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# Prioritizing policy interventions to enhance sustainability and climate resilience in Iranian agriculture: A hybrid fuzzy MCDM approach

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**ABSTRACT**
The purpose of this study is to evaluate climate change adaptation strategies based on economic, environmental, social, and technical indices, using the Fuzzy AHP and TOPSIS methods in the Doroodzan Dam basin in Fars Province, Iran. In the first step, the weights of the criteria were calculated using the fuzzy AHP process, pairwise comparisons, and questions from experts. Then, various climate change adaptation strategies were ranked by combining the results of fuzzy AHP and the calculated weights of the criteria, with the TOPSIS technique. The results showed that the environmental criterion, with a weight of 0.30, and the economic criterion, with a weight of 0.28, have the highest weight among the four criteria. The lowest weight is related to the social criterion. Among the adaptation options, improving irrigation channels, new irrigation technologies, and changing crop patterns were identified as the first to third options for adapting to climate change in the study area. Governments can encourage farmers to adopt modern irrigation methods through subsidies, education, extension services, demonstration projects, improved access to credit, water pricing policies, and public-private partnerships. These strategies create a supportive environment for sustainable and efficient water use in agriculture, and modifying cultivation patterns is a crucial strategy for adapting to climate change. This includes changing crop varieties, adjusting planting schedules, diversifying crops, and improving soil management. These measures not only help maintain agricultural productivity but also support sustainable farming practices in the face of climate change.

**Keywords:** Climate change, Water, AHP, TOPSIS, Adaptation, Sustainability.

## INTRODUCTION

Climate change is a global phenomenon that has become a significant challenge, necessitating immediate and concerted actions from all stakeholders. Mitigating the adverse effects of climate change and seizing opportunities for a green and sustainable future requires the reduction of greenhouse gas emissions, investment in low-carbon technologies, and enhancement of resilience and adaptation (Semeraro *et al*. 2023). By pursuing these measures, a more sustainable and equitable future that benefits society and the environment alike can be achieved (Alotaibi 2023). Owing to the extensive and mutual effects of climate on different production sectors, environmental factors,

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and human societies, climate change is considered one of the most important environmental challenges of the 21st century, which has serious economic consequences (Cohen & Waddell 2009). Based on various studies, it is estimated that an increase in global temperature of up to 2°C could result in a loss of 1-7% of global GDP, while an increase of up to 3°C could result in a loss of approximately 1-14%. If the increase reaches 5°C, the potential economic damage could range from 2.5% to 30% of global GDP. It is often observed that the majority of the financial burden arising from these damages is borne by developing countries. Although different economic sectors, such as agriculture, forestry, water and tourism industries, energy, and even financial and insurance markets, are affected by climate change (Toll *et al*. 2012), the agricultural sector is the most dependent on climate, and climate is the main determinant of location, production resources, and productivity of agricultural activities. In addition, the agricultural sector has a high share in the economy of developing countries and extensive connections with other economic sectors, while it is one of the sources of greenhouse gas production. These characteristics have made the agricultural sector the main focus of policy discussions and research projects related to climate change and different strategies to control greenhouse gases at the global and national levels (Falco *et al*. 2018).

Adaptation strategies are intended to build capacity for adaptation. Adaptive capacity is defined as the ability of a system to adapt within a specified range of environmental conditions (Smit & Wandel 2006). It encompasses the capacity of an organization to adjust its activities and decision-making processes in response to changing circumstances. The concept of adaptive capacity is crucial for organizations to ensure their long-term viability and resilience in the face of environmental uncertainties. Therefore, it is essential to invest in building adaptive capacity through strategic planning, resource allocation, and training programs (Brooks & Adger 2005). By doing so, organizations can enhance their ability to adapt and thrive in an ever-changing environment. Adaptation is a viable policy option for mitigating the adverse impacts of climate change. By adapting to the changing climate, individuals and communities can minimize the risks and maximize the opportunities presented by the evolving environment. Effective adaptation requires a combination of strategies, including but not limited to, enhancing resilience, improving infrastructure, and strengthening existing institutions. Successful adaptation hinges on collaborative efforts between governments, private sector entities, and civil society actors, with a shared commitment to reducing vulnerability and building a sustainable future (Folke *et al*. 2003).

Climate change poses significant economic and social challenges for agriculture. Its effects include reduced food productivity, increased weed growth, higher parasite infestations, water availability problems, soil changes, increased production costs, altered cultivars, reduced pollination, intensified fires, and changes in product quality (Semeraro *et al*. 2023). These impacts can lead to food insecurity in terms of both quantity and quality for future generations (Alotaibi 2023). To mitigate these risks, it is necessary to implement adaptation strategies that can enhance the resilience of agroecosystem. New technologies like new breeding techniques, and smart agricultural applications can assist in reducing risks caused by climate change, such as droughts and water shortages (Ahmed *et al*. 2023). Moreover, integrated approaches like breeding, transgenic methods, agronomic practices, cultivation of climate-resilient crops, and nanotechnology can help improve crop production despite climate change (Asante Gyamerah & Ikpe 2021). It is crucial to develop sustainable, socially, environmentally, and economically feasible solutions to reduce greenhouse gas emissions from the agriculture sector and transition towards sustainable farming systems (Amiri *et al*. 2023).

