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A Quantitative Strategic Planning Framework for Artificial Groundwater Recharge in Iran Based on Fuzzy AHP

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Abstract

This article studies the Artificial Groundwater Recharge (AGR) of the Esfarayen aquifer, in Iran, from the perspective of the strategic planning process. For this purpose, a SWOT systematic analysis was performed for the AGR of this aquifer, and its strengths, weaknesses, opportunities, and threats (SWOT) were identified. These factors were analyzed and ranked using Mikhailov's fuzzy analytic hierarchy process (AHP) and based on this analysis, prior strategies were proposed. The results showed that the share of two groups of threats and opportunities in higher priority factors was more than the two groups of strengths and weaknesses, so that the shares of threats and opportunities in the first half of the list of factors were 87.5% and 70% of the factors of these groups, respectively. In addition, strengths have been ranked higher than weaknesses. Therefore, in selecting appropriate strategies for the future of the AGR of Esfarayen aquifer, priority should be given to ST type strategies; strategies that use the strengths of the system to try to eliminate external threats to the system. After ST type strategies, due to the high importance of opportunities, SO type strategies can also be adopted for the AGR of Esfarayen aquifer.

Keywords: Aquifer Rehabilitation and Balancing**,** Artificial Groundwater Recharge, Esfarayen Aquifer, Strategic Planning, SWOT-FAHP Hybrid Approach.

1. Introduction

Iran is located in an arid and semi-arid region and with annual rainfall, about one-third of the global average is not in a good position to receive atmospheric precipitation. The lack of surface water resources has caused water consumption in most parts of Iran to rely on groundwater (Alizadeh, 2015). Population growth and development of agriculture and industry in recent decades have caused increasing pressure on groundwater resources and declining aquifer levels so that out of 609 plains in the country, 405 plains are in a critical and prohibited status (Iran Water Resources Management Company, 2020). This issue has led to a plan to control the fall and deficit of reservoirs in aquifers. The plan is called the Groundwater Resources Rehabilitation and Balancing Plan (GRRBP). GRRBP consists of 15 projects that were approved by the Iran Supreme Water Council (ISWC) to control and correct the critical situation of groundwater resources. GRRBP projects include three groups (Iran Ministry of Energy, 2016).

One of the projects of GRRBP, which is part of the third category of projects (projects that directly lead to water storage in aquifers), is the artificial groundwater recharge (AGR). AGR means increasing the infiltration and natural movement of surface water in groundwater formations using various construction methods such as the construction of basins, furrows, ditches, or other facilities so that water penetrates the soil and recharges the aquifer (Bouwer, 2002). Due to the antiquity of using AGR, several studies have been done about it. Karim and Ali (2017) simulated and studied the effect of AGR wells in the city of

Karbala in southern Iraq using the GMS model. Sun et al. (2019) investigated the effect of Wanghe underground dam construction in China on groundwater flow rate and quality. Jarraya et al. (2020) studied the AGR by treated wastewater in Tunisia as a suitable technical solution for counteracting seawater intrusion. Thiyagarajan et al. (2020) investigated the effect of AGR on the Thondamuthur block in India. Karamouz et al. (2021) developed a simulation-based method using a hydrological and hydraulic model to evaluate the AGR in the Qorveh Dehgolan subbasin in Kurdistan Province of Iran. Kim et al. (2021) evaluated the impact of AGR in water-scarce areas of Shingok village, Hongsung-gun, South Korea.

The above-mentioned studies have used statistical methods or simulation models to measure the effect of AGR on groundwater levels. Moreover, some researchers utilized the Geographic Information System (GIS) or other techniques to determine the appropriate places for AGR in different regions of the world. Senthilkumar (2019) identified suitable AGR areas in Tamil Nadu, India, using GIS and RS. Sandoval et al. (2019) determined potential AGR sites in Mount Makiling Forest Reserve, Philippines, using GIS and AHP. Khan et al. (2020) selected suitable locations for the implementation of AGR in the Yamuna River basin in India, using GIS and AHP. Ahirwar et al. (2020) identified suitable AGR in the Upper Betwa watershed in India, applying GIS. Kadhem and Zubari (2020) identified the optimal locations for AGR in Bahrain, using GIS. Anand et al. (2021) used the GIS system in combination with the Analytic Hierarchy Process (AHP) to identify suitable locations for AGR. Rajasekhar et al. (2021) identified suitable areas for AGR using geospatial methods and Multi Criteria Decision Making (MCDM) in the semi-arid regions of southern India. Githinji et al. (2022) studied potential areas for AGR in arid areas of the Ewaso Ng'iro – Lagh Dera basin, Kenya, by integrating AHP and Fuzzy-AHP in ArcGIS.

Reviewing the above-mentioned articles, it seems that the main AGR studies in recent years have been quantitative research with the view of measuring its impact on groundwater levels or finding suitable places for it in different regions. However, researchers have paid less attention to addressing the AGR from a management and planning perspective. Therefore, from a planning perspective, the study of AGR as one of the aquifer balancing strategies can illuminate its future for managers and planners of water resources and be effective in their decisions. A short-term view of planning cannot meet this goal and determine the future perspective of this system, so strategic planning (SP) in this area seems necessary. One of the SP tools is the analysis of strengths, weaknesses, opportunities, and threats (SWOT) of the system in which internal factors (strengths and weaknesses) and external factors (opportunities and threats) affecting the future of the system are analyzed and considering these factors, the development strategies of that system are formulated (Kurttila et al. 2000).

Various researchers have considered the use of the SWOT technique for issues related to water resources management and planning and several studies have been conducted in this field. Praveena and Aris (2009) used SWOT analysis to manage the groundwater of 55 islands in different parts of the world. Kallioras et al. (2010) used the SWOT method to manage the groundwater resources of the coastal aquifer of northern Greece, which is usually exposed to seawater intrusion. Podimata and Yannopoulos (2013) analyzed all stakeholders involved in the management of the Alfeios River Basin in southern Greece using the SWOT method. Nagara et al. (2015) examined various solutions to water scarcity in many parts of Asia and Africa using the SWOT method. Rachid et al. (2021) investigated the risks of seawater intrusion into groundwater aquifers with natural and human stimuli in 26 coastal aquifers of the Eastern Mediterranean using the SWOT method.

