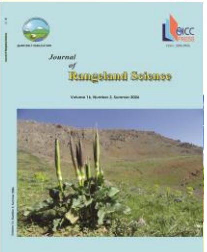

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Research Article

An Interpretive Structural Model for Balancing between Biodiversity Protection and Local Livelihoods in the Almabolaq Protected Area, Hamadan Province, Iran

Aminollah Sahab Mahmoodi, Mohammad Reza Gili, Iman Saeedi*

Department of Environmental Sciences and Engineering, Malayer University, Malayer, Iran

*Corresponding author: Isaeedi@malayeru.ac.ir

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Abstract

Protected areas worldwide face hard trade-offs between biodiversity conservation and supporting local livelihoods. This study was conducted to integrate the Fuzzy Delphi and Interpretive Structural Modeling (ISM) to evaluate socio-economic threats in Almabolaq protected area, Hamedan province, Iran, in 2023. This research was based on expert input from 16 specialists, who identified 10 key threats, including overgrazing, land-use changes, burning of shrubs, and the use of pesticides, which substantially contributed to biodiversity loss. The fuzzy Delphi analysis of 21 factors using triangular fuzzy numbers (Definite Value threshold = 3.65) revealed that among the 10 threats, overgrazing, with a value of 4.58 ± 0.14, accounted for 11.6% of the total threats, had the highest rank. The ISM modeling organized these threats into a four-tier strategy: Level 1: prioritize education and awareness. Level 2: had focused on strengthening legal oversight and managing population pressures. Level 3: emphasized enhanced management practices and social awareness, and Level 4: emphasized specific conservation interventions, such as determining grazing boundaries and promoting sustainable practices. Notably, community engagement emerged as the most influential strategy, effectively linking conservation objectives with local socio-economic needs.By explicitly addressing these trade-offs, our study provides actionable recommendations for policymakers and protected area managers, offering a practical framework to balance ecological integrity with sustainable human development.

Keywords: Biodiversity Conservation, Iran, Environmental Modeling, Socio-economic Drivers, Sustainable Development

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1. Introduction

Protected areas serve as vital hubs for both biodiversity conservation and human interaction with nature (Silva et al., 2025). While they safeguard ecological integrity, they also provide essential resources, supporting the livelihoods of approximately 1.1 billion people and supplying drinking water to major urban centers (Zhong et al., 2023). Additionally, these landscapes contribute to economic growth through ecosystem services and tourism (Stojanović et al., 2024; Wu et al., 2021). However, the benefits of protected area tourism are not evenly distributed; some communities experience limited socio-economic gains or even negative impacts (Mensah et al., 2021). This complex interplay between ecological protection and human well-being highlights the need for conservation strategies that acknowledge trade-offs and mitigate unintended consequences (Robaina et al., 2024). A range of human activities from large-scale industrial operations to small-scale livelihood practices like subsistence farming, overgrazing, and artisanal logging poses significant threats to biodiversity within protected areas through land degradation and resource depletion (Abdelsalam et al., 2017; Azhar et al., 2023; Darabi and Saeedi, 2019; Rawat and Agarwal, 2015). These pressures, compounded by habitat destruction, species displacement, and climate-related stressors, lead to profound biodiversity losses (Akhzari et al., 2015; Habibullah et al., 2022). This creates a critical challenge for conservation policies, which must navigate a delicate balance between safeguarding ecosystems and addressing the needs of local populations who often depend on these same natural resources for survival (McShane et al., 2011). The persistence of issues like illegal hunting, wildfires, and pollution further underscores the complexity of this task. Thus, effective strategies must move beyond traditional protectionist approaches and incorporate community engagement, equitable resource management, and sustainable policy interventions (McShane et al., 2011; Saeedi et al., 2022; Shiran et al., 2018). Explicitly acknowledging the unavoidable trade-offs between conservation and socio-economic priorities is a fundamental step toward more informed decision-making and realistic expectations (Cheung and Sumaila, 2008; McShane et al., 2011).

A review of the scientific literature highlights the complex interplay between ecological preservation and socio-economic factors in protected areas. For instance, McShane et al. (2011) examined the inherent trade-offs between biodiversity conservation and human well-being, challenging the feasibility of universally beneficial "win-win" solutions. Findings emphasize the need for transparency in acknowledging losses and costs, advocating for open discussions and negotiations to prevent unrealistic expectations and unresolved conflicts. The study critiques traditional conservation approaches and presents guiding principles to help conservationists navigate these trade-offs strategically, ensuring that both environmental and human interests are considered in decision-making. Dudley et al. (2014) examined the evolving role of protected areas as a fundamental conservation tool, assessing their effectiveness and addressing criticisms regarding their social and ecological impacts. They identified six major factors shaping protected areas: a refined definition emphasizing nature conservation, diverse governance models, recognition of broader socio-economic benefits, strengthened social safeguards, empirical evidence supporting their effectiveness, and an increased focus on large-scale and transboundary conservation. Mora and Sale (2011) highlighted the technical and practical shortcomings of protected areas and advocated for additional solutions to address biodiversity decline. Their results revealed that while well-managed protected areas can successfully stem biodiversity loss at local scales, they are insufficient as a standalone global solution. Key shortcomings include gaps in ecological coverage, failure to address broader environmental threats, budget constraints, and conflicts with human development.

Similarly, Gallacher et al. (2016) emphasized the role of socio-economic conditions in marine protected areas. They identified 13 key factors that influenced conservation success, underscoring the necessity of monitoring economic and social dynamics alongside ecological metrics. In South Africa, Clements et al. (2020) examined 112 protected areas. They showed that threats to biodiversity, including illegal hunting, severe weather, and invasive species, were deeply intertwined with broader socio-economic issues such as crime, national policies, and economic downturns. These findings highlight the importance of adaptive conservation frameworks that address both environmental and socio-political challenges. Shumba et al. (2021) examined how land use, governance structures, economic conditions, and ecological attributes shape the effectiveness of conservation efforts. Their findings underscored the need for integrated management approaches that account for both biodiversity and human well-being. By recognizing these interdependencies, conservation strategies can achieve more sustainable outcomes, particularly on private lands.