The challenge of climate change for agriculture necessitates adaptation strategies to cope with its impacts. Major strategies include climate risk planning, adjusting input applications, conservation techniques, and water stress-tolerant varieties (Rosales-Martínez *et al*. 2023). Additional strategies involve smart technologies and practices, such as smart crops and variety selection, climate-based cropping systems, water management, fertilization, contingency planning, and soil re-carbonization (Karri & Nalluri, 2023). Innovative technologies, such as breeding technologies, agrivoltaic systems, and smart agricultural applications, can enhance agroecosystem resilience in harsh environments (Semeraro *et al*. 2023). American farmers are also adopting various strategies, such as changing planting dates and using advanced technologies, to deal with climate change impacts (Ishtiaque 2023). Incorporating climate-smart agriculture practices, which include adapting crops to mitigate global impacts


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on productivity, into agricultural systems can help reduce the negative effects of climate change on agriculture (Gezimu Gebre *et al*. 2023). Khan *et al*. (2024) examined the livelihood adaptation strategies of rural households to climate change in Pakistan. The results showed that rural households in the study area have used a wide range of strategies to adapt their livelihoods to climate change, including poultry and livestock farming, livestock and agricultural product trading, small businesses, horticultural cultivation, and non-agricultural job. Zagre *et al*. (2024) examined climate change adaptation strategies among smallholder farmers in the semi-arid region of Senegal. The results showed that socio-economic and institutional factors, including access to credit and extension services, significantly influenced farmers' decisions to adopt technologies to adapt to climate change. Sewando (2023) examined climate change adaptation strategies among agro-pastoralists in Tanzania with the aim of clearly identifying the main factors influencing their choice of adaptation measures in the face of climate change. In this study, measures such as crop pattern modification, modern irrigation technologies, agricultural product insurance, and agroforestry were identified as effective options for adapting to climate change.

The adoption of climate change adaptation strategies by farmers is influenced by various factors including age, farming experience, education level, family size, farm income, farm size, distance to the market, access to credit, climate information, and extension access (Ansari 2023). Other significant factors that affect the adoption of adaptation strategies are knowledge of adaptation strategies, information-seeking behavior, scientific orientation, credit and subsidy orientation, decision-making ability, and extension contact (Mudekhere *et al*. 2023). Farmers can be incentivized to adopt climate change adaptation strategies through providing information (Ansari 2023), financial support (Mudekhere *et al*. 2023), tailoring policies, creating opportunities for non-farm activities (Baramo 2023; Gezimu Gebre *et al*. 2023), and access to markets and services (Landicho *et al*., 2023).

In the face of challenging socioeconomic and environmental conditions, farmers consistently demonstrate resourcefulness and resilience. They employ effective strategies to adapt to sudden climate change, severe pest attacks, and shifts in agricultural policies at local, national, and global levels. Their innate ability to adapt underscores the importance of gaining insights into their knowledge of climate change and adaptive practices. Researchers must conduct further studies to comprehend how farmers mitigate the impacts of climate change and develop sustainable practices. The present study aims to examine the economic, social, and behavioral aspects of farmers' climate change adaptation strategies, with a focus on prioritizing these strategies in the Doroodzan Dam basin. This basin is one of the strategic areas for agricultural production in Fars Province. Therefore, climate change in this region can affect the economic and social conditions of residents by affecting access to water resources and the growth cycle of agricultural products. Fars Province, one of the most important agricultural regions in Iran and the fourth wide province, due to climate variability has always been among the higher provinces in agricultural production. However, in general, drought is a phenomenon in which the average of every one year in this region and with great damage occurs and this climate change has caused constraints for crops production. Specifically, the main research question is: Based on various economic, social, environmental, and technical criteria, what are the most appropriate options for adapting to climate change in the Doroodzan Dam basin area, which has been facing changes in climatic conditions in recent years?

To manage the phenomenon of climate change, two approaches have been proposed worldwide: adaptation to climate change and reduction of greenhouse gas emissions, with adaptation to climate change receiving more attention, especially in developing countries. A review of global experiences shows that climate change adaptation is becoming a routine and essential part of planning at all levels. While, according to the United Nations Environment Program report in 2023, Iran is among the few countries that have not taken much action for climate adaptation at the strategic, policy, and planning levels. Evaluating climate change adaptation options based on the potential of each region is important for regional planning and policymaking. Therefore, this study attempted to identify the best climate change adaptation options based on economic, social, environmental, and technical impacts using a hybrid approach that has received less attention in previous studies.

This paper is organized as follows. The materials and methods and the features of the fuzzy hierarchy process and TOPSIS are presented in the next section. Then, the results of pairwise comparisons of criteria and ranking of adaptation options are presented in Section 4. Discussion and conclusions are also presented in Section 5.

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## MATERIALS AND METHODS

In this study, a combined fuzzy hierarchical ranking method and TOPSIS were used to rank climate change adaptation options. In more detail, after determining the criteria and adaptation options from a literature review, based on pairwise comparisons and interviews with 20 experts (including university professors, experts specializing in agriculture and climate), the weights of the criteria were calculated. The criteria for evaluating climate change adaptation options include economic, environmental, social and technical criteria. The economic criterion assesses the role of climate change adaptation options on farmers' profitability. The environmental criterion considers the impact of these climate change adaptation options on water and soil management. The social criterion refers to the effectiveness of implementing climate change adaptation options for employment and food security in rural areas. Finally, the technical criterion refers to the infrastructure necessary to implement these options. Climate change adaptation options in the study area include 11 options, which are presented in Table 1.