Despite the ability of SWOT analysis in the study of the environment of organizations and systems and strategy adaptation for them, the main weakness of this technique is its qualitative aspect. In this technique, only several factors are expressed in the four SWOT groups, without specifying their relative importance. In other words, in this method, the value of all factors is considered the same; while some factors may have more priority than the others and therefore should have a greater share in the adoption of system strategies (Kurttila et al. 2000). To cover this weakness in the SWOT analysis method, some researchers have used quantitative SWOT analysis. For example, Chande and Mayo (2019) have used this method to study the protection and management of groundwater quality for urban aquifers in the Luzaka region of Zambia, also, Lazaridou et al. (2019) have studied irrigation water in the Nestos river basin in Greece in this way.

Researchers have also utilized MCDM approaches to ascertain the relative significance of SWOT elements and groupings. MCDM methods are used to choose an option from several options or to rank them based on some criteria. However, various researchers have used these methods to quantify SWOT analysis. AHP, for example, has been used in combination with the SWOT analysis, to assess the current institutional and political context of the government in the field of water in Bangladesh (Chan et al., 2016), to provide a solution for the water shortage in Yazd Province, Iran (Chitsaz and Azarnivand, 2017), to formulate a strategic plan to manage water resources for Dili Municipality in Timor-Leste (Takeleb et al., 2020), and to analyze sustainable management of Hornad River Basin in Slovakia (Bakalár et al., 2021). In addition to the AHP method, other MCDM methods such as analytic network process (ANP) have been used in combination with SWOT analysis in some research. Conduction of a new approach within the ANP-SWOT framework for prioritization of ecosystem management (Arsić et al., 2018), the use of SWOT-ANP analysis for perceptions regarding active management of the Cross-timbers forest resources of Oklahoma, Texas, and Kansas (Starr et al., 2019), using a SWOT-ANP Analysis for Small-Scale Forest Cooperative Management of the Grain for Green Program in Xinjiang, China (Zhang & Paudel, 2021), are some of these studies.

Although using MCDM methods in SWOT analysis was a significant step toward addressing the fundamental weakness in this approach, the use of fuzzy MCDM methods creates more realistic conditions and more appropriately models the uncertainty and explicitness in expert opinions due to the use of expert opinions to rank factors and the uncertainty of the verbal expressions used by them. The quantification of SWOT analysis using fuzzy AHP has been used in some studies. Srinivas (2018) used hybridized SWOT-Fuzzy AHP for sustainable management of a river basin, Farzi and Mehrabadi (2019) utilized Fuzzy AHP for the SWOT analysis of on-site greywater reuse in Iran, Meena et al. (2019), employed this method for strategic analysis of the Indian agri-food supply chain, Wang and Solangi (2020) used SWOT-Fuzzy AHP approach for Strategic renewable energy resources selection for Pakistan, Ohoitimur et al. (2021) performed a SWOT analysis for the congregation of the missionaries of the Scared Heart using Buckley’s Fuzzy AHP, Gholizadeh et al. (2021) used Fuzzy AHP for the SWOT analysis of the solar desalination in Iran and Farzi et al. (2022) quantified their SWOT analysis of the Esfarayen plain aquifer using Buckley Fuzzy AHP. The SWOT- Fuzzy ANP combined method was also used by Aghasafari et al (2020), to determine the best strategies for the development of organic farming. In addition, Boostani et al. (2023) used the Fuzzy BWM for a SWOT analysis of the small-scale building solar power plants in Iran.

According to the mentioned studies, it seems that the use of the SWOT analysis method in combination with fuzzy MCDM methods has been considered by researchers as a relatively new solution to eliminate the shortcomings of classical SWOT analysis in the strategic planning of systems. Accordingly, in this paper, a systematic analysis with the combined approach of SWOT-Fuzzy AHP is used. The Fuzzy AHP method has some sub-methods that most researchers have used Chang’s (1996) fuzzy analysis method and Buckley's (1985) improved analysis method. Because in Chang’s (1996) fuzzy analysis, the priority of some factors may be zero, and in addition in these two methods the analysis of the consistency of comparisons an independent method such as Gogus and Boucher’s (1997) method should be used. This article used the Mikhailov (2004) method, which directly examines the consistency of comparisons. The integrated approach of this paper has been used for the strategic planning of AGR in Esfarayen Plain, located in northeastern Iran. SWOT analysis for AGR has received less attention from researchers and has been done rarely in some studies such as Starkl and Essl (2012) and Essl et al., (2014), but in their research, the quantitative analysis of factors and the determination of their relative importance have not been implemented.

According to the previously stated contents, the main goals and contributions of the present research are as follows. The main goal of the study is to investigate AGR from a systemic and strategic planning perspective in a long-term view and by using SWOT analysis, which will greatly help the relevant planners, managers, and decision makers in this area to plan and determine more effective aquifer balancing strategies. Another important contribution considered in this research is the use of the quantitative approach of the SWOT analysis, which takes into account the relative importance of the identified factors in determining the strategies of the AGR development system in the study area. Finally, another important contribution of this research is to consider the uncertainty conditions and the use of the fuzzy MCDM approach for the quantitative analysis of strategic planning and determining the relative importance of the SWOT factors. The remaining parts of this study are organized as follows: Section 2 presents the research methodology, results and discussion are provided in section 3 and Finally, Section 4 presents the conclusions of the article.

2. Materials and Methods

2.1. Study area (Esfarayen Plain)

In this paper, the area of study is the Esfarayen plain, which is one of the sub-basins of the central desert catchment and is located in the south of the North Khorasan province. The area of the Esfarayen region is 4579 square kilometers. The geographical coordinates of the study area are between 56 degrees and 57 minutes to 58 degrees and 7 minutes of the east longitude and 36 degrees and 40 minutes to 37 degrees and 17 minutes of the north latitude. The geographical location of the study area is represented in Figure 1.

The climate of the study area is semi-arid and the average long-term (42 years) rainfall in Khosh station is equal to 220 mm. There is also no permanent river in the Esfarayen region. However, there are 3 active hydrometric stations in the area; the average annual yield volume of Sankhast River, Bidvaz River, and Roeen River at these hydrometric stations are estimated at 9.36, 28.92, and 13.63 million cubic meters, respectively.

The mentioned study area has 746 deep and semi-deep wells, 75 qanats, and 306 springs. In terms of the consumption of extracted water by wells in different sections, about 90% is used in the agriculture sector and the rest in household usage. In the pattern of water consumption, the share of the other sectors including industry is low. A hydrographic study of Esfarayen plain shows that the groundwater levels in this plain have a declining trend, and the volume of reservoir deficit during 23 years is equal to 972.77 MCM, also the average reservoir deficit per year is about 42.29 MCM. Due to the high reservoir deficit of the Esfarayen aquifer, the development of exploitation of its groundwater resources is currently prohibited (Farzi et al., 2022).

