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New Formulation of Fuzzy Comprehensive Evaluation Model in Groundwater Resources Carrying Capacity Analysis

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Authors
Bahar Gogani M.[1] *MSc*,
Douzbakhshan M. * *MSc*,
Shayesteh K.[2] *PhD*,
Ildoromi A. R.[3] *PhD*

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*Department of Environmental Sciences, Faculty of Natural Resources and Environment, Malayer University, Malayer, Iran
[1]Department of Electrical Engineering, Faculty of Electrical and Electronics Engineering, Shahid Beheshti University, Tehran, Iran
[2]Department of Environmental Sciences, Faculty of Natural Resources and Environment, Malayer University, Malayer, Iran
[3]Department of Rangelands & Watershed Management, Faculty of Natural Resources and Environment, Malayer University, Malayer, Iran

Correspondence
Address: Department of Environmental Sciences, Malayer University, Malayer, Iran
Phone: -
Fax: -
mdouzbakhshan@yahoo.com

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ABSTRACT

Aims Groundwater, especially in comparison with surface water, is one of the most critical sources of water supplies in different parts of the world. Due to the increasing demand in various parts of agriculture, household, industry, etc., and also decreasing groundwater level in recent years in Hamadan province, it is necessary to estimate the carrying capacity of groundwater resources.

Materials & Methods In this article, seven factors, having greater impacts on the carrying capacity of the region, were selected based on experts' views during the 2001–2011 period. Furthermore, fuzzy comprehensive evaluation method using different membership functions (MF) was used to estimate the carrying capacity of groundwater resources.

Findings By considering different numbers of MF, the results of this study pointed out that groundwater carrying capacity decreased throughout the 2001–2011 period. Moreover, by considering the rate of decline of water level, it is obvious that by the use of five member functions in comparison with other methods, the reduction level of groundwater resources is better observed. Hence, the process of recognition of reduction groundwater resources carrying capacity in Hamadan Province can be immediately done.

Conclusion As a consequence, governments can make some proper and quick decisions and effective strategies to compensate the reduction and save implementation cost and time.

Keywords Carrying Capacity; Fuzzy Logic; Groundwater Resources; Hamadan Province

CITATION LINKS

[1] Water and energy cycles [2] The analysis of water resource ecological carrying capacity of Hainan International Island [3] Assessment of water resources carrying capacity for sustainable development based on a system dynamics model: A case study of tieling city, China [4] High demand in a land of water scarcity: Iran [5] Status report on the application of integrated approaches to water resources management [6] Water and the green economy: Capacity development aspects [7] Effect of drought on qualitative and quantitative parameters of Zahedan plain Aquifer [8] Vulnerability assessment of malayer plain groundwater by Sintacs, Drastic And SI Models [9] Simulation of malayer plain groundwater level based on weather data using artificial neural network [10] Optimal utilization of the Chahnimeh Water reservoirs in Sistan region of Iran using goal programming method [11] Measurement and assessment of water resources carrying capacity in Henan Province, China [12] Study on the assessment of water resources carrying capacity in strategic environmental assessment [13] Evaluation of water resources carrying capacity based on fuzzy comprehensive evaluation on river basin in Arid Zone [14] Studies on carrying capacity of water resources in Beijing, Tianjin, and Hebei. In: Report on development of Beijing, Tianjin, and Hebei province [15] Studies on carrying capacity of water resources in Beijing and Tianjin: Based on the water footprint [16] Assessment of water resources carrying capacity in Tianjin city Of China [17] Fuzzy comprehensive evaluation model for water resources carrying capacity in Tarim river basin, Xinjiang, China [18] Comprehensive evaluation of the water resource carrying capacity for China [19] The study of three evaluation models of water resources carrying capacity in Manas River Basin [20] Investigating the changes of seasonal rainfall pattern in Hamedan Province [21] Temporal and spatial study of water use efficiency of strategic crops in regional scale (Case study: Hamadan Province) [22] The feasibility study of pressurized irrigation systems performance based on water quality (Case study: Hamadan Province Plains) [23] Office of Studies and Planning Hamadan Regional Water Company [24] A new approach to water resources system assessment- set pair analysis method [25] Fuzzy comprehensive evaluation for carrying capacity of regional water resources [26] Surface runoff processes and sustainable utilization of water resources in Manas River Basin, Xinjiang, China