**Table 1.** Definition of climate change adaptation options.

| Adaptation options | Define | Reference |
|---|---|---|
| **Crop varieties** | Climate adaptation requires farmers to adjust their crop varieties over time and use the right varieties to minimize climate risk. | Li *et al.* (2025) |
| **New irrigation technology** | This technology enables smallholder farmers to optimize water usage and efficiently supplies crops with enough water for their development. | Ahmed *et al.* (2023) |
| **Land sale** | Selling agricultural land and exiting the sector. | Baramo (2023) |
| **off-farm employment** | Off-farm employment refers to work opportunities outside of a person's primary agricultural or farming activities, which can help diversify household risk and provide additional income. | Khan *et al.* (2024) |
| **Laser leveling of lands** | Laser land leveling is a laser-guided technology used to level fields by removing soil from high points of the field and depositing it in low points of the field. | Okolie *et al.* (2022) |
| **Drainage management** | The management and control over the quantity and quality of the drainage water generated in an agricultural drainage basin in arid and semi-arid areas and its final safe disposal. | Gezimu Gebre *et al.* 2023 |
| **Insurance** | A relevant mechanism to manage risks to help farmers to avoid financial losses and keep their businesses running. | Mudekhere *et al.* (2023) |
| **Minimum / Zero tillage** | Zero tillage is a minimum tillage practice in which the crop is sown directly into soil not tilled since the harvest of the previous crop. | Karri & Nalluri (2023) |
| **Less irrigation** | Reduced irrigation means less water available for crops. | Khan *et al.* (2024) |
| **Change crop pattern** | A change in cropping pattern refers to a change in the proportion of area distributed to different crops grown in the area. | Ishtiaque (2023) |
| **Irrigation cannels repair** | The recovery and maintenance of irrigation canals reduce losses and promote more efficient use of water resources. | Ishtiaque (2023) |

The research steps are presented in Fig. 1.

### Fuzzy Analytic Hierarchy Process (Fuzzy AHP)

The Analytic Hierarchy Process (AHP) has been criticized for its inability to capture the inherent vagueness and imprecision associated with mapping evaluators' judgments, expressed in words, to exact numbers. As the evaluation criteria are often qualitative, expressing the strength of preferences and providing exact pairwise comparison judgments can prove to be a challenging task for decision-makers. One potential solution to address such vague judgments is to employ fuzzy ratios in place of exact ones, as the former better reflects the vagueness of human thinking. By doing so, decision-makers can gain a more accurate and comprehensive understanding of the decision-making process and make more informed decisions (Anagnostopoulos & Petalas, 2011).

The Fuzzy Analytic Hierarchy Process (FAHP) is a preferred method for decision-making when dealing with an unbalanced scale of judgment and uncertainty associated with converting one's qualitative judgment into a numerical value. This method employs the concept of fuzzy logic to address the vagueness or imprecision of human judgment and provides a more accurate and reliable decision-making framework in complex and uncertain situations (Kabir & Hasin 2011).

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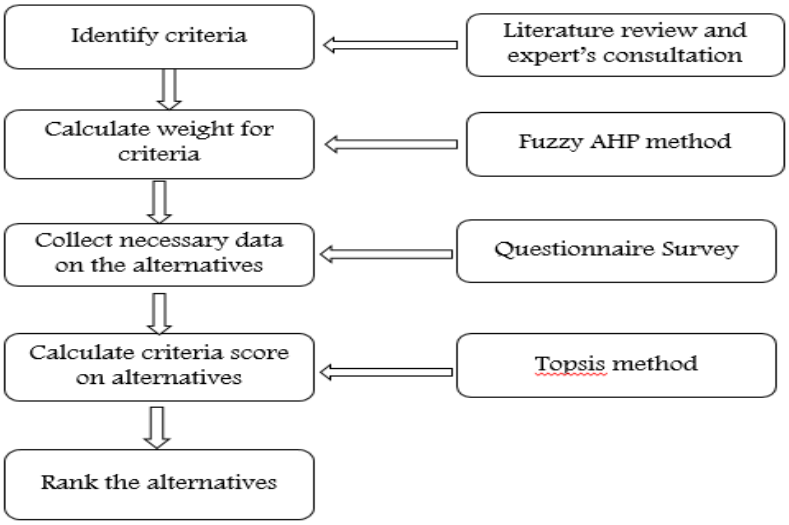



**Fig. 1.** Methodological steps followed.

This study employs the fuzzy Analytic Hierarchy Process (AHP) methodology to determine the weight of the climate change adaptation criteria that have been identified. The triangular fuzzy membership function is used in this research as it is straightforward to use and comprehend by decision-makers compared to other shapes (Shamsuzzoha *et al*. 2021).

To start with, we need to create a fuzzy pairwise comparison matrix. This matrix is built by comparing the identified criteria based on their significance for green practice. To make these comparisons, we rely on expert opinions, which are expressed on a linguistic scale as defined by Saaty (1999; see Table 1 in the appendix).

In the matrix equation 1 the element $x_{kij}$ represents the linguistic scale obtained from an expert (k) regarding the degree of preference of i[th] criterion.

$$D_{kij} = \begin{bmatrix} x_{k11} & x_{k12} \dots & x_{k1n} \\ \vdots & x_{k22} \dots & x_{k2n} \\ & & \vdots \\ \dots & \dots & x_{knm} \end{bmatrix} \quad (1)$$

In fuzzy matrix based on the fuzzy membership and fuzzy reciprocal scales $x_{ij}$ is $(l_{ij}.m_{ij}.u_{ij})$ and $x_{ji}$ is $\left(\frac{1}{u_{ij}}.\frac{1}{m_{ij}}.\frac{1}{l_{ij}}\right)$.