2.2. Research methodology

The research process including the steps of developing the problem model framework proposed in the present study is shown in Figure 2. According to Figure 2, the first step of the research is the SWOT standard analysis to identify strengths and weaknesses (internal factors), and opportunities and threats (external factors), affecting the artificial groundwater recharge of Esfarayen Plain to balance the aquifer of that area. To do this, a set of factors was prepared and listed for each of the four SWOT groups, based on a study of the relevant literature as well as interviews with experts in the related field. A group of 10 experts then validated these factors. The interviewed experts were selected from among academic and industrial specialists who had sufficient knowledge and experience in the field of regional water management and were active in the study area.

After determining the hierarchical structure of the problem, the first questionnaire was prepared for pairwise comparisons of factors within the SWOT groups and provided to experts. Experts performed pairwise comparisons using the linguistic terms listed in Table 1. By replacing the linguistic terms with the corresponding fuzzy numbers in the table and using Mikhailov's fuzzy prioritization approach, the local relative priorities of the SWOT factors were calculated.

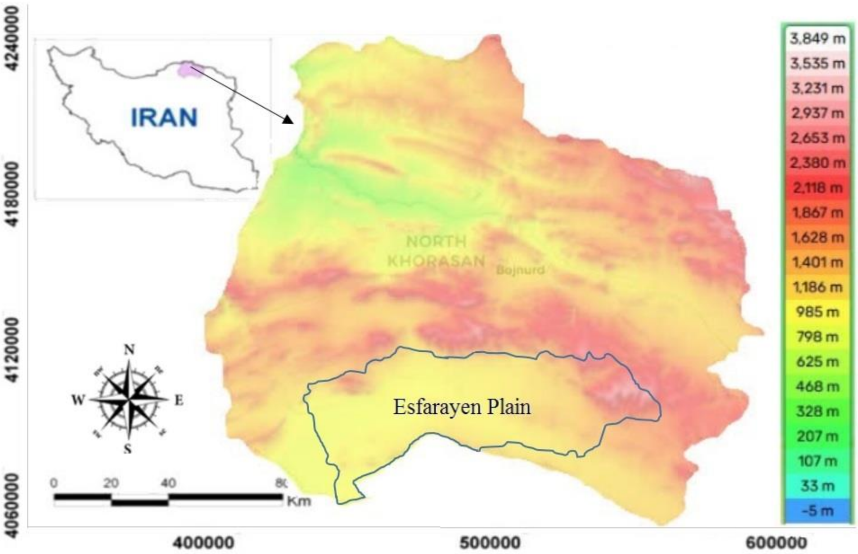

Fig. 1. Geographical location of the study area including aquifer extend and elevation map

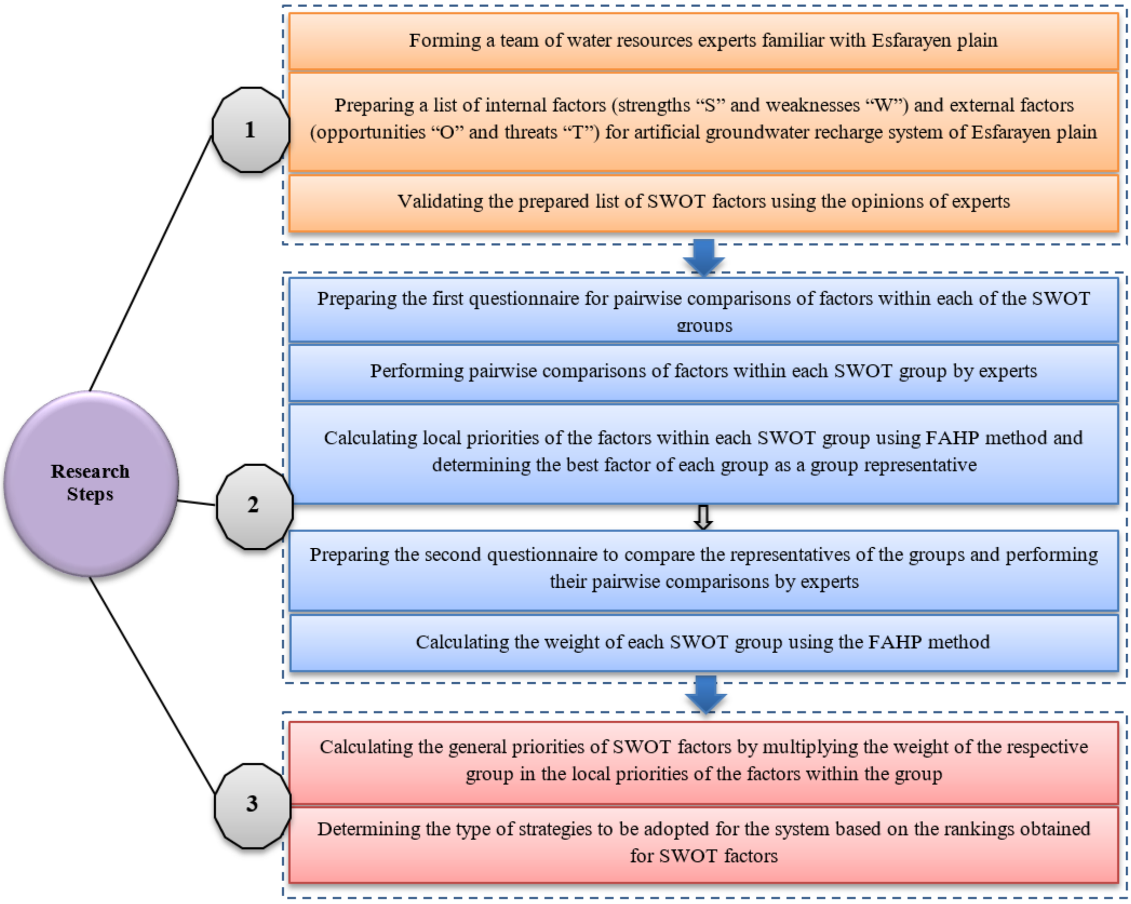

Fig. 2. The research model process

After calculating the local priorities of the factors in each group, the factor with the highest local priority in each group was selected as the representative of that group to perform pairwise comparisons of the groups; therefore, a new questionnaire was prepared to compare the group representatives and presented to the experts. At this stage, the relative priority of the groups was calculated using the fuzzy analytic hierarchy process (Mikhailov's fuzzy prioritization approach). Finally, the overall priority of each factor was calculated by multiplying the local priority of that factor by the priority of the respective group. In fact, in this research, SWOT analysis is considered as a multi-criteria decision making problem.

