option among suggested options to solve watershed problems was only done based on economical criterion - profit in relation to cost - and on changing social and environmental criteria into the economical criterion. However, today, while using Multi criteria decision making, it is not necessary to use financial equivalent of social and environmental criteria to select the best option. In fact, various qualitative and quantitative criteria can be used to prioritize and select the best options for water resources management.

Nowadays, because of uncontrolled exploitation of ground water, the rate of water shortage has doubled. Accurate control and management of these water resources can alleviate the problem of drought inherently. One of the management techniques of ground water resources is artificial recharge of basins and determination of the most appropriate place for it. The ground water resources are the largest and most important reservoirs of fresh water on earth for human beings after glaciers and glacial zones (Freeze, 1979). Since these resources are 99% of the entire available fresh water, it is necessary to determine and exploit the ground water (Kouthar, 1986: 19), though 80% of these

Table 1. Decision matrix (X).

Regions	Materials	Precipitation	Stream density	Slope	Habitual density	Elevation	Area
1	1	115.74	51.27	2.37	3399.55	1013	2048.31
2	5	131.18	48.24	7.86	4512.28	1261.5	2279.65
3	9	145.65	45.43	19.58	3867.19	1496	1566.8
4	7	163.36	54.33	25.54	2489.93	1779.5	952.43
5	5	186.67	54.39	38.62	1989.5	2154	442
6	3	217.05	45.07	45.65	1316.31	2647	300.45
7	1	263.5	25.55	62.1	869.02	3405	147.52

Table 2. Dimensionless matrix (Matrix R).

Regions	Materials	Precipitation	Stream density	Slope	Habitual density	Elevation	Area
1	0.0724	0.2887	0.4188	0.0344	0.4435	0.2284	0.5672
2	0.3618	0.3272	0.3941	0.1142	0.5886	0.2844	0.6313
3	0.6512	0.3633	0.3711	0.2844	0.5045	0.3373	0.4339
4	0.5065	0.4075	0.4438	0.3709	0.3248	0.4012	0.2637
5	0.3618	0.4656	0.4443	0.5609	0.2595	0.4856	0.1224
6	0.2171	0.5414	0.3682	0.6630	0.1717	0.5968	0.0832
7	0.0724	0.6573	0.2087	0.9019	0.1134	0.7677	0.0409

Table 3. Paired comparison matrix of different criteria (S).

Criteria	Materials	Precipitation	Stream density	Slope	Habitual density	Elevation	Area	Weight vector
Materials	1	3	5	5	7	7	9	0/3868
Precipitation	0.33	1	3	5	5	7	7	0/2349
Stream density	0.2	0.33	1	3	5	7	7	0/1585
Slope	0.2	0.2	0.33	1	3	5	7	0/1028
Habitual density	0.14	0.2	0.2	0.33	1	3	5	0/0603
Elevation	0.14	0.14	0.14	0.2	0.33	1	3	0/0353
Area	0.11	0.14	0.14	0.14	0.2	0.33	1	0/0214

Inconsistency rate: 0/0252 (due to being less than 0/1 compatibility matrix indices are acceptable).

Table 4. Weighted dimensionless decision matrix (V).

Regions	Materials	Precipitation	Stream density	Slope	Habitual density	Elevation	Area
1	0.0279	0.0678	0.0663	0.0035	0.0268	0.0081	0.0122
2	0.1397	0.0769	0.0624	0.0117	0.0356	0.0101	0.0136
3	0.2515	0.0853	0.0588	0.0292	0.0305	0.0120	0.0093
4	0.1956	0.0957	0.0703	0.0381	0.0197	0.0143	0.0057
5	0.1397	0.1094	0.0704	0.0577	0.0157	0.0173	0.0026
6	0.0838	0.1272	0.0583	0.0682	0.0104	0.0212	0.0018
7	0.0279	0.1544	0.0331	0.0927	0.0069	0.0273	0.0009

resources are used in arid and semi-arid areas in most countries (Sedaghat, 2009). Due to Iran‟s situation in desert and semi-desert areas, and its average annual rainfall which amount to about 250 mm, various ways to prepare fresh water for agriculture, drinking and industry in different parts of country were formulated a long time ago. Therefore, determination and zoning of the most appropriate area for artificial recharge of underground

Table 5. Amounts of positive and negative ideals (highest and lowest function of indicator).

Ideals	Materials	Precipitation	Stream density	Slope	Habitual density	Elevation	Area
A+	0/ 2515	0/ 1544	0/ 070	0/ 0035	0/ 00356	/00273	0/ 0136
A-	0/ 0279	0/ 0678	0/ 0331	0/ 0927	0/ 0069	0/ 0081	0/ 0009

Table 6**.** Distance o i-alternative by ideals using Euclidean method.

Distance	Regions						
	1	2	3	4	5	6	**7**
D_i^+	0/ 240	0/ 137	0/ 076	0/ 090	0/ 134	0/ 184	0/ 245
D_i^-	0/ 0979	0/ 144	0/ 235	0/ 183	0/ 130	0/ 089	0/ 088

Table 7. Relative distance of i-alternative (A_I) to ideal solution.

Cl_i	C1	C2	C3	C4	C5	C6	C7
Amount	0/ 289	0/ 512	0/ 755	0/ 668	0/ 492	0/ 327	0/ 265

Table 8. Points and ranks of zones.

Region	1	2	3	4	5	6	7
Point (Fuzzy Logic)	0/ 289	0/ 512	0/ 755	0/ 668	0/ 492	0/ 327	0/ 265
Rank	Sixth	Third	First	Second	Fourth	Fifth	Seventh

aquifers should be considered in this plain.

In recent years, the rate of water exploitation has become greater for many reasons such as population growth, industrial development, urbanization growth and consequently increased demand for food products. Hence the rate of exploitation and consumption of ground water has become greater than recharging them; in other words, input of ground water system is less than its output, though the system with negative balance sheet has positive feedback and is collapsing. Thus it is very significant to determine and assign the suitable position for this case.

Water resources management is a set of various management activities aimed at the optimum utilization of water resources and reduction of economical, social and environmental damages and losses. Decision making issue in water resources management is very complex and complicated because of several decision indicators and criteria. Achieving a determined purpose, there are lots of solutions with different priorities for various issues such as environmental, social, organizational and political problems. These necessities lead to the use of multiple criteria decision making aimed at selection of the best solution among different solutions.

This study aimed at ranking the water resources potential in SHAHROUD-BASTAM watershed by TOPSIS method. TOPSIS algorithm is a Multi Criteria Decision Making model which combines quantitative and qualitative indicators, weighs each indicator in relation to its importance and helps decision makers to select the best alternative. In this method, all options are analyzed and evaluated by non-ranked comparisons. However, the complete stages of this method are based on coordinated and uncoordinated sets and thus it is called “coordination analysis”. The results and findings of different studies show that in TOPSIS method, zone 3 with (0/755) point comes first among the 7 studied zones and thus it is the most appropriate zone to establish the proper damp. In contrast, zone 7 with (0/265) point comes last after zones 4, 2, 5, 6 and 1 with (0/668), (0/512), (0/492), (0/327) and (0/289) points respectively and so it is not suitable for establishing damp.

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