The proposed approach involves aggregating the fuzzy matrices obtained from various experts using the geometric mean method, as outlined in Arunachalam *et al*. (2020). The total number of participating experts is represented by the variable *k* in Equation 2.

$$B_{ij} = \sqrt[k]{\prod_{k=1}^{k} F_{kij}} \qquad \forall F_{kij} \in (l_{kij}.m_{kij}.u_{kij}) \quad (2)$$

To rank hierarchy parameters and alternatives, determining priority fuzzy vectors is not enough. Defuzzification is the process of converting fuzzy variables into crisp values. Techniques for obtaining crisp values from fuzzy sets and ranking alternatives have various approaches. Defuzzification is applied to local priorities or to fuzzy synthetic extents evaluated for each project (Chang 1996). The aggregate fuzzy matrix is defuzzified using the best non-fuzzy performance (BNP) technique, which was suggested by Bhosale & Kant (2016).

$$BNP_{ij} = \frac{(u_{ij} - l_{ij}) + (m_{ij} - l_{ij})}{3} + l_{ij} \quad (3)$$

After acquiring the score through the BNP technique, it is then subjected to normalization using Equation 4.


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$$N_{ij} = \frac{BNP_{ij}}{\sqrt{\sum_{i=1}^{n} BNP_{ij}^2}} \quad (4)$$

The determination of criterion weightage for climate change adaptation entails the utilization of Equation 5. Weightage denotes the degree of significance assigned to a particular criterion in comparison to the others. This process aids in prioritizing the criteria to be considered for climate change adaptation.

$$W_i = \frac{\sum_{i=1}^{n} N_{ij}}{\sum_{i=1}^{n}\sum_{j=1}^{n} N_{ij}} \quad (5)$$

**Checking the consistency of pairwise comparison matrix**

Ensuring consistency in pairwise comparisons is a crucial aspect of the AHP. To verify the consistency of expert judgments during pairwise comparisons, a consistency ratio is calculated using Equation 6. It is imperative to maintain consistency in pairwise comparisons to obtain accurate and reliable results using the AHP method. Therefore, the consistency ratio serves as a tool to assess the degree of consistency in the expert's judgments and helps in making informed decisions based on the AHP method.

$$CR = \frac{CI}{RI} \quad (6)$$

$$CI = \frac{\lambda_{max} - n}{n - 1}$$

In Equation 7, $\lambda_{max}$ is the principle eigenvalue of the pairwise comparison matrix, which can be calculated using Equation 8.

$$\lambda_{max} = \frac{\sum_{j=1}^{n} B_{ij} W_j}{W_i} \quad (7)$$

The concept of consistency ratio (RI) is a fundamental parameter, the value of which is determined by the number of criteria (n; Yap *et al*. 2018). The pairwise comparison matrix would be accepted only if the consistency ratio is less than 0.1 (Torfi *et al*. 2010). Otherwise, decision-makers must reassess their evaluations since inconsistency would violate the transitivity principle (Khanna *et al*. 2015).

**TOPSIS method**

The Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) is a well-established method for multi-criteria decision-making. This technique enables the ranking of alternatives by evaluating their proximity to the positive ideal solution and negative ideal solution. The positive ideal solution is the one that maximizes the benefit criteria and minimizes the cost criteria, whereas the negative ideal solution follows the opposite approach (Benitez *et al*. 2007). The optimal alternative is the one that is closest to the positive ideal solution and farthest from the negative ideal solution, in geometric terms. The ranking of alternatives is based on their relative similarity to the ideal solution. This approach ensures that an alternative is not ranked similarly to both positive and negative ideal solutions (Seçme *et al*. 2009).

Hwang & Yoon (1981) introduced the TOPSIS methodology, which involves the following steps:

**Step 1:** The first step is normalization, where the decision matrix (Saaty's 1-9 ratio scale was employed based on expert evaluation; Table 2 in the appendix) is standardized to eliminate measurement unit discrepancies. This ensures that all criteria are measured on the same scale, enabling accurate ranking of alternatives.

$$r_{ij} = \frac{Y_{ij}}{\sqrt{\sum_{j=1}^{J} Y_{ij}^2}} \qquad j = 1.2 \ldots . J; \quad i = 1.2 \ldots . n \quad (8)$$

**Step 2:** In the second step, a weighted normalized decision matrix is procured by multiplying the normalized matrix with the respective weights of the criteria. This process is executed following Expression 9.

$$V_{ij} = W_i^* r_{ij} \qquad j = 1.2 \ldots . j \qquad i = 1.2 \ldots . n \quad (9)$$

**Step 3:** Expressions 10 and 11 are used to determine the maximum value (positive ideal solution) and minimum value (negative ideal solution).

$$A^+ = \{V_1^+ . V_2^+ \ldots . V_n^+\} \quad (10)$$


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$$A^- = \{V_1^-.V_2^- \ldots .V_n^-\} \quad (11)$$

**Step 4:** Proceeding to Step 4, the calculation of the distance between each alternative and the positive ideal solution, as well as the negative ideal solution, is executed using Expressions 12 and 13.