Koricha and Jemal Adem (2024) in the Bale Mountains National Park, Ethiopia, demonstrated that communities engaged in conservation associations had substantially higher benefits from the park. Furthermore, communities engaged in conservation contributed more actively to its protection, such as controlling wildfires and mitigating human-wildlife conflict, compared to non-associated groups (Koricha and Jemal Adem, 2024). This finding underscores a powerful global lesson: the success of conservation strategies is often contingent upon tangible socio-economic incentives and genuine community participation. This global narrative of trade-offs is vividly reflected in the context of Iran's protected areas. The country's network of conservation zones faces a convergence of intense, interconnected pressures. Widespread issues such as overgrazing, illegal hunting, and agricultural encroachment are frequently compounded by broader national challenges, including economic sanctions. These challenges limit conservation funding, climate change-induced droughts, and substantial land-use changes driven by development projects (Jowkar et al., 2016; Karimi & Jones, 2020; Saeedi et al., 2023). These factors create a complex socio-ecological landscape where biodiversity conservation is persistently pitted against immediate human livelihood needs, making the development of context-specific,

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balanced management strategies not just beneficial but important for the survival of these ecosystems. In Iran, research on the socio-economic pressures affecting biodiversity conservation remains limited. Jowkar et al. (2016) identified key threats, including population growth, climate change, agriculture, illegal hunting, and economic sanctions, all of which contributed to ecological degradation. Karimi and Jones (2020) further explored human pressures on Iran's protected areas, advocating for expanded conservation zones and improved management practices. They acknowledged that balancing conservation priorities with human needs is essential for developing policies that promote long-term ecological resilience and support local livelihoods. The Almabolaq Protected Area is located in the mountainous region of Hamadan province, Iran. SafiKhani (2023) provided an inventory of plant diversity, identifying 161 species across 48 families, with Asteraceae, Fabaceae, and Poaceae as dominant groups in the area. This rich plant diversity includes endemic and medicinal species, contributing to both conservation value and potential socio-economic benefits. However, the increasing anthropogenic pressures on Almabolaq emphasize the urgency of developing management strategies that align conservation efforts with sustainable resource use. Preserving plant diversity must go beyond restrictive protection measures—it should include collaborative approaches that enable local communities to participate in conservation while maintaining their economic stability. Despite Almabolaq's ecological significance, targeted research on the socio-economic dynamics influencing its conservation remains scarce. Given its location and reliance on natural resources, understanding how agricultural practices, overgrazing, and encroachment interact with biodiversity loss is important. Therefore, this study aimed to: 1) Identify and quantitatively prioritize the key socio-economic threats to biodiversity in the Almabolaq Protected Area using Fuzzy Delphi, and 2) Develop a structured hierarchy of management strategies to mitigate these threats using Interpretive Structural Modeling (ISM), explicitly addressing the trade-offs between conservation and local livelihoods. By integrating ecological sustainability with socio-economic development, Almabolaq can serve as a model for protected areas of Iran, demonstrating how biodiversity conservation and human well-being can coexist through informed, adaptive management approaches.

2. Materials and methods

2.1. Study area

The Almabolaq Protected Area is a mountainous, hilly, and sloped region located in the geographical domain of Hamadan Province, in the western part of Iran (Fig1). This area is situated approximately 14.4 km north of Asadabad County and 35 km southwest of Hamadan City, within the geographical coordinates of 34°53' to 34°57' north latitude and 48°07' to 48°12' east longitude. The total area of this region is 9,696 ha. Almabolaq Protected Area, characterized by its mountainous and hilly landscape. It is also an important habitat for the Armenian sheep and goats in the province. This area is renowned for its rich biodiversity, particularly as a vital habitat for the endangered Armenian mouflon (*Ovis orientalis gmelini*) and numerous plant species. Although the Almabolaq area is classified as a protected zone, our field observations indicated that traditional pastoral use by local herders and nomads persists.

Almabolaq's ecological substance is complemented by its varied topography, with elevations ranging from 1,975 to 2,946 m above sea level, resulting in a unique microclimate that supports a wide range of flora and fauna. The region has slopes exceeding 30%, predominantly having relatively flat areas only in the northern regions near villages. According to the nearest meteorological data station (2010-2020), the average annual precipitation is 354.7 mm. Water resources include rivers, subterranean canals (Qanats), and numerous springs that sustain the region's wildlife. Additionally, the area hosts a rich and diverse plant cover comprising herbaceous, shrub, and tree species, which thrive due to the favorable geographical and climatic conditions.

This area is near 20 villages, among which the most important are Malhamsadeh, Tajabad, Tarakhinabad, Biyaj, Chenar-e-Aliya, Mohammadabad, Pir Malu, Qara Kand, and Baba Ali. The main economic activities of the inhabitants are agriculture and animal husbandry, while some are employed in mining. The residents of these villages speak Turkish, Kurdish, and, in some communities, Luri and Laki. One of the main challenges facing the region is excessive livestock grazing due to the presence of nomadic groups. Other threats include land encroachments, land use changes, habitat destruction, hunting and poaching, large-scale projects, deforestation, and desertification. To address the landscape context and the socio-economic diverse central to this study, Fig 2 presents a Normalized Difference Vegetation Index (NDVI) map of the Almabolaq Protected Area and its immediate periphery (Landsat 9, 2025, summer). The NDVI values, derived from satellite imagery, serve as a robust proxy for evaluating the distribution and health of plant communities across the region. As shown in Fig 2, the vegetation cover within Almabolaq is limited and vulnerable, with the densest and healthiest plant communities concentrated in valleys and areas of more fertile soil. The mountainous terrain and inherently limited vegetation suggest that the area is susceptible to degradation, allowing us to predict that overgrazing would have a significant impact on its plant diversity. Furthermore, the map highlights two critical anthropogenic pressures: the proximity of the protected area to roads, which helps access and potential disturbance, and the presence of an iron ore mine in the northeast of the study area, which is a manipulated area and a source of visual pollution on the landscape.