Table 1. Conversion of linguistic terms to Triangular Fuzzy Numbers (TFNs)

Verbal phrase	**Equivalent triangular fuzzy number**
Same preference	(1,1,1)
A little preferred	(2,3,4)
Very preferred	(4,5,6)
Very much preferred	(6,7,8)
Absolutely preferred	(9,9,9)

As mentioned previously, in this study, a fuzzy prioritization approach is used to rank the factors and groups, which was first introduced in 2004 by Mikhailov. One of the important features of this method is the calculation of the consistency ratio in fuzzy mode, which has not been addressed in most other methods. In addition, it does not require a complete set of fuzzy pairwise comparisons, and the resulting nonlinear model is easier to solve than other nonlinear models. In this method, it is assumed that fuzzy pairwise comparisons are as triangular fuzzy numbers $\tilde{a}_{ij} = (\, l_{ij}, m_{ij}, u_{ij})$. The deterministic weight (priority) vector $(w = (\, w_1, w_2, \dots, w_n))$ is obtained in such a way that the priority rates $\frac{w_i}{w_j}$ are approximately within the range of the initial fuzzy judgments. In other words, the weights are determined so that the fuzzy relation (1) be established (Mikhailov, 2004);

$$l_{ij} \lessapprox \frac{w_i}{w_j} \lessapprox u_{ij} \qquad i = 1,2,\dots,n-1 \qquad j = 2,3,\dots,n, \quad j > i \tag{1}$$

where the symbol $\lessapprox$ indicates the phrase "approximately less than or equal to".

The approximate satisfaction range of (1) can be determined as $\hat{a}_{ij} = (l_{ij} - p_{ij}, u_{ij} + p_{ij})$ interval, where p_{ij} denotes a deviance parameter. Therefore we'll have an extended range as;

$$S_e = \left\{ w \middle| (l_{ij} - p_{ij}) \le \frac{w_i}{w_j} \le (u_{ij} + p_{ij}) \right\} \tag{2}$$

$$w_i > 0; \ \sum_{i=1}^{n} w_i = 1; \ \ i \neq j = 1,2,\dots,n$$

The decision maker would be most satisfied with the solution ratio if $\frac{w_i}{w_j} = m_{ij}$; satisfied if $\frac{w_i}{w_j} \in (l_{ij}, u_{ij})$; partly satisfied if $\frac{w_i}{w_j} \notin (l_{ij}, u_{ij})$ but $\frac{w_i}{w_j} \in (l_{ij} - p_{ij}, u_{ij} + p_{ij})$, and dissatisfied if $\frac{w_i}{w_j} \notin (l_{ij} - p_{ij}, u_{ij} + p_{ij})$. So, the satisfaction degree with the solution ratio in each extended range can be indicated by the following membership function;

$$\mu_{ij}^{N}\left(\frac{w_i}{w_j}\right) = \begin{cases} 1 + \dfrac{1}{p_{ij}}\left(\dfrac{w_i}{w_j} - l_{ij}\right), & \dfrac{w_i}{w_j} \le m_{ij}, \\ 1 + \dfrac{1}{p_{ij}}\left(u_{ij} - \dfrac{w_i}{w_j}\right), & \dfrac{w_i}{w_j} \ge m_{ij}, \end{cases} \tag{3}$$

Solving the fuzzy prioritization problem is based on two main assumptions; the first assumption requires the presence of a non-empty fuzzy feasible region P on the $\mathrm{n} - 1$ dimensional simplex Q^{n-1} superplane (Mikhailov, 2004).

$$Q^{n-1} = \left\{ (w_1, w_2, \dots, w_n) \middle| w_i > 0 \,, \sum_{i=1}^{n} w_i = 1 \right\} \tag{4}$$

The membership function of the fuzzy feasible region P is obtained from the following relation:

$$\mu_p(w) = \min_{ij}\{\mu_{ij}(w) \mid i = 1,2,\dots,n-1; \ j = 2,3,\dots,n; \ j > i\} \tag{5}$$

The second assumption specifies a selection rule. This assumption determines a priority vector with the highest degree of membership in the relation (5) aggregated membership function. It is proved that $\mu_P(w)$ is a convex set, so there is always a priority vector $w^* \epsilon Q^{n-1}$ that has the highest degree of membership (λ^*) (Mikhailov, 2004).

$$\lambda^* = \mu_p(w^*) = \max_{w \epsilon Q^{n-1}} \min_{ij}\{\mu_{ij}(w)\} \tag{6}$$

Given the specific shape of the membership functions, the former max-min prioritization problem becomes a nonlinear optimization problem:

maximize λ

subject to

$$\begin{aligned} & p_{ij} w_j \lambda + (l_{ij} - p_{ij}) w_j - w_i \le 0, \\ & p_{ij} w_j \lambda + (l_{ij} - p_{ij}) w_j - w_i \le 0, \\ & \qquad i = 1,2,\dots,n-1 \end{aligned} \tag{7}$$

$$j = 2,3,\ldots,n, \qquad j > i$$

$$\sum_{l=1}^{n} w_l = 1, \qquad w_l > 0, l = 1,2,\ldots,n$$

The optimal solution to the problem (7) is (w^*, λ^*), where w^* denotes the preference vector which maximizes the membership degree of the aggregated function (5), also, λ^* presents the optimal (maximum) degree value, and is denominated a consistency index. The positive value of λ^* indicates the consistency of the fuzzy judgments and the negative value of λ^* indicates the inconsistency of the judgments.

3. Results and Discussion

In this section, the research findings are presented including the identification of strengths, weaknesses, opportunities, and threats related to AGR of Esfarayen plain and prioritization of them using fuzzy AHP. For this purpose, several factors in each group were identified by the authors and adjusted using the opinions of experts. Finally for each group of strengths, weaknesses, opportunities, and threats, 7, 6, 10, and 8 factors were identified, respectively, which are listed in Table 2.