$$d_i^+ = \sqrt{\sum_{j=1}^{n}(V_{ij} - V_j^+)^2} \qquad j = 1.2 \ldots .J \quad (12)$$

$$d_i^- = \sqrt{\sum_{j=1}^{n}(V_{ij} - V_j^-)^2} \qquad j = 1.2 \ldots .J \quad (13)$$

**Step 5:** In the fifth step of the process, the closeness coefficient ($CC_i$) is determined for each alternative by applying Expression 14. This involves a technical calculation which takes into account various factors and parameters. The resulting $CC_i$ value provides insight into the degree of similarity between each alternative and the ideal solution, allowing for a more informed decision-making process.

$$CC_i = \frac{d_i^-}{d_i^+ + d_i^-} \quad (14)$$

**Step 6**: At the end of the analysis, the ranking of alternatives is made possible by comparing the $CC_i$ values.
Fig. 2 shows the climate change adaptation criteria and options in the present study in a hierarchical manner.

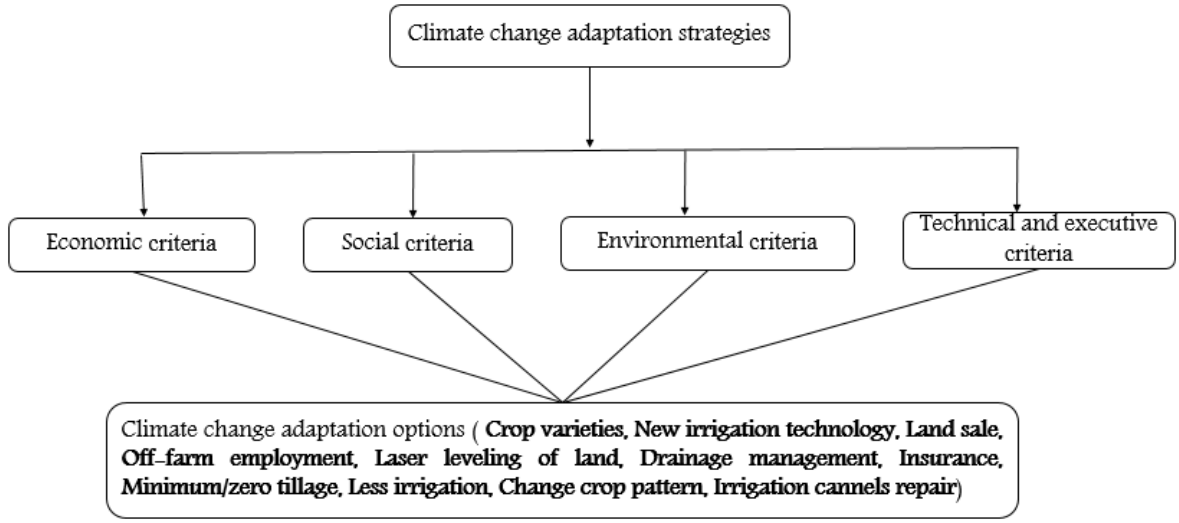



**Fig. 2.** Adaptation climate change strategies.

## RESULTS

After the experts completed the questionnaire, the results of the questionnaire were analyzed to extract a pairwise comparison matrix of criteria. This matrix serves as an essential tool in evaluating the effectiveness of various strategies in managing the impact of climate change on agriculture. The matrix that was provided by the experts underwent a conversion process into a fuzzy matrix using a fuzzy membership function. This allowed for a more nuanced and precise representation of the data, which can be useful in complex decision-making scenarios. Table 2 presents the unified matrix which is based on the fuzzy pairwise comparison matrix obtained from all experts. The unification process is carried out by employing the geometric mean method as discussed in the preceding section.

**Table 2.** Fuzzy pairwise comparison matrix.

| Criteria | Economic indicator | Social indicator | Technical indicator | Environmental indicator |
|---|---|---|---|---|
| Economic indicator | (1,1,1) | (1.15,1.57,1.82) | (0.92,1.39,1.53) | (0.73,1.01,1.07) |
| Social indicator | (0.55,0.63,0.85) | (1,1,1) | (1.71,0.90,1.25) | (0.47,0.58,0.78) |
| Technical indicator | (0.65,0.72,1.09) | (0.75,1.03,1.29) | (1,1,1) | (0.61,0.75,0.97) |
| Environmental indicator | (0.93,1.01,1.32) | (1.26,1.64,2.05) | (1.02,1.32,1.63) | (1,1,1) |


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After generating the pairwise comparison matrix, its consistency was checked to ensure its reliability and accuracy. The unified pairwise comparison matrix was evaluated, and it was found that the consistency ratio (CR) was 0.0063. Given that the value of CR is less than 0.1, the matrix can be considered consistent. This outcome indicates that the pairwise comparison matrix can be relied upon to provide valid and relevant information for further analysis.

The identification of criterion weights is a crucial step in decision-making processes, as it provides valuable insights into the relative importance of each criterion. To this end, the non-fuzzy and normalized aggregate matrix (Tables 3 and 4) were employed to determine the weight of each criterion, as presented in Table 4. The results indicate that environmental indicator holds the highest rank in terms of weight, followed by economic and technical indicators, respectively. Conversely, social indicator holds the least weight. Therefore, the results show that, from the experts' perspective, the environmental effectiveness of climate change adaptation options plays a decisive role in choosing the best adaptation option. After the environmental criterion, the economic criterion is the most important criterion from the experts' perspective, which indicates the high priority of financial efficiency, cost-effectiveness, and profitability in decision-making related to climate adaptation.