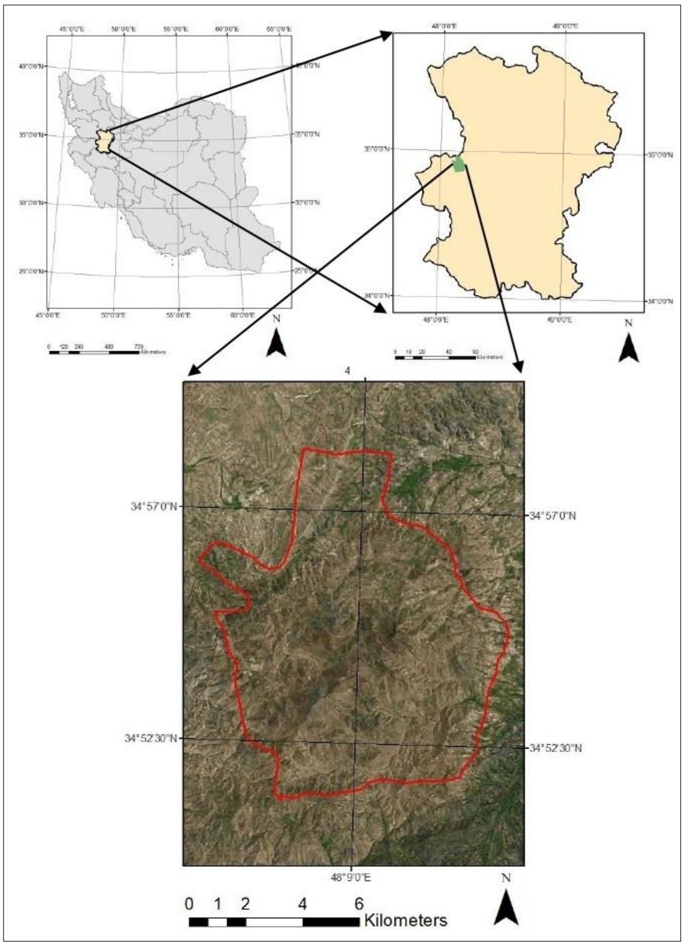

Figure 1. The location of the study area in the west of Hamedan province, Iran

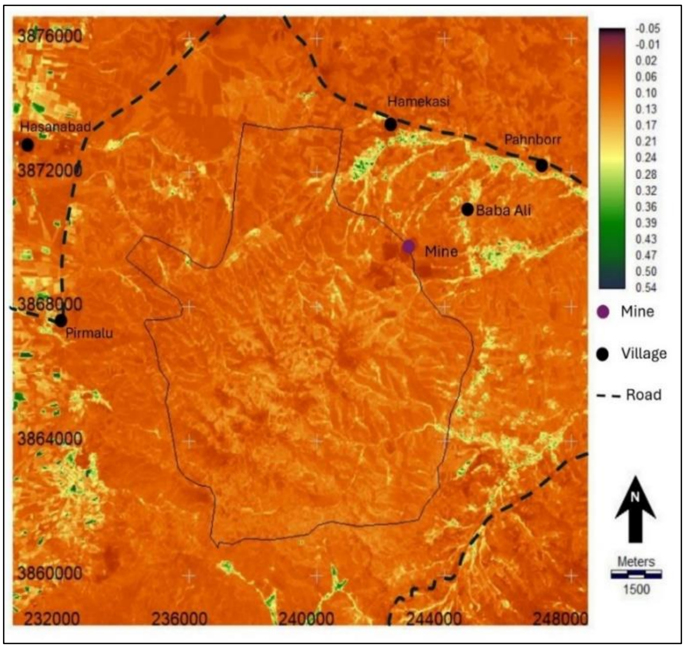

Figure 2. NDVI index of Almabolaq Protected Area as well as surrounding villages and roads

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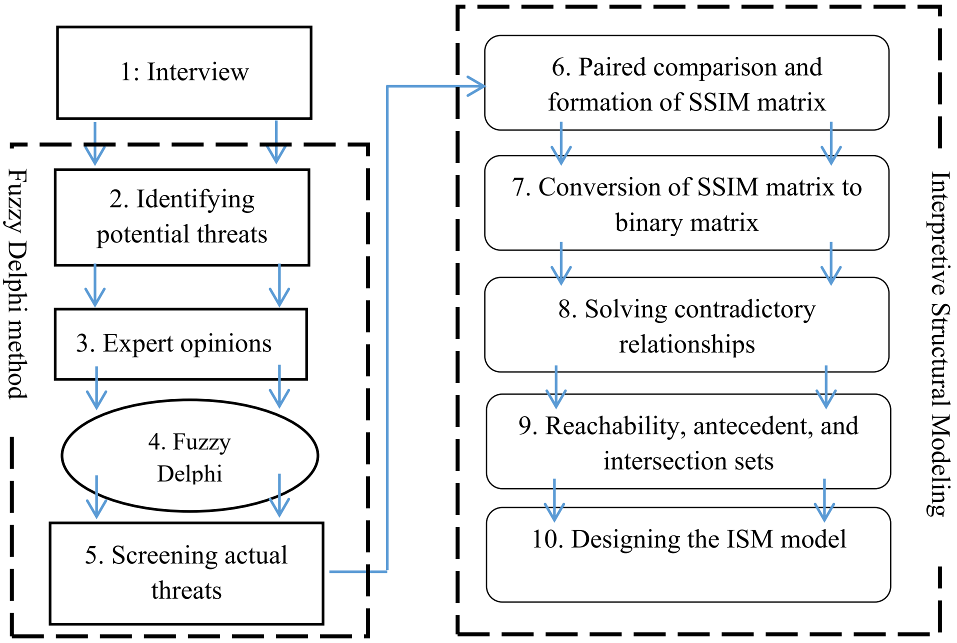

Figure 3. Steps of the methodology used in this research

2.2. Research method

This study adopts a structured two-step methodological approach to examine the trade-offs between biodiversity conservation and socio-economic factors. First, expert interviews were conducted to identify key socio-economic factors affecting conservation efforts. The fuzzy Delphi method was then employed to systematically filter and prioritize these influencing factors, ensuring a nuanced understanding of their significance. Second, Interpretive Structural Modeling (ISM) was used to analyze the interrelationships between these factors, highlighting the complex interactions that shape conservation outcomes. For the Fuzzy Delphi analysis, Microsoft Excel (Version 2021) was used. The Interpretive Structural Modeling (ISM) was performed using R software (Version 4.3.1) with the ism package. This approach helped a balanced evaluation, enabling the development of strategies that acknowledge both ecological protection and socio-economic realities. The methodological framework guiding this research is illustrates in Fig 3.