Introduction

Water is one of the most important resources for the survival of human and all other organisms.[1] It plays an important role in maintaining the ecological environment and ecosystems and manufacturing the processes in economic and social area.[2, 3] Water demand in different regions, particularly in arid and semi-arid areas, is considered as an important subject, and water issues and related problems have been studied at different levels in the past, present, and also in future. Water shortage could threaten food security, safety, and sustainable development.[4] Increased water demand has led to an increased need to manage water resources.[5] Water demand management is defined as a set of technology, politics, government, economy, education, and an increase in awareness, and communication tools. Water demand management seeks to determine how to exploit water supply correctly.[6]

Groundwater is a subsystem of water resources needed in several areas. It results from the penetration of atmospheric rainfall in cracks and crevices of rocks in the mountainous areas and the pores of land in alluvial plains. Groundwater, which is a part of the water cycle in nature, is accessible through wells, canals, and fountains and is one of the most important and crucial water resources in different areas.[7] It is of great importance because it is less polluted and possesses much storage capacity than surface water.[8] Furthermore, groundwater is later affected by climate change rainfall fluctuations.[9]

Groundwater is more important in arid and semi-arid areas[4] because of the irregular distribution of rainfall in time and space in different regions of the country.[10]

Carrying capacity of water resources is an important component of natural resources carrying capacity in the process of sustainable development in a country or region.[11] When estimating the carrying capacity of water resources, in addition to the relationship between demand and supply of water, the population stability and social and economic development should be studied.[12, 13]

There are three general theories about the carrying capacity of water resources:

1. The theory of water resources development scale: This theory suggests that the impure water resources to which it is assigned[14, 15] determine the level of socioeconomic development and the environment.
2. Theory of maximum population that water resources can withstand: This theory refers to the maximum population at a particular stage, as well as the conditions for regional sustainable development that can exploit water resources in the region.[14]
3. Theory of carrying capacity of water resources in the socioeconomic context of sustainable development: The theory poses carrying capacity of water resources in accordance with socioeconomic development and also environmental protection of the region.[14]

The researchers use a series of concepts based on the carrying capacity of water resources, of which some of them are at the acceptable level of water exploitation, ecological limits of water resources, and the limits of natural systems of water resources.[16] The carrying capacity of water resources is a new concept and does not provide a clear definition of it, but some of the definitions of carrying capacity of water resources are as follows:

The maximum capacity of population growth and socioeconomic development at a particular stage of development,[14] a supporting capacity of human activities, and a given standard of living in an optimal ecological system.

Various studies have been conducted on water resources carrying capacity in different regions. Meng *et al*.[17] calculated the water resources carrying capacity for the Tarim River basin using fuzzy comprehensive evaluation method. The results showed high amounts of utilization and the necessity of robust management in this field.

Liu *et al*.[18] discussed that an inappropriate distribution of water in China is a serious limitation for socioeconomic development and there are direct relationships between socioeconomic development, ecological environment, and water resources. In this research, comprehensive evaluation model was used for calculating water resources carrying capacity. The results showed that water resources distribution is not in line with population distribution and socioeconomic development. Southwestern provinces of China have a high carrying capacity. The Yangtze River basin, the Pearl River basin, and northern and northwestern plains of China have appropriate water carrying capacity, but Xinjiang and Ningxia Hui regions, as well as Gansu Province, suffer from severe shortage of water resources.