**Table 3.** Non-fuzzy matrix of pairwise comparisons ($BNP_{ij}$).

| Criteria | Economic indicator | Social indicator | Technical indicator | Environmental indicator |
|---|---|---|---|---|
| Economic indicator | 1 | 1.52 | 1.28 | 0.95 |
| Social indicator | 0.68 | 1 | 0.96 | 0.62 |
| Technical indicator | 0.82 | 1.03 | 1 | 0.78 |
| Environmental indicator | 1.09 | 1.66 | 1.33 | 1 |

**Table 4.** Normalized matrix of pairwise comparisons ($N_{ij}$).

| Criteria | Economic indicator | Social indicator | Technical indicator | Environmental indicator |
|---|---|---|---|---|
| Economic indicator | 0.55 | 0.57 | 0.56 | 0.56 |
| Social indicator | 0.37 | 0.38 | 0.42 | 0.36 |
| Technical indicator | 0.45 | 0.39 | 0.43 | 0.46 |
| Environmental indicator | 0.60 | 0.62 | 0.57 | 0.59 |
| **Weight of criteria** | **0.28** | **0.19** | **0.22** | **0.30** |

After determining the criteria weights, we use the TOPSIS method to evaluate the alternatives' order. In this study, the adaptation options considered include crop diversification, land sale, off-farm employment, low tillage and no-tillage practices, adoption of new irrigation technology, agricultural product insurance, change of cultivation pattern, and irrigation cannels repair. These options are based on available resources and past studies. First, we create a decision matrix for the alternatives based on various parameters and then present a normalized decision matrix in Table 5. Saaty's 1-9 ratio scale was employed based on expert evaluation, followed by the computation of the geometric mean of the expert opinions. The weighted normalized decision matrix is then calculated and displayed in Table 6.

To prioritize options for adapting to climate change, we calculated the positive and negative ideals for each criterion and then determined the distance of each option from these ideals. Finally, we assessed the relative closeness of each option to the ideal solution. A value closer to one indicates that a strategy is superior to others. The analysis revealed that the most suitable strategies for adapting to climate change in the study area are the modification of irrigation cannels repair and modern irrigation technology, with respective scores of 0.6658 and 0.5935 respectively. This study supports evidence from previous observation (e.g. Donati *et al*. 2013 and Hashemi *et al*. 2019). One of the most significant advantages of modern irrigation methods is water efficiency. Techniques like drip irrigation deliver water directly to the plant roots, minimizing evaporation and runoff. This precision ensures that crops receive the optimal amount of water, leading to better growth and yield.

The next priority actions are modifying the cultivation pattern with a score of 0.5526 and implementing drainage management with a score of 0.5385. Adjusting the cultivation pattern based on regional potential is crucial for resource management, particularly water resources, as agriculture is the primary water consumer in Iran. By


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modifying the cultivation pattern, we can not only enhance the economic status of farmers but also improve environmental indicators. Drainage water management is the practice of using a water control structure in the main, submain, (or sometimes lateral) drain to raise the drainage outlet to various depths. Drainage serves to reduce or remove salts, to control groundwater table levels in general and, in some specific areas, to reduce waterlogging. An important benefit (often mentioned by farmers) is improved aeration. This finding is also reported by Jat *et al.* (2020) and Bank (2024).

**Table 5.** Average opinion of experts using TOPSIS and normalized matrix.

| Criteria / alternatives | Decision matrix | | | | Normalized decision matrix | | | |
|---|---|---|---|---|---|---|---|---|
| | Economic indicator | Social indicator | Technical indicator | Environmental indicator | Economic indicator | Social indicator | Technical indicator | Environmental indicator |
| Crop varieties | 4.51 | 2.35 | 1.58 | 6.42 | 0.307 | 0.196 | 0.131 | 0.417 |
| New irrigation technology | 5.05 | 3.95 | 2.19 | 6.83 | 0.344 | 0.329 | 0.182 | 0.443 |
| Land sale | 1.81 | 1.07 | 2.73 | 2.59 | 0.123 | 0.089 | 0.226 | 0.168 |
| off-farm employment | 6.85 | 4.04 | 1.62 | 2.49 | 0.466 | 0.336 | 0.134 | 0.162 |
| Laser leveling of lands | 3.93 | 3.95 | 4.25 | 4.57 | 0.268 | 0.329 | 0.352 | 0.297 |
| Drainage management | 4.37 | 3.54 | 4.06 | 4.57 | 0.298 | 0.294 | 0.336 | 0.297 |
| Insurance | 4.28 | 3.73 | 3.97 | 3.62 | 0.291 | 0.310 | 0.329 | 0.235 |
| Minimum / Zero tillage | 4.44 | 4.06 | 3.97 | 4.06 | 0.303 | 0.338 | 0.329 | 0.264 |
| Less irrigation | 1.44 | 2.29 | 2.45 | 5.34 | 0.096 | 0.190 | 0.203 | 0.347 |
| Change crop pattern | 3.97 | 4.04 | 4.35 | 4.76 | 0.270 | 0.336 | 0.359 | 0.309 |
| Irrigation cannels repair | 5.44 | 5.07 | 6.14 | 3.73 | 0.370 | 0.422 | 0.508 | 0.242 |
| Criterion type | Max | Max | Max | Max | Max | Max | Max | Max |

Laser land leveling is a water-saving technology that optimally uses scarce groundwater, minimizes run-off and water-logging, and helps farmers use water more efficiently. In addition, utilizing low-tillage or no-tillage operations can effectively minimize soil erosion, enhance water penetration into the soil, increase soil water storage, and reduce runoff. According to the findings, the use of laser land leveling, low-tillage, and no-tillage scored 0.5316 and 0.5265, ranking them fifth and sixth in priority, respectively. The results corroborate the finding of a great deal of the previous work in this field, e.g. Bai *et al*. (2019) and Li *et al*. (2024). Conservation agriculture is a farming system that promotes minimum soil disturbance (i.e. no tillage), maintenance of a permanent soil cover, and diversification of plant species.