Table 2. Factors of SWOT groups of the AGR of Esfarayen plain

Strengths- S	**Weaknesses- W**
S1: compensating for the decrease in groundwater levels	W1: possibility of reducing soil permeability (congestion)
S2: Agricultural development	W2: reduction of water quality in AGR due to evaporation and leaching
S3: Potential of underground reservoir for storing surplus water in non-crop seasons	W3: The possibility of damage to AGR facilities due to unpredictable rainfalls and floods
S4: Lower cost than other GRRBP projects	W4: The possibility of microbial contamination in groundwater due to the use of surface water
S5: Possibility for rehabilitating springs and qanats	W5: operation problems and costs
S6: flood control and preventing its destruction	W6: possibility of subsidence in some cases
S7: preventing the intrusion of saline water into the aquifer	
Opportunities- O	**Threats- T**
O1: possibility of public participation	T1: lack of adequate budget for allocation to AGR projects
O2: possibility of intrusion of saline water from Kal-e-Shoor river in the south of the plain	T2: lack of feeling of the Need for AGR projects due to the existence of smart water meters on the plain
O3: the existence of good recharge sources and seasonal rivers	T3: lack of priority in the plain for allocating budget for AGR projects because of its medium balance
O4: Major dependence of water consumption on groundwater	T4: lack of proper formation of water consumer NGOs to participate in water governance
O5: absence of land subsidence in the plain	T5: private ownership of lands required for AGR projects
O6: good aquifer permeability	T6: high evaporation rate in Esfarayen plain
O7: suitable alluvial thickness	T7: lack of scientific approach in the field of AGR
O8: Downing groundwater level and being forbidden plain	T8: cultivation area beyond the potential of groundwater resources
O9: enactment of GRRBP and AGR as one of its projects	
O10: the possibility of the user of the effluent of the Esfarayen wastewater treatment plant for AGR	

After performing a SWOT analysis and determining the factors of each of the SWOT groups; Mikhailov's Fuzzy AHP technique was used for ranking. The first of the four SWOT groups is the S group or strengths. The factors of this group were compared by experts using verbal variables and according to the steps of Mikhailov's fuzzy prioritization approach, the local priorities of these factors were calculated as shown in Figure 3. As can be seen in this figure, factor S7, i.e. "preventing the intrusion of saline water into the aquifer" has the highest priority, and factors S1, S6, S4, S5, S3, S2, ranked second to seventh, respectively. Due to the location of the Kal-e-Shoor saline river in the south of the Esfarayen plain and the decreasing water level in the aquifer, the intrusion of salt water into the aquifer is one of the most important risks of this aquifer. Therefore, it seems that the reason why the experts have chosen the S7 factor as the first factor of this group was due to the understanding of this risk and the unique role of AGR in reducing this risk. After this factor, which aims to maintain the water quality of the aquifer, experts have assigned the second rank to maintain the quantity of aquifer water in the form of factor S1, i.e. compensation of the water level by AGR projects. Also, due to the occurrence of numerous floods in the rivers feeding the plain and the damages caused by them, experts have considered factor S6, i.e. flood control using these projects, in the third place. These three factors in total account for 65% of the weights of the factors of group S, which shows that the rest of the factors in this group were less important compared to these three factors.

The second group of four SWOT groups is group W or weaknesses. Similar to the previous group, the local priorities of the factors in this group were also calculated. The results are shown in Figure 4. As can be seen in this figure, factor W3 i.e. "the possibility of damage to AGR facilities due to unpredictable rainfalls and floods" has the highest priority, and factors W4, W2, W5, W1, and W6, ranked second to sixth, respectively. In hydrological projects, due to the design of the project based on a design flood with a certain return period, there is always a risk of a flood occurring more than the design flood and causing damage to the designed facilities. It seems that the understanding of this risk by the experts has caused the selection of factor W3 as the first factor in the group of weaknesses. In addition, the stagnation of water in AGR projects, on the one hand, causes the growth of bacteria in it, and on the other hand, increases evaporation and decreases the chemical quality of water. It seems that assigning ranks 2 and 3 to two factors W4 and W2 is due to the understanding of these two risks by the experts. It is obvious that between these two qualitative factors, factor W4 is more important than factor W2 due to the human risk of microbial contamination. These three factors in total account for 66% of the weight of W group factors, which shows that the rest of the factors in this group were less important compared to these three factors.

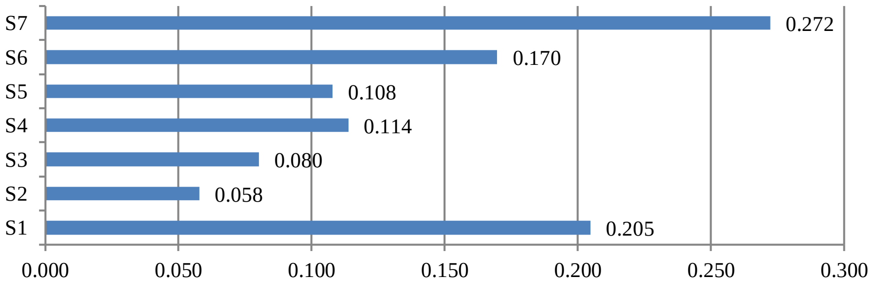

Fig. 3. Local priorities of strengths factors

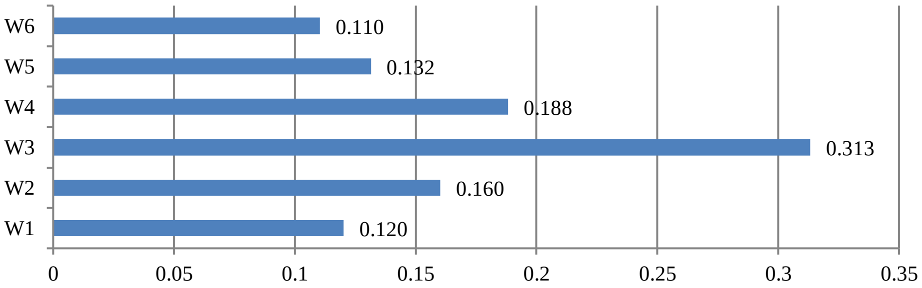

Fig. 4. Local priorities of weaknesses factors

The third of the four SWOT groups is Group O or Opportunities. The values of the local priorities calculated for the factors of this group are shown in Figure 5. As can be seen in this figure, factor O3, i.e. "existence of good recharge sources and seasonal rivers" has the highest priority, and factors O6, O4, O10, O8, O9, O1, O2, O5, had the second to tenth ranks, respectively. The availability of sufficient water for the AGR of the aquifer in the first degree of importance and the possibility of water infiltration into the aquifer in the second degree of importance are two effective factors in the success of AGR projects. These two important factors have been provided as two natural opportunities in this plain due to the existence of numerous recharge sources and the good permeability of the aquifer. Therefore, from the experts' point of view, two factors O3 and O6 were placed in the first and second ranks of the opportunities group. Allocating the majority of water use in the

Esfarayen Plain to agricultural uses and the dependence of these uses on ground water is another opportunity that represents the need to develop restoration projects such as AGR. Therefore, factor O4 is ranked 3rd. The existence of the city of Esfarayen and the significant amount of municipal wastewater produced in this city suggests the possibility of using treated wastewater as another source of water for the artificial recharge of the aquifer, and has caused the O10 factor to be ranked fourth in this group. In addition, the fact that the plain is prohibited also shows the importance of using AGR projects to balance the aquifer and places factor O8 in the fifth place. The above-mentioned five factors account for a total of 67% of the weight of group O, which shows that the rest of the factors in this group were less important compared to these factors.