2.3. Step one: identifying potential socio-economic influencing factors

The data collection process, including expert interviews and the distribution of all questionnaires for both the Fuzzy Delphi and ISM phases, was conducted during Spring 2024 (March to June). The identification of potential socio-economic factors influencing biodiversity conservation in Almabolaq was conducted through structured expert interviews with professionals specializing in environmental sciences, watershed management, forestry, biodiversity, and rangeland engineering. Recognizing socio-economic conditions as opportunities rather than threats, the study sought to understand how conservation efforts could integrate local livelihoods while maintaining ecological integrity. A purposive sampling approach was employed to ensure diverse perspectives from experts with wide experience in environmental management and conservation. A total of 16 experts participated, all holding executive positions in their respective fields, with employment histories ranging from 10 to more than 20 years. The selection of 16 experts was determined through a purposive sampling strategy aimed at achieving thematic saturation, the point at which additional interviews or survey rounds no longer yield original information or insights. Given that all participants were highly experienced executives and specialists with direct, long-term, direct engagement in the environmental management of the region, their collective expertise provided a deep and detailed understanding of the socio-economic dynamics in Almabolaq. The high degree of consensus achieved in the Fuzzy Delphi phase, coupled with the rich, nuanced data obtained from this expert cohort, confirms that saturation was reached, making a larger sample size unnecessary for the purposes of this study. Their academic backgrounds include Master's and Doctorate degrees, ensuring a high level of expertise in areas such as environmental sciences, biodiversity, watershed management, forestry, and rangeland engineering. The expert group was selected based on their direct engagement with conservation issues and resource management, ensuring well-informed insights relevant to Almabolaq's socio-economic and ecological landscape.

The interviews followed a semi-structured format, enabling both guided inquiries and open-ended discussions. Experts provided insights into the

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interactions between socio-economic activities and biodiversity conservation, emphasizing resource dependence, governance frameworks, agricultural expansion, and land management strategies.

Key discussion themes included:

1. Community Resource Use: How local populations rely on Almabolaq's ecosystems for livelihoods.
2. Governance Challenges: Policy limitations affecting conservation outcomes.
3. Economic Drivers: The role of agricultural expansion, livestock management, and employment pressures.
4. Collaborative Opportunities: Pathways for integrating conservation efforts with sustainable development.

The insights gathered from these discussions were synthesized into an initial list of influencing factors, which formed the basis for further evaluation.

2.4. Screening key factors using the fuzzy delphi method

After identifying the relevant socio-economic conditions affecting biodiversity, the next step was to systematically evaluate and prioritize these factors using the fuzzy Delphi method. This approach is particularly suited to addressing complex and uncertain contexts, as it incorporates expert consensus while refining variables that influence conservation and development outcomes. The selected group of experts was invited to participate in this stage, where they assessed the significance of each identified factor through a structured questionnaire. Each question solicited expert opinions on the degree to which specific socio-economic conditions impact biodiversity conservation and sustainable resource management.

The fuzzy Delphi method combines traditional Delphi techniques, which help expert consensus through iterative surveys, with fuzzy theory, which enables nuanced data processing under uncertainty (Habibi et al., 2015).

Below are the key steps in applying this method:

1. Problem Identification: Defining the research objectives and key questions surrounding conservation and socio-economic interactions.
2. Questionnaire Development: Designing a structured questionnaire to capture expert opinions on the relative importance of various socio-economic and ecological factors.
3. Opinion Collection: Conducting surveys where experts evaluate factors using fuzzy scales (such as fuzzy numbers or Likert scales) to allow for nuanced assessments.
4. Data Analysis: Applying mathematical and statistical techniques to synthesize expert input and identify prioritized variables for conservation planning.
5. Final Results Compilation: Refining the findings through multiple rounds of expert feedback, leading to a comprehensive list of prioritized socio-economic conditions that influence conservation efforts.

By positioning socio-economic dynamics as conditions and opportunities rather than threats, this research fostered an approach that integrates biodiversity conservation with sustainable development. The goal is to create adaptive strategies that not only protect Almabolaq's ecosystems but also empower local communities, ensuring that conservation and human livelihoods evolve in tandem.

The fuzzy Delphi method has been explained for screening purposes in various scientific texts, with one of the most reputable approaches involving the use of averages (Habibi et al., 2015). In this study, calculations were based on averages. In this method, the opinions of experts were presented as triangular fuzzy numbers (l, m, u), which are combined by computing the average for each component separately. Thus, the averages of the triangular fuzzy numbers l, m, and u were computed, respectively. The final result is a new triangular fuzzy number that indicates the average opinions of all experts. Equations (1), (2), and (3) describe how to calculate the averages of triangular fuzzy numbers (Habibi et al., 2015).

calculation of *l*:

$$l = \frac{\sum_{i=1}^{n} l_i}{n} \quad (1)$$

calculation of *m*:

$$m = \frac{\sum_{i=1}^{n} m_i}{n} \quad (2)$$

calculation of *n*:

$$n = \frac{\sum_{i=1}^{n} n_i}{n} \quad (3)$$

Where:

n represents the number of experts.

l_i, m_i, and n_i correspond to the minimum, most likely, and maximum values, respectively, as provided by expert i.

The values l, m, and n denote the triangular fuzzy number resulting from the averaging process. Finally, to calculate the fuzzy value for each criterion is the average of l, m, and n values.

2.5. Step two: Identifying relationships among influencing factors using ISM

The goal of this step is to develop a clear structural model for the conservation of biodiversity in the study area. The ISM phase builds upon this by strategically structuring these pre-validated factors to reveal their interplay and hierarchy, providing a clear roadmap for intervention that a simple list of weighted factors cannot offer. "The Interpretive Structural Model (ISM) was conducted in five phases to clarify the relationships between the socio-economic factors. The ISM is a popular method developed

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by Warfield in 1973 for analyzing the intricate interrelations among various components within complex situations. It enables researchers to transform ambiguous and complex systems into clear and organized models by leveraging the insights and expertise of specialists (Saeedi et al., 2022). Essentially, ISM serves as a tool for effectively delineating the interactions among specific elements in a system (Gholami et al., 2020). The primary goal of ISM is to streamline the creation of a diagram, which can later be developed into a structural model that reflects users' perspectives of the given situation through inspection and revision (Malone, 1975). According to Raut et al. (2017), the ISM approach has several advantages: it simplifies complex systems with numerous variables, provides clarity on fixed objects, and helps the identification of a system's structure.