**Table 6.** Weighted Normalized Decision Matrix.

| Climate change adaptation strategies | Economic indicator | Social indicator | Technical indicator | Environmental indicator |
|---|---|---|---|---|
| Crop varieties | 0.0589 | 0.0372 | 0.0287 | 0.1250 |
| New irrigation technology | 0.0962 | 0.0624 | 0.0399 | 0.1330 |
| Land sale | 0.0345 | 0.0169 | 0.0498 | 0.0505 |
| off-farm employment | 0.1304 | 0.0639 | 0.0296 | 0.0485 |
| Laser leveling of lands | 0.0749 | 0.0624 | 0.0773 | 0.0890 |
| Drainage management | 0.0833 | 0.0559 | 0.0740 | 0.0890 |
| Insurance | 0.0815 | 0.0590 | 0.0723 | 0.0705 |
| Minimum / Zero tillage | 0.0847 | 0.0643 | 0.0723 | 0.0791 |
| Less irrigation | 0.0269 | 0.0361 | 0.0446 | 0.1040 |
| Change crop pattern | 0.0757 | 0.0639 | 0.0791 | 0.0927 |
| Irrigation cannels repair | 0.1036 | 0.0802 | 0.1117 | 0.0726 |

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By the conservation of soil cover in conservation agriculture a habitat is created for a number of species that feed on pests, which in turn attracts more insects, birds and other animals. The rotation of crops and cover crops restrains the loss of genetic biodiversity, which is favoured with mono-cropping. Agricultural insurance, less irrigation, and land sales were considered lower priorities for climate change adaptation. The agricultural sector is vulnerable to natural and unnatural factors, leading to less investment compared to less risky sectors like industry. The uncertainty of income, profit, and high initial capital in agriculture discourages private sector investors. This may lead to a decline in the agricultural sector's growth rate as investors opt for more profitable and less risky alternatives.

**Table 7.** Positive ideal solution and negative ideal solution final ranking of alternatives.

| Climate change adaptation strategies | $d_i^+$ | $d_i^-$ | $CC_i$ | Rank |
|---|---|---|---|---|
| Crop varieties | 0.1038 | 0.0986 | 0.4872 | 8 |
| New irrigation technology | 0.0814 | 0.1189 | 0.5935 | 2 |
| Land sale | 0.1544 | 0.0225 | 0.1270 | 11 |
| off-farm employment | 0.1190 | 0.1136 | 0.4885 | 7 |
| Laser leveling of lands | 0.0807 | 0.0915 | 0.5316 | 5 |
| Drainage management | 0.0785 | 0.0916 | 0.5385 | 4 |
| Insurance | 0.0911 | 0.0844 | 0.4810 | 9 |
| Minimum / Zero tillage | 0.0825 | 0.0917 | 0.5265 | 6 |
| Less irrigation | 0.1341 | 0.0608 | 0.3120 | 10 |
| Change crop pattern | 0.0771 | 0.0952 | 0.5526 | 3 |
| Irrigation cannels repair | 0.0661 | 0.1317 | 0.6658 | 1 |

## DISCUSSION

The objective of the current study was to apply the FAHP and TOPSIS to evaluate climate change adaptation measures in the Doroodzan Dam basin in Fars Province. The goal was to identify the most economically viable, ecologically sustainable, and technically feasible adaptation strategy for farmers in this basin from a range of options available to address climate change impacts. According to the findings, the most suitable options for adapting to climate change are the modification of irrigation channels and the implementation of new irrigation technology, with scores of 0.6658 and 0.5935, respectively. Conversely, the sale of land, with a score of 0.1270, was deemed the least appropriate option. This finding broadly supports the work of other studies (Delgado *et al*. 2011; Kenney 2014; Rosa 2022) in this area linking water conservation activities with climate change. Based on the assessment of adaptive strategy adoption, it is advised to enhance irrigation efficiency in agricultural operations. To achieve this, it is recommended to repair channel covers, implement suitable water distribution systems at the farm level, and transition from traditional surface irrigation methods to modern irrigation systems. In the context of Iran experiencing less than 33% of the world's average annual rainfall, the reliance of agricultural output on irrigated lands is estimated at 90% in Iran, compared to 40% globally. This indicates a significant reliance on irrigation water in Iran's agricultural sector, with water serving as the primary and constraining factor for production. Inefficient irrigation methods and improper water allocation have led to over 60% wastage of water during various stages of plant growth in the country. Considering the evolving weather patterns and the pivotal role of the agricultural sector in ensuring food security, it is imperative to address the water scarcity issue. Enhancing irrigation technology is one viable approach to mitigate water scarcity. The adoption of modern irrigation techniques has the potential to boost agricultural production by 20-70% while reducing water consumption by 30-60% (Pérez-Blanco *et al*. 2020). One of the key strategies to adapt to climate change is to adjust crop cultivation patterns, which ranks as the third priority. This study supports evidence from previous observations (e.g. Abdi-Dehkordi *et al*. 2018; Ghaffar *et al*. 2022; Sedighkia *et al*. 2023). A critical factor in farmers' decision-making is the efficient allocation of resources, often achieved by determining the optimal cultivation pattern. This approach enables farmers to establish the highest income from a specific input combination or at least determine the cost of producing a specific product combination. According to experts,