In defining the concept of water resources carrying capacity, Song *et al.*,[16] the size of the population and economic scale were defined as two major indices. They used the method of related resources carrying capacity model. The results showed that Tianjin water resources are being heavily utilized and there is a considerable difference between the water resources carrying capacity of Tianjin and the mean of China.

Wang *et al.*,[13] in their study, used fuzzy comprehensive evaluation model for calculating the water resources carrying capacity of the Manasi River basin. The results of their study showed that water reservation technology and the progress of industries' reconstruction will improve water resources carrying capacity within the next 20 years. It also introduced spatial and temporal distribution of water resources as a limiting factor for socioeconomic development and ecological environment conditions.

Yang *et al*.[19] considered calculating the carrying capacity of water resources at Manas River Basin as a very important task, due to lack of water resources. The different factors under the system of water resources, such as social, economic, and ecological, were estimated using fuzzy comprehensive evaluation model, matter-element model, and track projects carrying capacity model. The results showed that the carrying capacity of water resources in this area by 2000 would be at V1 (poor state), 2010 at V2 (average state), and 2020 at V3 (better state). In general, the carrying capacity of water resources is in perfect condition.

Materials and Methods

Study area

Hamadan Province is one of the mountainous areas in the West of Iran[20] and is located at the geographical coordinates of 34°46'N 34°46'N and 35°N and 47°48' and 49°28'E [Figure 1]. Hamadan area is 19491 km^2, which is 1.2% of the total area of the whole country.[21]

Hamadan Province with an average annual rainfall of 330 mm and annual temperatures of 12°C is located in a semi-arid and cool climate[21] (Hamadan province has three main drainage basins and eight main rivers). In recent years, according to available information, the portion of groundwater in total renewable waters is 2075 million cubic meters, while the uptake of groundwater resources is 2390.73 million cubic meters. It represents a deficit of 231 million cubic meters of the container in the province.[22] Most of the water requirements in Hamadan Province are supplied from groundwater reservoirs. In recent times, because of rising temperatures and reducing rainfalls, changing consumption patterns and also increasing the uptake of groundwater have led to the reduction of groundwater resources availability in Hamadan Province.[23]

Methodology

In this study, to investigate the groundwater resources carrying capacity, Fuzzy Comprehensive Evaluation Model is used.

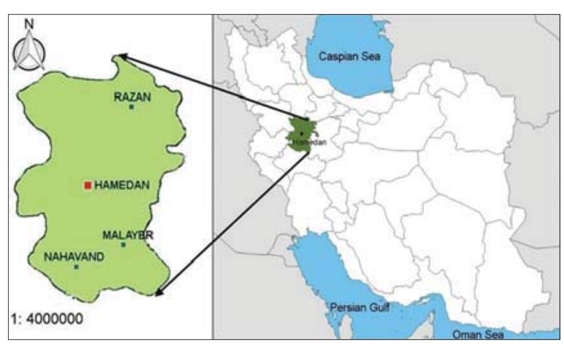

Figure 1: Geographical position of Hamadan Province

In this model, two groups of factors (U and V) are defined. U indicates factors of the comprehensive evaluation and V expresses levels of divisions of the factors. The carrying capacity of groundwater resources is affected by many factors. In this study, according to the study area, seven main ones are selected:

Groundwater supply coefficient (U_1: The ratio of total amount of groundwater supply to land area), Groundwater demand coefficient (U_2: The ratio of total amount of groundwater demand to land area), Plantation irrigation rate using groundwater[18] (U_3: The ratio of irrigation area of groundwater to plantation area).[24] Industrial groundwater consumption quota (U_4: The ratio of industrial groundwater consumption to gross industrial output value).[18] Portion of agricultural groundwater consumption (U_5: The ratio of agricultural groundwater consumption to gross agricultural output value).[18] Groundwater exploitation rate (U_6: The ratio of total amount groundwater supply to total amount groundwater demand)[24] and Groundwater quality (U_7: Temperature, total hardness, total dissolved solids, electrical conductivity, and pH).