The modeling steps included paired comparisons, the establishment of a Structural Self-Interaction Matrix (SSIM), conversion of the SSIM relationships into a binary matrix, correction of any conflicting relationships, determination of accessibility capabilities, and design of a hierarchical diagram. In the first stage, a questionnaire based on the ISM framework was designed to elicit the participants' tacit knowledge regarding the relationships among the screened indicators in the study area. The core of this questionnaire involved a matrix filled with the screened indicators from the previous stage. Participants were asked to indicate whether indicator *i* influences indicator *j*, whether the reverse is true, or if there is a mutual influence between the two components.

According to the ISM method, four symbols (V, A, X, O) are used to represent the types of relationships between two indicators. Specifically, if indicator (i) influences indicator (j), symbol V is employed. If indicator (j) influences indicator (i), symbol A is used. In cases of mutual influence, symbol X is applied, and symbol O is used when there is no relationship between indicators (i) and (j). The output of this process results in the creation of a Structural Self-Interaction Matrix (SSIM). The authors used mode to compile a comprehensive SSIM. The application of mode statistics in the ISM to generate the SSIM has been documented in previous studies (Mandal and Joshi, 2015; Saeedi et al., 2022; Sarikhani et al., 2020). Subsequently, The converting of the SSIM into a binary matrix is presented in Table 1.

There may be contradictions in the results of these primary accessibility matrices. For example, if indicator A influences indicator B, and indicator B influences indicator C, we would logically expect that indicator A should also influence indicator C. To address these conflicting relationships, Equation 4 was used (Azar et al., 2019).

$$SSIM = Boolean(A^{n-1} = A^{n}) \quad (4)$$

Where:

A, equals to the matrix, and n equals to the number of iteration

3. Result

3.1. Identifying potential socio-economic factors

In the first step, to identify potential socio-economic factors affecting biodiversity in the protected area, a questionnaire was designed and distributed among specialists, familiar with the Almabolaq Protected Area. As stated in the research method, the development of this questionnaire involved a review of the scientific literature, as well as interviews with experts and specialists. According to expert opinion and considering the research objective, a threshold of 3.65 was selected. Accordingly, 10 criteria were identified as influential factors in the assessment of socio-economic threats affecting biodiversity in the Almabolaq Protected Area. Descriptive statistics of the experts' responses is presented in Table 2. The filled percentage, defined as the percentage of non-zero filled cells (cells with values 1, 2, 3, 4) to the total cells, reflected the complexity of relationships in the system. A higher fill rate in the matrix indicates greater complexity in the direct relationships between variables, making it more challenging to focus on indirect and potential relationships, which come with higher uncertainty. The 100% "Filled Percentage" indicated that every expert provided a rating for every one of the 21 potential threats, demonstrating high engagement and a comprehensive assessment. The distribution of scores showed a strong tendency towards higher-impact ratings, with 157 responses of "4" (Very High Impact) and 116 of "3" (High Impact), collectively constituting 74% of all responses. This indicates a high level of expert consensus on the severity of the socio-economic threats facing the protected area (Table 2).

Table 1. Guidelines for Converting the Self-Interaction Matrix (SSIM) to the binary Matrix (Shahabi et al., 2020)

Symbols of Cell (i,j) in SSIM*	Cell (i,j) In the initial accessibility matrix	Cell (j, i) in SSIM
V	1	0
A	0	1
X	1	1
O	0	0

Table 2. Descriptive Statistics of the Fuzzy Delphi Phase

Filled Percentage	Total Number	N0. 4 (Very High Impact)	N0. 3 (High Impact)	N0. 2 (Medium Impact)	N0. 1 (Low Impact)	N0. 0 (No Impact)	Number of Rows
100%	368	157	116	54	30	11	16

Table 3. Results of Screening Criteria Using the Fuzzy Delphi Method

Question Number	Influential Factors on Biodiversity	L Bound	M Bound	N Bound	Definite value	Status	% of Importance
1	Presence of illegal nomads	1	3.45	5	3.15	✗	
2	Overgrazing and degradation of vegetation cover	4	4.73	5	4.58	✓	11.6
3	Illegal hunting and poaching	1	3.85	5	3.28	✗	
4	Burning of shrubs and bushes	3	4.63	5	4.21	✓	10.7
5	Use of various pesticides	2	4.07	5	3.69	✓	9.4
6	Changes in land use	2	4.07	5	3.69	✓	9.4
7	Deforestation	2	3.76	5	3.59	✗	
8	Farming	2	3.80	5	3.60	✗	
9	Low wages of park rangers	1	3.71	5	3.24	✗	
10	Low number of park rangers	2	3.95	5	3.65	✗	
11	Presence of mines in the area	2	4.04	5	3.68	✓	9.3
12	Proximity to waste disposal sites	1	3.32	5	3.11	✗	
13	Lack of awareness and insufficient information among locals	3	4.52	5	4.17	✓	10.6
14	Population growth and excessive exploitation of resources	2	4.00	5	3.67	✓	9.3
15	Global warming (climate change)	2	3.30	5	3.43	✗	
16	Management of the protected area	2	3.96	5	3.65	✓	9.3
17	Locations of summer and winter grazing areas	1	3.28	5	3.09	✗	
18	Presence of livestock in the protected area	3	4.10	5	4.03	✓	10.2
19	Economic conditions of the country	2	3.89	5	3.63	✗	
20	Tourism in the protected area	1	2.90	5	2.97	✗	
21	Importance and rationale for conservation of the area	1	4.24	4	4.06	✓	10.3
	SUM of accepted status					39.40	100

Note: In this Table, each criterion's status is indicated by a symbol for easy interpretation
(✓) denotes that the criterion was Accepted based on the Fuzzy Delphi method threshold (3.65)
(✗) indicates that it was rejected

Table 4. Factors Affecting Biodiversity and Proposed Solutions for Improving Them

Symbol	Influential Factors on Biodiversity	Proposed Solutions
A1	Overgrazing and degradation of vegetation cover	Limitations on livestock grazing
A2	Burning of shrubs and bushes	Education and cultural awareness
A3	Use of various pesticides	Organic farming
A4	Changes in land use	Strengthening regulations and rules
A5	Presence of mines within the area	Development of sustainable mineral extraction methods
A6	Lack of awareness and insufficient information among locals	Conducting Educational courses
A7	Population growth and excessive exploitation of resources	Population control and sustainable resource use
A8	Management of the protected area	Improvement of management practices
A9	Importance and rationale for conservation of the area	Social and cultural awareness
A10	Presence of livestock in rangelands	Designation of grazing limits