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effective drainage management and laser land leveling are ranked as the fourth and fifth priority techniques for adapting to climate change. In addition, the findings of the research showed that the option of low tillage and zero tillage is the next priority for adapting to climate change. Conservation agriculture is a crop and ecosystem management strategy aimed at enhancing and maintaining production productivity. Its objective is to increase profitability and food security while mitigating the impact of drought, aligning with findings from prior research (Pisante *et al*. 2015; Powlson *et al*. 2016; Zhang *et al*. 2022). Considering the expected negative effects of climate change on farmers' production and income in the basin, developing non-agricultural activities and small industries in rural areas can help offset potential weather-related damage. Among the various adaptation options to climate change, insurance for agricultural products, less irrigation, and land sales were considered lower-priority options compared to other adaptation strategies. Given the adverse impact of risk on agricultural activities, stakeholders and policymakers are actively seeking strategies to mitigate or minimize these risks. One effective strategy is insuring agricultural products, which can increase farmer income, prevent illegal migration, promote advanced technology, spread new agricultural methods, and provide economic security. An emerging insurance option in the agricultural sector involves utilizing weather indicators as the basis for coverage (Adetoro *et al*. 2022). This type of insurance is specifically tailored to address losses in agricultural output resulting from fluctuations in weather patterns. These plans rely on weather indicators, particularly precipitation and temperature, which have a strong correlation with agricultural yields. Increasing awareness about the effects of climate change adaptation strategies can significantly influence farmers to adopt adaptive measures. Thus, organizing promotional workshops and raising farmers' awareness can effectively incentivize the implementation of resource conservation activities and adaptation to climate change in the region.

## CONCLUSION

As mentioned in the literature review, in recent decades, climate change has emerged as a critical concern in the agriculture sector, significantly impacting crop production. Understanding how farmers adapt to climate change is crucial for policymakers to develop effective policies. The adaptation process can be divided into two stages: first, farmers need to be aware of the changing climate, and then they should respond to these changes through adaptation. Adapting to climate change involves a range of strategies to help communities, ecosystems, and economies become more resilient to its impacts. Given that sustainable water resources management options have been identified as the best adaptation options and the water crisis is considered one of the most serious challenges for the province's agricultural sector, water policymaking should shift from supply management to demand management. This transformation requires moving from the traditional approach of building water infrastructure towards optimizing consumption at the farm level. Governments can encourage farmers to adopt modern irrigation methods through subsidies, education, extension services, demonstration projects, improved access to credit, water pricing policies, and public-private partnerships. These strategies create a supportive environment for sustainable and efficient water use in agriculture. In addition, modifying cultivation patterns is a crucial strategy for adapting to climate change. Crop pattern planning based on the actual capacity of water resources by creating a trading system for agricultural water rights could be suitable for the region, so that farmers who reduce water consumption by changing their cultivation pattern can sell their rights to others. Finally, our study is one of the first attempts to combine fuzzy hierarchy processes and TOPSIS in evaluating climate change adaptation options in Iran, which ranked climate change adaptation solutions with the participation of experts in model development. However, there are some limitations of our study that can be addressed to increase the accuracy of our results. These limitations include the subjective nature of expert judgments, the static nature of MCDM, the regional specificity that limits the possibility of recommending these options for other regions, and the lack of a cost-benefit analysis of implementing the selected options. It is suggested that future research should consider integrating dynamic modeling into the assessment of climate change adaptation options, stakeholder participatory approaches, and agent-based modeling, or post-implementation evaluation of implemented strategies.

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**Appendix**

**Table 1:** Linguistic, fundamental and fuzzy scales

| Linguistic terms | The fundamental scale of AHP (i) | Fuzzy membership function ($l_{ij}$, $m_{ij}$, $u_{ij}$) | **Fuzzy** Reciprocals ($1/l_{ij}$, $1/m_{ij}$, $1/u_{ij}$) |
|---|---|---|---|
| Equal importance (Eq) | 1 | (1,1,1) | (1,1,1) |
| Moderate importance (M) | 3 | (2,3,4) | (1/4,1/3,1/2) |
| Strong importance (S) | 5 | (4,5,6) | (1/6,1/5,1/4) |
| Very strong importance (VS) | 7 | (6,7,8) | (1/8,1/7,1/6) |
| Extremely strong importance (ES) | 9 | (9,9,9) | (1/9,1/9,1/9) |
| Intermediate values | 2 | (1,2,3) | (1/3,1/2,1/1) |
| | 4 | (3,4,5) | (1/5,1/4,1/3) |
| | 6 | (5,6,7) | (1/7,1/6,1/5) |
| | 8 | (7,8,9) | (1/9,1/8,1/7) |

**Table 2**: Saaty's 1-9 ratio scale (Saaty, 1990)

| **Numerical values** | **Verbal preferences** |
|---|---|
| **1** | Equally preferred |
| **3** | Slightly preferred |
| **5** | Well preferred |
| **7** | Very well- preferred |
| **9** | Extremely preferred |
| **2,4,6 and 8** | Represent the values in between |

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