The last of the four SWOT groups is the T group or the threats group. The values of local priorities calculated for the factors of this group are shown in Figure 6. As can be seen in this figure, factor T1, i.e. "lack of adequate budget for allocation to AGR projects" has the highest priority, and factors T4, T3, T6, T7, T2, T8, and T5, ranked second to eighth, respectively. According to the governmental structure of water governance in Iran, the lack of allocation of government funds to AGR projects is the most important factor in the failure of these projects. Therefore, experts have assigned the first rank to factor T1 in the group of threats. The NGOs of the water sector, which act as drivers of the development projects of this sector in many parts of the country, are not fully developed in the Esfarayen Plain. This lack of development has caused the experts to assign T4 the second place in the group of threats. Due to the presence of plains with worse conditions in the country, the lack of priority of Esfarayen Plain to attract funds related to the implementation of AGR projects has been considered by experts as the third threat.

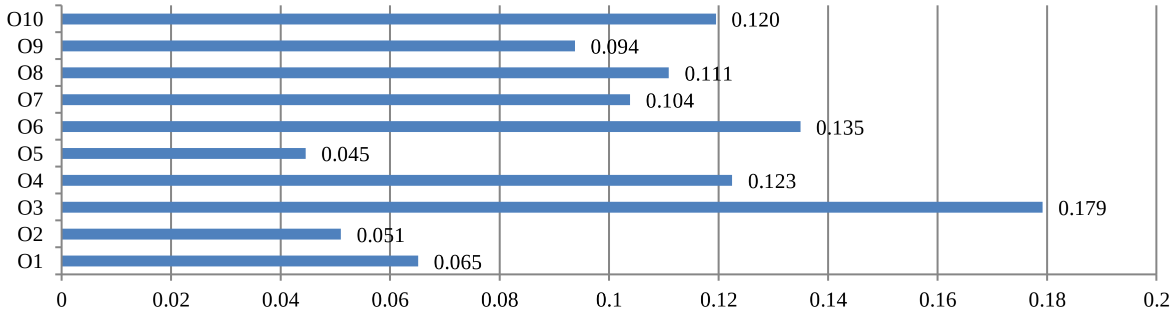

Fig.5. Local priorities of opportunities factors

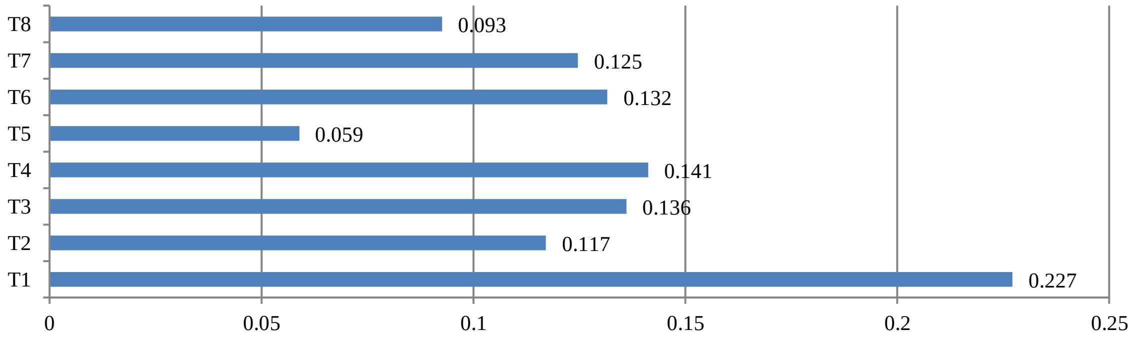

Fig. 6. Local priorities of threats factors

The group of threats includes eight factors, and these three factors account for more than 50% of the weight of the factors in this group, which shows that the rest of the factors in this group were less important compared to these factors.

In the SWOT-FAHP analysis method, after analyzing the factors of each group, the factor with the highest local priority in each group is selected as the representative of that group to compare the groups. The final results of the comparison of these representatives are considered as the weight of the group. The factors with the highest local priority are described in Table 3. These factors were compared by experts as representatives of the four groups, and like the calculation of local priorities in each group, the weight of each group was calculated using Mikhailov's fuzzy prioritization method. The group of threats ranked first place (p=0.421), the group of opportunities ranked second place (p=0.386), the group of strengths ranked third place (p=0.131), and the group of weaknesses ranked fourth (p=0.067).

Table 3. Representatives of the four groups

Group	Group representative	Representative factor description
S	S7	preventing the intrusion of saline water into the aquifer
W	W3	the possibility of damage to AGR facilities due to unpredictable rainfalls and floods
O	O3	existence of good recharge sources and seasonal rivers
T	T1	lack of adequate budget for allocation to AGR projects

Finally, the global priorities of the factors are calculated. To do this, the weight of each group was multiplied by the local priority of the factors of that group. The results are shown in Figure 7. As can be seen in this figure, among all the factors, the first rank belongs to factor T1 from the group of threats; this factor is "Lack of adequate budget for allocation to AGR projects". Although despite the critical condition of groundwater resources, the budget allocation for GRRBP compared to other sectors of the water industry such as dams and inter-basin water transfer is much lower, among the GRRBP projects there is a priority in allocating funds to measures overseeing demand management, such as providing and installing volumetric and smart water meters on wells, establishing patrol teams, and blocking unauthorized wells. It seems that supply management measures such as compensating for the drop in the reservoir through AGR are not the priorities of budget allocation. As the implementation of AGR projects requires the construction of various structures, without allocating a special budget for this project, this important project is practically neglected from the GRRBP projects and it seems that this situation has led the experts questioned in this study to choose this factor as the first factor.

Factor O3 has the second overall rank. The rank of this opportunity factor is due to the existence of good recharge sources and seasonal rivers in the plain. Without reliable surface water resources, implementing AGR projects is futile. The Esfarayen plain aquifer is located on the southern slope of the eastern Alborz mountain range. So several seasonal rivers recharge this aquifer, such as Bidvaz, Rouein, and Sarband Rivers. Most of the water of these rivers in the rainy season, without control, after causing flood damage, is poured into the saline areas of the central Kavir of Iran and is out of reach for effective use. However, Esfarayen Plain has suitable opportunities for the implementation of AGR projects, and the selection of this factor as the second factor in the overall list of factors can be the familiarity of the experts with these morphological conditions of Esfarayen. It seems that conducting an extensive study on the water supply of seasonal rivers in Esfarayen, a feasibility study of AGR projects, and determining suitable places for AGR in this plain, as an initial strategy can pave the way for achieving the desired situation in the field of the use of AGR to rehabilitate and balance the aquifer.