Furthermore, according to Table 1, the groundwater quality parameters are classified into three levels due to experts` opinions.

In the present study, membership functions (MF) from 1 to 7 factors in three methods are considered using different fuzzy sets to reach the best analysis.

Definitions of levels

In this section, definitions of levels are expressed to consider the MF in all methods.

Table 1: Classification of parameters of groundwater quality

Parameter	Class 1	Class 2	Class 3
pH	1–3	3–6	6–9
EC (μS/cm)	2000–1500	1500–400	400–0
TDS (mg/L)	2000–1500	1500–500	500–0

TDS: Total dissolved solids, EC: Electrical conductivity

Each level of classification was awarded a score between 0 and 1 in this scoring; the higher degree shows, the higher potential exploitation of groundwater resources.[17, 25] In the following, MF in three methods is described.

Method 1:

V1 in all methods V2 in Method 3	Represents lack of groundwater resources. It indicates that further exploitation of groundwater has led to a shortage of groundwater
V3 in Method 1 V4 in Method 2 V4, V5 in Method 3	Demonstrates the good potential of groundwater resources and guarantees groundwater demand for regional development
V2 in Method 1 V3 in Method 3	Represents a moderate position and show a balanced supply and demand of water resources
V2, V3 in Method 2	Represents position between two other levels

According to Table 2, in this method, three MF in the fuzzy set to describe evaluation factors are used. It must be noted that this classification is based on experts' advice.

To obtain crisp value in the output of fuzzy set, defuzzification is used. In this study, by the use of points definitions for the output of fuzzy set listed in Table 2, the crisp value was achieved. Meanwhile, to calculate the MF of factors, the following Equations 1-12 are used.[17]

Table 2: Ranking of evaluation factors indices

Evaluation factors	v1	v2	v3
U1	140>	90–140	>90
U2	140>	90–140	>90
U3	50>	15–50	>15
U4	10>	15–10	>15
U5	100>	200–100	>200
U6	75>	50–75	>50
U7	4>	7–4	>7
Score	0.05	0.5	0.95

$$\mu_{v1}(u_i)\begin{cases} 0.5\left(1+\dfrac{u_i-k_1}{u_i-k_2}\right) & u_i \le k_1 \\ 0.5\left(1-\dfrac{k_1-u_i}{k_1-k_2}\right) & k_2 \ge u_i > k_1 \\ 0 & u_i > k_2 \end{cases} \quad (1)$$

$$\mu_{v2}(u_i)\begin{cases} 0.5\left(1-\dfrac{u_i-k_1}{u_i-k_2}\right) & u_i \le k_1 \\ 0.5\left(1+\dfrac{k_1-u_i}{k_1-k_2}\right) & k_2 \ge u_i > k_1 \\ 0.5(1+\dfrac{u_i-k_3}{k_2-k_3}) & k_3 \ge u_i > k_2 \\ 0.5\left(1-\dfrac{k_3-u_i}{k_2-u_i}\right) & u_i \ge k_3 \end{cases} \quad (2)$$

$$\mu_{v3}(u_i)\begin{cases} 0 u_i > k_2 \\ 0.5\left(1-\dfrac{u_i-k_3}{k_2-k_3}\right) & k_3 \ge u_i > k_2 \\ 0.5\left(1+\dfrac{k_3-u_i}{k_2-k_i}\right) & u_i \ge k_3 \end{cases} \quad (3)$$

Method 2:

In this method according to Table 3, four MF in the fuzzy set are used to describe the level of factors.