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The results obtained from the screening of the potential indicators are shown in Table 3. As indicated, out of 21 criteria examined, 10 criteria were confirmed as influential. To illustrate the relative weight of each accepted threat, the 'Percent of importance' in Table 3 was calculated by normalizing their Definite Values against the sum of the Definite Values for all ten accepted threats (SUM = 39.40). Each criterion was evaluated based on three fuzzy points, L (minimum), M (medium), and N (maximum) bounds, indicating the severity or significance of the issue. The results include a definitive value calculated from these points and an indicator status that categorizes each issue as either accepted or rejected. Notably, issues related to overgrazing, burning of shrubs, use of various pesticides, changes in land use, presence of mines in the area, lack of awareness, population growth, management of the protected area, and the presence of livestock in the protected area received affirmation. This structured approach underscores the varied impact of human activities and environmental management within the protected region. To further contextualize the relative influence of each threat, the percentage contribution of each accepted factor's Definite Value to the sum of all top 10 threats' Definite Values was calculated. The cumulative Definite Value for all ten threats was 39.40. Overgrazing, with a Definite Value of 4.58, therefore accounted for approximately 11.6% of the total quantified influence ((4.58/39.40)×100). This metric highlights its disproportionate impact compared to other socio-economic threats in the Almabolaq Protected Area (Table 3). Among the 21 criteria evaluated through the Fuzzy Delphi process, illegal hunting and poaching were ultimately rejected (Table 3), with a definite fuzzy value of 3.28 below the acceptance threshold of 3.65. Although illegal hunting is widely recognized as a critical threat in many protected areas, its comparatively lower ranking in Almabolaq appears to be context-specific. Experts indicated that, in this region, factors like overgrazing, land-use changes, and habitat degradation exert a more immediate and detrimental impact on biodiversity. Additionally, local enforcement measures and traditional land-use practices in Almabolaq may effectively suppress illegal hunting activities, reducing their overall influence on biodiversity loss relative to other threats. This decision does not diminish the global significance of illegal hunting; rather, it reflects the particular socio-economic dynamics and existing management practices of the Almabolaq Protected Area.

Based on the aforementioned factors, it was recommended that actions be implemented to enhance and advance the Almabolaq protected area, such as increasing oversight of illegal activities, providing education and awareness programs for local communities, and developing natural resource management initiatives to preserve biodiversity. These measures can contribute significantly to the conservation and improvement of the area's biodiversity status. Consequently, for each of the socioeconomic challenges facing the Almabolaq protected area, the solutions were proposed in Table 4.

The pivotal link between the identified threats and the proposed management strategies is presented in Table 4. As a result, the top 10 socio-economic threats (from Table 3) were translated into actionable solutions. Each solution is directly targeted at mitigating a specific threat. For example, the burning of shrubs poses a serious threat to the ecosystem, as it leads to loss of biodiversity and habitat destruction. The use of various pesticides in the area raises concerns about contamination and the health of non-target species, thereby emphasizing the need for integrated pest management strategies. Changes in land use are critically important, as they affect ecological balance and land sustainability, warranting careful monitoring and regulation. The presence of mines within the protected area poses risks to wildlife and plant species, necessitating stricter enforcement of mining regulations. A lack of awareness among local communities regarding conservation policies indicates the need for education and outreach programs to foster community engagement. Additionally, population growth further strains resources, highlighting the importance of implementing sustainable development practices. Effective management of the protected area is crucial for conservation efforts, enhancing the need for comprehensive policy frameworks. Lastly, the presence of livestock within the area can lead to habitat degradation, signaling the necessity for better management practices to minimize their impact on the ecosystem. This structured approach underscores the varied impact of human activities and environmental management within the protected region.

3.2. Interpretive Structural Modeling

In this section, ISM was employed to outline the relationships among the proposed solutions introduced in the previous stage. The results obtained from the survey questionnaires formed the SSIM matrix. To convert the SSIM into the initial reachability matrix, the procedures outlined in the research methodology were followed (Table 5). Table 5 is the Initial Reachability Matrix, which is a binary (1, 0) representation of the direct relationships between the solutions (A1-A10) as perceived by the experts. A value of '1' in cell (i, j) indicates that solution i directly influences or enables solution j. For example, the '1' at (A1, A9) shows that "Limitations on livestock grazing" (A1) directly influences "Social and cultural awareness" (A9), possibly by making the need for conservation more visible. This matrix is derived directly from the expert responses but may contain transitive inconsistencies (e.g., if A Influences B and B Influences C, then A should also influence C), which are resolved to create the final matrix. As previously mentioned, some relationships between components in the initial reachability matrix may exhibit inconsistencies. Therefore, using the inconsistency removal formula (Equation 4), these inconsistencies were resolved, and the final accessibility matrix was constructed (Table 6). Table 6 is the Final Reachability Matrix, which has been processed to remove inconsistencies and include all transitive relationships. This matrix now shows both direct and indirect influences. The "Driving Power" (sum of each row) indicates the total number of solutions a particular element influences. The "Dependence" (sum of each column) indicates how many solutions influence it. For instance, solution A5 ("Sustainable mineral extraction") has a high dependence (it is influenced by many other solutions) but a low driving power (it influences very few others), making it a highly dependent outcome. Conversely, solution A6 ("Educational courses") has a very high driving power, meaning it is a key leverage point that influences almost every other solution in the system. Based on the final reachability matrix (Table 6), the reachability, antecedent, intersection sets and the level of each solution were identified (Table 7). As explained in the research methodology section, the reachability sets comprised components that can influence a specific component, while the antecedent sets consist of components that a specific component may affect. This Table was used to determine the level of each element in the ISM hierarchy. The process involves iteratively identifying elements whose "Reachability Set" (what they influence) is entirely contained within their "Intersection Set." These elements are placed at the top level of the hierarchy (level four in the model). They are considered the most immediate or output-oriented solutions. In this case, A3 (Organic farming), A5 (Sustainable mineral extraction), and A10 (Designation of grazing limits) are classified at Level 4. This signifies that while they are crucial final interventions, they are highly dependent on the successful implementation of the solutions at lower levels (level three). The level assignment for all solutions is the foundational step for building the hierarchical model (Fig 2). According to this information, the final model representing the relationships among the proposed strategies for enhancing biodiversity within the study area was developed and is presented in Fig 4.