The third overall rank belongs to factor T4 in the threat group. This factor is the "lack of proper formation of water consumer NGOs to participate in water governance. One of the most important non-structural projects of the GRRBP is the project of creating and activating water consumer NGOs to implement participatory management of water resources and reduce government tenure. Although it seems that with the transfer of regional water governance to NGOs formed by water consumers, the aquifer will be better managed, due to various socio-cultural and economic-agricultural reasons and barriers, these organizations still have not been formed or have not had an effective performance in different regions of the country. Socio-cultural barriers include rejection by farmers, lack of knowledge and motivation to join these organizations, the spirit of individualism in farmers, etc., and economic-agricultural barriers include limitation of farmers in water consumption, the lack of government financial support for these organizations, and the interference of farm and water management (Adham Maleki et al., 2021). It seems that the familiarity of experts with the situation of these NGOs and considering the unsuccessful experiences of some of them, has caused a high ranking of this factor in the global list of factors. Increasing transparency in the goals of these NGOs and continuous training of water consumers by using the power of educational organizations such as universities can be helpful in this regard.

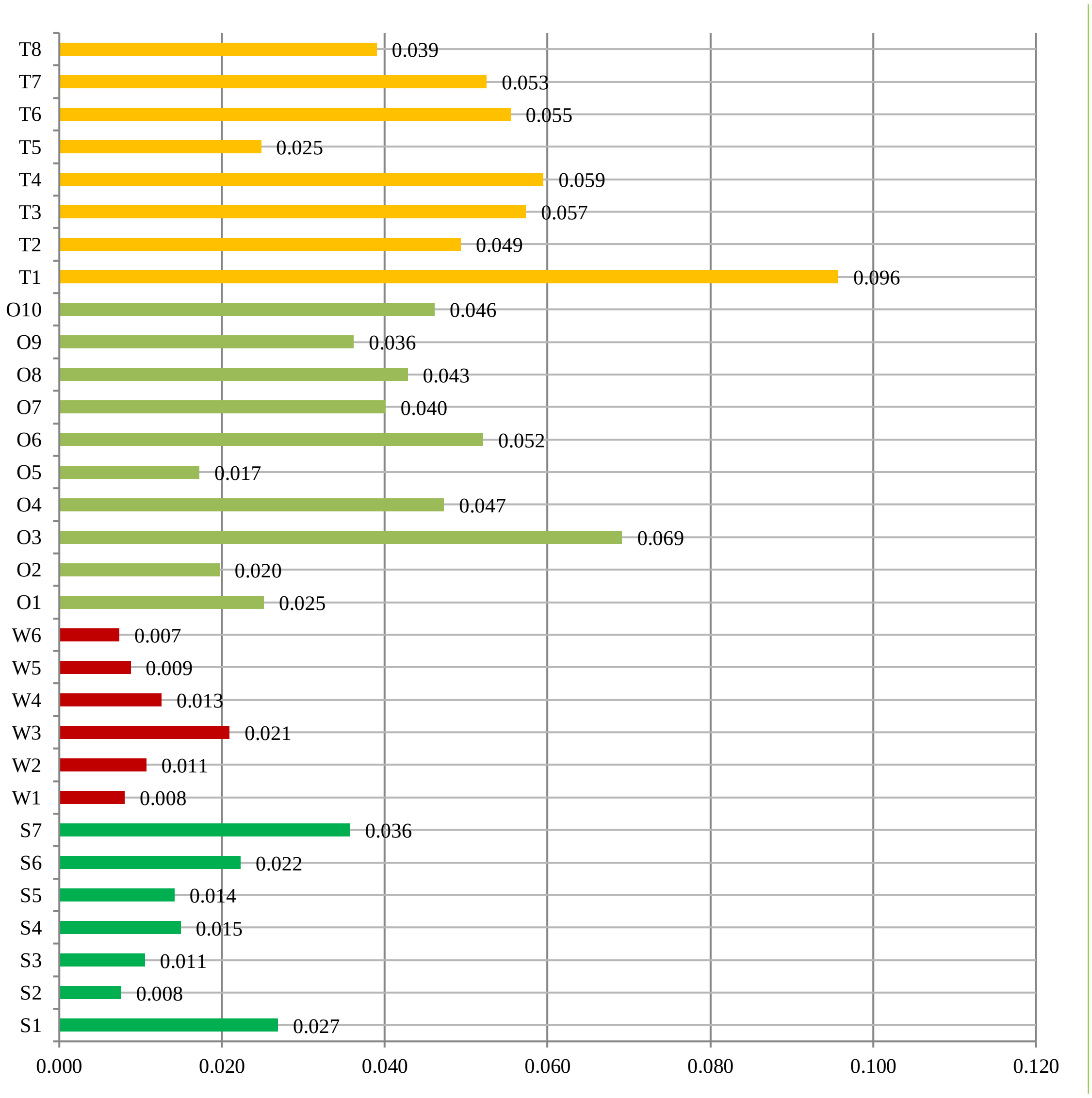

Fig. 7. General priorities of SWOT factors

The fourth overall rank belongs to factor T3. This factor is “the lack of priority the plain for allocating budget for AGR projects because of its medium balance”. Although the Esfarayen Plain is a critically forbidden plain, but due to the installation of smart water meters on its wells, the operation conditions of the aquifer have been improved slightly and the rate of annual decline of the aquifer has been decreased.

This situation has caused the allocated funds for AGR projects in this plain not to be considered as a priority, instead, the budget for AGR projects has been allocated to plains with more unfavorable situations. Factor T6 has the fifth overall rank, that is, “the high evaporation rate in Esfarayen Plain”. Due to the reduction of water infiltration rate into the soil over time, for AGR projects, which is mainly based on the distribution of water on land increasing the water surface, the role of evaporation rate would be considerable. Therefore, it seems that some other AGR projects such as feeding wells have higher priority for Esfarayen Plain.

As it was clear from the above discussions, at the beginning of the global ranking list of factors, the role of threats is more prominent. To better analyze the dominant and recessive strategies and better interpret the results, all SWOT factors of this study are divided into 4 categories according to the priority (first to fourth quartiles), and the number of factors related to strengths, weaknesses, opportunities, and threats in each of these quartiles is shown separately in Figure 8.