In addition, the following formula was used to calculate the MF of factors: [26]

$$\mu_{v1}(u_i)\begin{cases} 0.5\left(1+\dfrac{u_i-k_1}{u_i-k_2}\right) & u_i \le k_1 \\ 0.5\left(1-\dfrac{k_1-u_i}{k_1-k_2}\right) & k_2 \ge u_i > k_1 \\ 0 & u_i > k_2 \end{cases} \quad (4)$$

$$\mu_{v2}(u_i)\begin{cases} 0.5\left(1-\dfrac{u_i-k_1}{u_i-k_2}\right) & u_i \le k_1 \\ 0.5\left(1+\dfrac{k_1-u_i}{k_1-k_2}\right) & k_2 \ge u_i > k_1 \\ 0.5\left(1+\dfrac{u_i-k_3}{k_2-k_3}\right) & k_3 \ge u_i > k_2 \\ 0.5\left(1-\dfrac{k_3-u_i}{k_3-k_4}\right) & k_4 \ge u_i > k_3 \\ 0 & u_i \ge k_4 \end{cases} \quad (5)$$

$$\mu_{v3}(u_i)\begin{cases} 0 & u_i < k_2 \\ 0.5\left(1-\dfrac{u_i-k_3}{k_2-k_3}\right) & k_3 \ge u_i > k_2 \\ 0.5\left(1+\dfrac{k_3-u_i}{k_3-k_4}\right) & k_4 \ge u_i > k_3 \\ 0.5\left(1+\dfrac{u_i-k_5}{k_4-k_5}\right) & k_5 \ge u_i > k_4 \\ 0.5\left(1-\dfrac{k_5-u_i}{k_4-u_i}\right) & u_i \ge k_5 \end{cases} \quad (6)$$

$$\mu_{v4}(u_i)\begin{cases} 0 u_i < k_4 \\ 0.5\left(1-\dfrac{u_i-k_5}{k_4-k_5}\right) & k_5 \ge u_i > k_4 \\ 0.5\left(1+\dfrac{k_5-u_i}{k_4-u_i}\right) & u_i \ge k_5 \end{cases} \quad (7)$$

Method 3:

In this method according to Table 4, five MF in the fuzzy set were used to describe the level of factors.

Furthermore, the following formula was used to calculate the MF of factors in this method:

$$\mu_{v1}(u_i)\begin{cases} 0.5\left(1+\dfrac{u_i-k_1}{u_i-k_2}\right) & u_i \le k_1 \\ 0.5\left(1-\dfrac{k_1-u_i}{k_1-k_2}\right) & k_2 \ge u_i > k_1 \\ 0.5\left(1+\dfrac{u_i-k_3}{k_2-k_3}\right) & k_3 \ge u_i > k_2 \\ 0.5\left(1-\dfrac{k_3-u_i}{k_3-k_4}\right) & k_4 \ge u_i > k_3 \\ 0 & u_i \ge k_4 \end{cases} \quad (8)$$

$$\mu_{v2}(u_i)\begin{cases} 0.5\left(1-\dfrac{u_i-k_1}{u_i-k_2}\right) & u_i \le k_1 \\ 0.5\left(1+\dfrac{k_1-u_i}{k_1-k_2}\right) & k_2 \ge u_i > k_1 \\ 0.5\left(1-\dfrac{u_i-k_3}{k_2-k_3}\right) & k_3 \ge u_i > k_2 \\ 0.5\left(1+\dfrac{k_3-u_i}{k_3-k_4}\right) & k_4 \ge u_i > k_3 \\ 0.5\left(1+\dfrac{u_i-k_5}{k_4-k_5}\right) & k_5 > u_i > k_4 \\ 0.5\left(1-\dfrac{k_5-u_i}{k_4-u_i}\right) & u_i \ge k_5 \end{cases} \quad (9)$$

$$\mu_{v3}(u_i)\begin{cases} 0 & u_i < k_2 \\ 0.5\left(1+\dfrac{u_i-k_3}{k_2-k_3}\right) & k_3 \ge u_i > k_2 \\ 0.5\left(1-\dfrac{k_3-u_i}{k_3-k_4}\right) & k_4 \ge u_i > k_3 \\ 0.5\left(1-\dfrac{u_i-k_5}{k_4-k_5}\right) & k_5 \ge u_i > k_4 \\ 0.5\left(1+\dfrac{k_5-u_i}{k_5-k_6}\right) & k_6 \ge u_i > k_5 \\ 0 & u_i \ge k_6 \end{cases} \quad (10)$$