Table 5. Initial reachability matrix of Interpretive Structural Modeling

Symbols of the proposed solutions	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10
A1=Limitations on livestock grazing	1	0	0	0	0	0	0	0	1	1
A2=Education and cultural awareness	1	1	1	1	0	1	1	1	1	1
A3=Organic farming	0	1	1	0	0	0	0	0	0	1
A4=Strengthening regulations and rules	1	1	1	1	1	0	0	1	1	1
A5=Development of sustainable mineral extraction methods	0	0	0	0	1	0	0	0	0	0
A6=Conducting Educational courses	0	1	1	1	1	1	1	1	1	0
A7=Population control and sustainable resource use	0	0	1	1	1	0	1	1	0	1
A8=Improvement of management practices	1	0	1	1	1	0	0	1	0	1
A9=Social and cultural awareness	0	0	1	0	1	1	1	1	1	1
A10=Designation of grazing limits	1	0	1	0	0	0	0	0	0	1

Table 6. Final reachability matrix of Interpretive Structural Modeling

Symbols of the proposed solutions	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10
A1=Limitations on livestock grazing	1	0	1	0	1	1	1	1	1	1
A2=Education and cultural awareness	1	1	1	1	1	1	1	1	1	1
A3=Organic farming	1	1	1	1	0	1	1	1	1	1
A4=Strengthening regulations and rules	1	1	1	1	1	1	1	1	1	1
A5=Development of sustainable mineral extraction methods	0	0	0	0	1	0	0	0	0	0
A6=Conducting Educational courses	1	1	1	1	1	1	1	1	1	1
A7=Population control and sustainable resource use	1	1	1	1	1	0	1	1	1	1
A8=Improvement of management practices	1	1	1	1	1	0	0	1	1	1
A9=Social and cultural awareness	1	1	1	1	1	1	1	1	1	1
A10=Designation of grazing limits	1	1	1	0	0	0	0	0	1	1

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Table 7. The reachability, antecedent, and intersection sets and level for each of the 10 components

Symbol	Reachability set	Antecedent set	Intersection sets	level
A1	A1 A3 A5 A6 A7 A8 A9 A10	A1 A2 A3 A4 A6 A7 A8 A9 A10	A1 A3 A6 A7 A8 A9 A10	3
A2	A1 A2 A3 A4 A5 A6 A7 A8 A9 A10	A2 A3 A4 A6 A7 A8 A9 A10	A2 A3 A4 A6 A7 A8 A9 A10	2
A3	A1 A2 A3 A4 A6 A7 A8 A9 A10	A1 A2 A3 A4 A6 A7 A8 A9 A10	A1 A2 A3 A4 A6 A7 A8 A9 A10	4
A4	A1 A2 A3 A4 A5 A6 A7 A8 A9 A10	A2 A3 A4 A6 A7 A8 A9	A2 A3 A4 A6 A7 A8 A9	2
A5	A5	A1 A2 A4 A5 A6 A7 A8 A9	A5	4
A6	A1 A2 A3 A4 A5 A6 A7 A8 A9 A10	A1 A2 A3 A4 A6 A9	A1 A2 A3 A4 A6 A9	1
A7	A1 A2 A3 A4 A5 A7 A8 A9 A10	A1 A2 A3 A4 A6 A7 A9	A1 A2 A3 A4 A7 A9	2
A8	A1 A2 A3 A4 A5 A8 A9 A10	A1 A2 A3 A4 A6 A7 A8 A9	A1 A2 A3 A4 A8 A9	3
A9	A1 A2 A3 A4 A5 A6 A7 A8 A9 A10	A1 A2 A3 A4 A6 A7 A8 A9 A10	A1 A2 A3 A4 A6 A7 A8 A9 A10	3
A10	A1 A2 A3 A9 A10	A1 A2 A3 A4 A6 A7 A8 A9 A10	A1 A2 A3 A9 A10	4

#The Symbols of A1…, A10, is presented in the Table 6

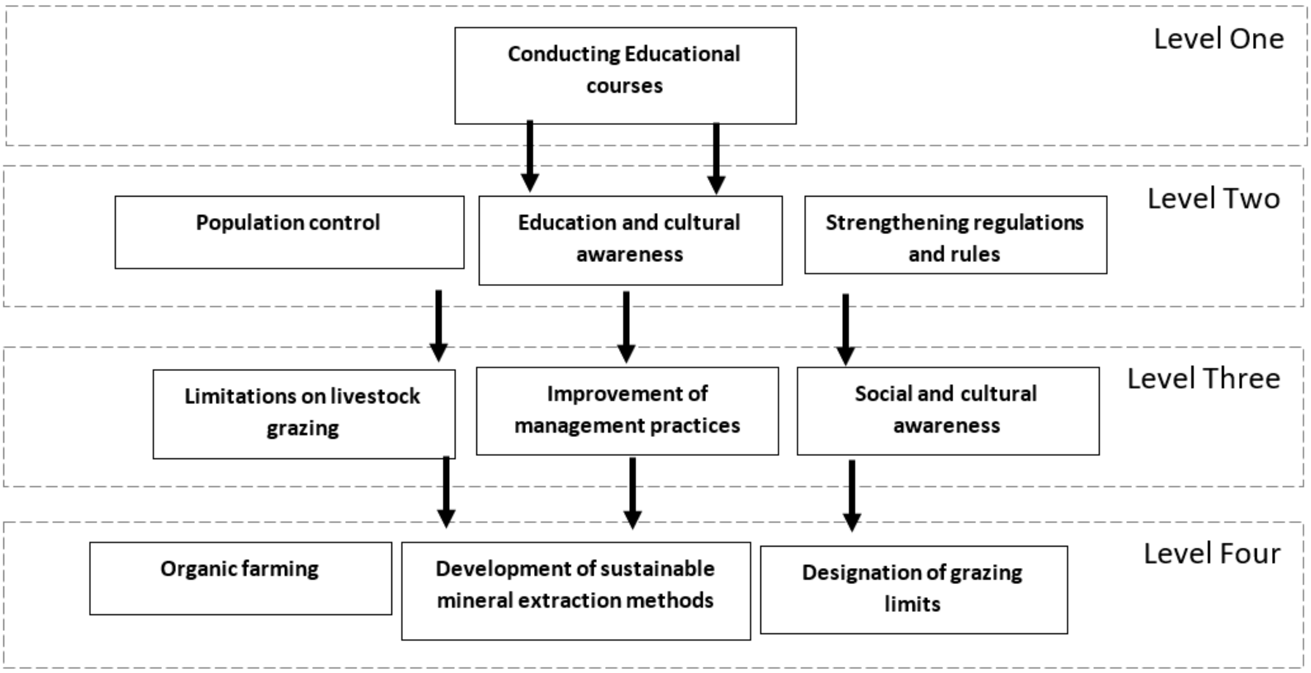

Figure 4. Final Interpretive Structural Model for balancing between biodiversity protection and local livelihoods in the Almabolaq Protected Area