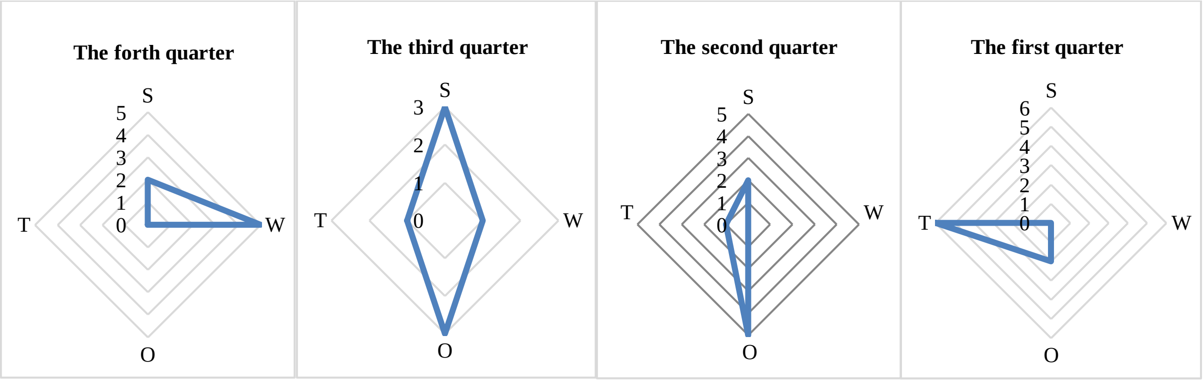

Fig. 8. Classifying SWOT factors according to the priority of importance

Looking at the first 8 factors (first quartile) of the list of SWOT factors, it can be seen that among these factors there are two opportunities and six threats that show the greater share of the group of threats in these quartiles. There is no representative of strength and weakness in this quartile. The general position of the factors in different quartiles is shown in Figure 8.

As can be seen in this Figure, in the second quartile, there are two strengths, one threat, and 5 opportunities and there is no representative for the group of weaknesses in this quartile. In the third quartile, there are three factors for each of the positive strengths and opportunities groups and one factor for each of the negative weaknesses and threats groups. Also in the fourth quartile, there are 2 strengths and 5 weaknesses and there are no factors from the opportunities and threats groups.

Also, considering Figure 8, it can be seen that the share of threats, opportunities, strengths, and weaknesses in the first half of the list of factors (first and second quartiles) are 7, 7, 2, and 0 factors among 8, 10, 7, and 6 factors of these groups, which are 87.5, 70, 28.6, and 0% of the factors of these groups, respectively.

Therefore, the share of two groups of threats and opportunities in the first half of the list was more than 50% of the factors of these groups, and in other words, external factors were more important from the perspective of experts questioned in this study. Comparing the ranks of internal factors in Figure 8, it can be seen that the strengths have higher ranks compared to the weaknesses, so most of the weaknesses (5 factors out of 6 factors) are in the fourth quartile, while most of the strengths (5 out of 7 factors) are in the second and third quartiles. Therefore, it seems that in adopting appropriate strategies for the future of the AGR system of Esfarayen Plain, priority should be given to ST strategies.

Strategies that use the strengths of the system to try to eliminate external threats to the system. After this type of strategy, due to the high importance of opportunities, SO type strategies can also be adapted for AGR of Esfarayen Plain. Some of the strategies that can be adopted for AGR of the Esfarayen Plain aquifer are given in Table 4.

Table 4. Proposed strategies

Strategy	Strategy type	Strategy description
St1	ST	Allocating a special budget to prevent the salinity of water in wells in the south of the plain
St2	ST	Conducting extensive scientific studies in the plain in relation to the effect of different balancing methods on reducing aquifer decline and prioritizing budget allocation based on it
St3	ST	Launching non-governmental organizations with the topics and missions of reviving springs and canals, preventing the salinization of wells, etc.
St4	ST	Scientific studies to find suitable artificial feeding methods in accordance with the ecosystem to reduce the effect of evaporation

Table 4. Continue

Strategy	Strategy type	Strategy description
St5	ST	Reviewing the way of allocating budget to artificial feeding projects and considering local conditions such as salt water infiltration
St6	SO	Considering incentives or reducing water withdrawal restrictions in the villages where artificial feeding projects are implemented
St7	SO	Using the effluent of the Esfarayen wastewater treatment plant for artificial feeding to prevent the infiltration of saline water into the aquifer
St8	SO	Identifying and prioritizing suitable areas for artificial nutrition in the plains and allocating budgets based on priority

4. Conclusion

In this paper, the strategic planning of the use of AGR was investigated as a method for balancing the aquifer of Esfarayen Plain. For this purpose, internal and external factors (i.e. strengths, weaknesses, opportunities, and, threats) of this system were identified. The SWOT factors then ranked using the Mikhailov's fuzzy AHP method. The results of this study showed that among the strengths group, the factor of "preventing the intrusion of saline water into the aquifer" had the highest local priority.

Among the weaknesses group, the factor of "possibility of damage to AGR facilities due to unpredictable rainfalls and floods" was determined as the highest rank. Among the opportunities group, the factor of "the existence of good recharge sources and seasonal rivers" was selected as the highest rank. Among the threats group, the factor of "lack of adequate budget for allocation to AGR projects" was determined as the factor of the highest importance.

In reviewing and analyzing the results of the comparison between groups, the group of threats had the highest importance, the group of opportunities was ranked second, the group of strengths was ranked third, and the group of weaknesses was ranked last. Also, considering that in examining the global priorities of the factors, in the first half of the list, 87.5% of the threats, 70% of the opportunities, and 22% of the strengths were present and there was no weakness, and in comparison of strengths and weaknesses, Strengths have higher ranks, it seems that in adopting the appropriate strategies for the future of AGR system of Esfarayen plain, ST strategies should have the highest priority. Strategies that use the strengths of the system to try to eliminate external threats to the system. After these types of strategies, due to the high importance of opportunities, SO type strategies can also be adapted for AGR of Esfarayen Plain.

Although in selecting the experts of the present study, an attempt was made to use the composition in such a way as to use both groups of academic experts and field experts, nevertheless, it seems that the experts may have differences in their judgment depending on their expertise and mastery of the topics related to this research, so one of the limitations of this research can be attributed to the same weight of the experts in question. Undoubtedly, the opinions of some experts may be more accurate than those of others, and weighting the experts can help to improve the decision-making process.

Another limitation of this study and similar studies based on expert opinions is that with any different combination of experts, the results of the research can change. Although there does not seem to be a way out of the second limitation, it is suggested that weighting be given to experts in future research. Also, the use of other fuzzy MCDM methods such as the fuzzy best-worst method can also be considered as a suggestion for future research and development by other researchers.

5. Disclosure statement

No potential conflict of interest was reported by the authors

6. References

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