$$\mu_{v4}(u_i)\begin{cases} 0.5\left(1-\dfrac{u_i-k_3}{u_i-k_4}\right) & u_i \le k_3 \\ 0.5\left(1+\dfrac{k_3-u_i}{k_3-k_4}\right) & k_4 \ge u_i > k_3 \\ 0.5\left(1+\dfrac{u_i-k_5}{k_4-k_5}\right) & k_5 \ge u_i > k_4 \\ 0.5\left(1-\dfrac{k_5-u_i}{k_5-k_6}\right) & k_6 \ge u_i > k_5 \\ 0.5\left(1+\dfrac{u_i-k_7}{k_6-k_7}\right) & k_7 > u_i > k_6 \\ 0.5\left(1-\dfrac{k_7-u_i}{k_6-u_i}\right) & u_i \ge k_7 \end{cases} \quad (11)$$

$$_5(\ _i)\begin{cases} 0 & u_i \le k_4 \\ 0.5\left(1-\dfrac{u_i \quad k_5}{k_4 \quad k_5}\right) & k_5 \ge u_i > k_4 \\ 0.5\left(1+\dfrac{k_5 \quad u_i}{k_5 \quad k_6}\right) & k_6 \ge u_i > k_5 \\ 0.5\left(1-\dfrac{u_i \quad k_7}{k_6 \quad k_7}\right) & k_7 \ge u_i > k_6 \\ 0.5\left(1+\dfrac{k_7 \quad u_i}{k_6 \quad u_i}\right) & u_i \ge k_7 \end{cases} \quad (12)$$

Furthermore, in all these three methods, to calculate the MF of factors U1, U2, U3, and U6, it is necessary to change ≤ to ≥ and <to> in mentioned equations. It is obvious that there are lots of factors each of which has a different influence on underwater resources carrying capacity analysis. Hence, to considering the priority of each factor, analytic hierarchy process (AHP) weights method along with multiplying R matrix are applied on every factor.[17] Moreover, MATLAB software is used to analyze the fuzzy system, and by coding in M-file, the results are achieved.

Findings

With regard, the location and climate characteristics of Hamadan province, the carrying capacity of underwater resources in years 2001, 2006, and 2011 are evaluated, and the results of the evaluation are shown in Table 5:

By considering AHP Method, the weights are considered for each factor. Furthermore, incompatibility rate graph of factors weights is equal to 0.5 (Figure 2).

Using the coding in Matlab software, the degrees of membership of every factor, every surface, and groundwater resources carrying capacity in the Hamadan province are estimated (Tables 6-8).

Furthermore, the summary of results in the mentioned tables is presented in Table 9.

According to Figure 3, using three, four, and five MF, the carrying capacity of groundwater resources in Hamadan province during the years 2001–2011 gradually reduced. It must be noted that this figure is drawn from Table 10.

We can also propose a criterion to determine the rate of decline of water level to analyze the difference between given fuzzy systems using different MF. The rate of decline of water level = −slop of each plots (mentioned method) in Figure 3 during 10 years.

In addition to the standard rate of decline, the following criterion has also been used to compare three conditions in the fuzzy system. The results of this criterion are shown in Table 11.

The greatest difference (GF) = Absolute (Maximum value of membership degrees in each MF - Minimum value of membership degrees in each MF). For example, in three MF method, the calculated GF during 10 years is given as follows (according to Table 9): →GF= 0.6763-0.4628=0.2135. According to Table 4, the points awarded to the evaluation factors in AHP method showed that the factor of groundwater quality in Hamadan province is the most important and the factor of groundwater demand ratio is less important than the others.

Discussion

According to the results in MATLAB software, in each three cases (using the different number of MF), the reduction in the carrying capacity of groundwater resources in Hamadan province during 2001–2011 is an indication of lack of compliance with the balance of supply and demand. Furthermore,

Table 3: Ranking of evaluation factors indices

Evaluation factors	v_1	v_2	v_3	V_4
U_1	140>	115–140	115–90	>90
U_2	140>	115–140	115–90	>90
U_3	50>	32.5–50	32.5–15	>15
U_4	10>	12.5–10	12.5–15	>15
U_5	100>	150–100	150–200	>200
U_6	75>	62.5–75	62.5–50	>50
U_7	4>	5.5–4	5.5–7	>7
Score	0.05	0.33	0.66	0.95

Table 4: Ranking of evaluation factors indices

Evaluation factors	V_1	V_2	V_3	V_4	V_5
U_1	140>	123.33–140	123.33–106.66	106.66–90	>90
U_2	140>	123.33–140	123.33–106.66	106.66–90	>90
U_3	50>	38.33–50	38.33–26.66	26.66–15	>15
U_4	10>	11.66–10	11.66–13.33	13.33–15	>15
U_5	100>	133.33–100	133.33–166.66	166.66–200	>200
U_6	75>	66.66–75	66.66–58.33	58.33–50	>50
U_7	4>	5–4	5–6	6–7	>7
Score	0.05	0.25	0.5	0.75	0.95

Table 5: Status of evaluation factors and the weight of factors

Evaluation factors	Unit	Weight	Year		
			2001	2006	2011
U_1	10^3 m^3 km^{-2}	0.154	80.39	82.7435	77.9148
U_2	10^3 m^3 km^{-2}	0.11	91.89	94.2387	95.998
U_3	%	0.131	42.74	44.91	51.57
U_4	m^3 10^{-6} IRR	0.153	16.228	10.413	2.088
U_5	m^3 10^{-6} IRR	0.121	465.7069	103.4987	59.065
U_6	%	0.121	86.6683	86.3539	79.0007
U_{17}	-	0.21	8	8	7

Table 6: Comprehensive evaluation results of groundwater resources carrying capacity of Hamadan Province

Groundwater resources carrying capacity (Hamadan Province)	Year	V_1	V_2	V_3	Total Score
	2001	0.1581	0.2921	0.5498	0.6763
	2006	0.2863	0.3878	0.3259	0.5178
	2011	0.4129	0.2569	0.3302	0.4628

Table 7: Comprehensive evaluation results of groundwater resources carrying capacity of Hamadan Province

Groundwater resources carrying capacity (Hamadan Province)	Year	V_1	V_2	V_3	V_4	Total Score
	2001	0.1127	0.1393	0.1926	0.5554	0.7064
	2006	0.2318	0.2942	0.1674	0.3066	0.5104
	2011	0.4066	0.1194	0.2255	0.2485	0.4446

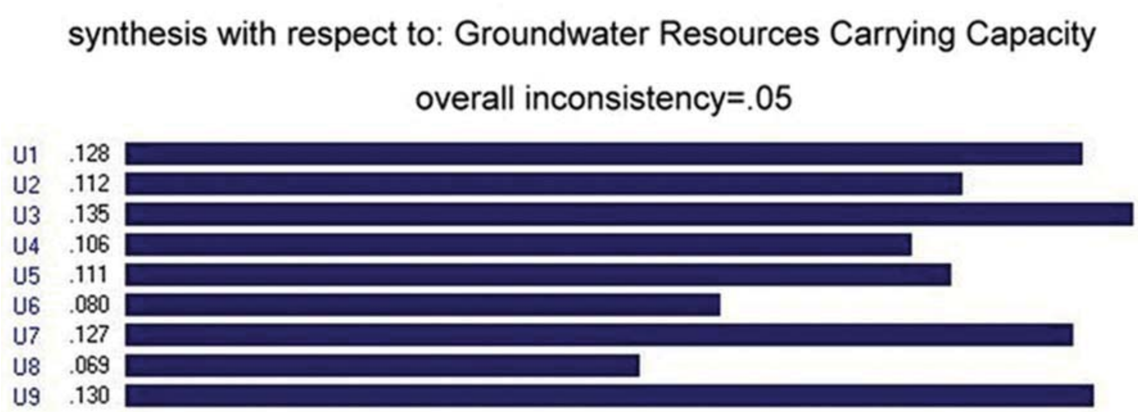

Figure 2: The weight of groundwater resources carrying capacity factors in Hamadan Province (output of Expert Choice software)

it shows that demand in comparison with supply in 2011 increases.

The results of this study show that whatever the number of MF increases, the reduction in the amount of carrying capacity of groundwater resources in different years is explained better than before and as a result, the best analysis can be reached. It is

Table 8: Comprehensive evaluation results of groundwater resources carrying capacity of Hamadan Province

Groundwater resources carrying capacity (Hamadan Province)	Year	V_1	V_2	V_3	V_4	V_5	Total Score
	2001	0.2214	0.1097	0.115	0.2152	0.5799	0.8083
	2006	0.2009	0.3881	0	0.2521	0.3149	0.5953
	2011	0.4252	0.1772	0	0.2818	0.243	0.5077

Table 9: The final results of groundwater resources carrying capacity (Hamadan Province) in three, four, and five membership functions

Final results	Number of MF	Year		
		2001	2006	2011
	Three	0.6763	0.5178	0.4628
	Four	0.7064	0.5104	0.4446
	Five	0.8083	0.5953	0.5077

Table 10: Degrees of reduction of membership of groundwater resources carrying capacity

	Three membership functions	Four membership functions	Five membership functions
Rate of decline	−0.1068	−0.1309	−0.1503

Table 11: The greatest difference between the changes in degrees in each membership functions

	Three membership functions	Four membership functions	Five membership functions
GF	0.2135	0.2618	0.3006

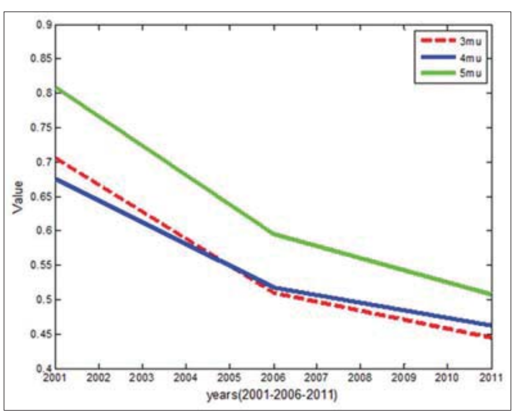

Figure 3: Hamadan province carrying capacity of groundwater resources (output of MATLAB software)

obvious that as the number of MF increase (that is clear in the formula with five MF), the complexity of fuzzy system calculation increases as well. For this purpose, we should establish a tradeoff between computational complexities and improved responsiveness. Considering this issue and the fact that the results of the carrying capacity of groundwater in three and four MF are similar and moreover the certain improvement in results was not obtained in these two methods (Figure 3), therefore to solve this drawback, we increased the number of MF to five. In other words, according to Figure 3, improved performance of the fuzzy system as compared with other states is obtained by taking five MF. Furthermore, by considering the results presented in Table 9 showing the rate of decline in the number of different MF, it is obvious that by the use of five MF the reduction level of groundwater resources is better shown than the other. In conclusion, rapid detection of the reduction can help the experts to present proper and quick strategies to compensate the reduction, and save implementation cost and time.

Conclusion

In addition, based on results of the study, Hamadan province will face a future reduction in groundwater resources. Since large water demand in the province is supplied by groundwater and due to a reduction in carrying capacity of groundwater resources, providing water resources need in the various sectors, such as agriculture, home, and industries will be a vital issue in the recent future.

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Ethical Permissions

None declared by authors.

Conflict of Interests

The authors state that there is no conflict of interests.

Authors’ Contributions

Each of the author contributed to the development of the paper.

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