4. Discussion

The findings of this study underscore the complex interplay between conservation priorities and socio-economic challenges in the Almabolaq Protected Area. The results align with broader conservation research emphasizing the necessity of adaptive governance and community engagement (Gallacher et al., 2016; Shumba et al., 2021). It is noteworthy to mention, the application of Fuzzy Delphi and Interpretive Structural Modeling (ISM) has enabled a structured evaluation of these threats, facilitating a tiered strategy that prioritizes both ecological integrity and socio-economic resilience. Our findings from Almabolaq align with the threat profiles identified in other Iranian protected areas. The prominence of overgrazing, land-use change, and population pressure as primary drivers of biodiversity loss resonates strongly with the nationwide human footprint analysis conducted by Karimi and Jones (2020), who identified agriculture and urban expansion as substantial pressures. Similarly, the threats we identified support the work of Jowkar et al. (2016), who listed population growth, agricultural expansion, and illegal hunting as key national challenges. However, our localized analysis reveals a critical nuance: while illegal hunting is a nationally recognized threat (Jowkar et al., 2016), it was filtered out in Almabolaq during the Fuzzy Delphi phase. This indicated that in this specific socio-ecological context, habitat degradation from livelihood activities like overgrazing was a more immediate and severe driver of biodiversity loss than hunting, possibly due to effective local enforcement or cultural norms. A substantial challenge in conserving biodiversity in the Almabolaq Protected Area lies in the negotiated outcomes between ecological preservation and local socio-economic realities. The local population's limited awareness of the area's ecological significance due to restricted access to scientific and educational resources contributes to harmful behaviors such as illegal hunting, tree cutting, and habitat destruction. While strengthening environmental education is crucial for biodiversity conservation, it must be approached with sensitivity to local livelihoods. Simply advocating for strict conservation policies without addressing the economic dependencies of local communities may cause resistance rather than cooperation. Therefore, integrating biodiversity awareness programs with tangible socio-economic benefits such as ecotourism and sustainable agricultural practices can enhance both conservation effectiveness and local engagement (Bunch, 2003).

In the Almabolaq Protected Area, population growth and resource overexploitation were identified as critical challenges, directly pressuring biodiversity through the expansion of unsustainable agriculture and pastoralism. Our ISM model positioned "population control and sustainable resource use" as a level 2 strategy, indicating it is a key leverage point that enables more specific interventions like organic farming and grazing limits. This suggests that managing this driver is fundamental to reducing habitat degradation and the decline in species diversity within Almabolaq. While strategies to manage population pressure are essential, conservation policies must explicitly recognize the associated trade-offs. This finding aligns with global research; for instance, overly restrictive measures can hinder local economic opportunities and social stability, making it critical to develop policies that balance ecological protection with socio-economic resilience (Cafaro et al., 2022). The intensification of resource use leading to habitat degradation is a pattern also was observed in other contexts (Galbraith et al., 2014), underscoring the universal complexity of this dilemma.

The management approach of the region plays a decisive role in shaping conservation outcomes. Top-down conservation policies that fail to incorporate local perspectives can inadvertently exacerbate habitat destruction and ecosystem degradation. By adopting stakeholder-inclusive management models, conservation initiatives can align with both ecological goals and community priorities, thereby reducing conflict and fostering long-term sustainability (Armatas et al., 2022). Ensuring that negotiated outcomes in conservation decisions are acknowledged and negotiated—rather than overlooked—can lead to more robust conservation strategies and improved biodiversity outcomes (Kyaschenko et al., 2022). Beyond biodiversity, the Almabolaq Protected Area offers critical ecosystem services that directly support local communities, serving as a source of drinking water and a habitat for unique species. Conservation policies must account for both ecological integrity and socio-economic needs, ensuring that protected areas remain viable for future generations while sustaining the quality of life for residents. Ignoring these trade-offs risks alienating communities whose dependence on natural resources cannot be disregarded. As such, successful conservation efforts require alignment with local socio-economic aspirations, ensuring equitable outcomes.

This study has proposed an ISM model for addressing socio-economic factors reinforces the need for an explicit discussion of trade-offs. A successful conservation approach must be multifaceted, beginning with education that is carefully framed to address local socio-economic realities, as awareness alone is insufficient without tangible benefits. Strengthening laws and oversight is necessary, but these legal interventions depend on active community participation to avoid being perceived as external impositions. At the management level, strategies like controlling overgrazing through designated zones and promoting sustainable agriculture must balance ecological preservation with local livelihoods. Furthermore, community-based models, such as ecotourism, provide viable alternatives by integrating socio-economic development with conservation goals. Essential to all levels is a collaborative framework where government bodies, NGOs, and local communities work together in decision-making. Ultimately, by openly negotiating trade-offs and aligning conservation strategies with economic sustainability, initiatives can achieve long-term community resilience and greater biodiversity protection. By explicitly acknowledging trade-offs, conservation strategies can move beyond idealized win-win approaches and realistically address conflicts between ecological integrity and human well-being. Sustainable conservation depends on transparent negotiations, in which losses, costs, and benefits are clearly discussed and incorporated into decision-making. Collaborative conservation models,

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grounded in local participation, economic incentives, and ecological foresight, offer the most viable pathway toward effective and equitable biodiversity protection in the Almabolaq Protected Area.

5. Conclusion

The ISM framework developed in this study outlined four levels of interventions: education and awareness-raising, legal reinforcement, improved management practices, and sustainable resource use, each of which requires careful consideration of the competing demands on protected areas. While conservation initiatives must address biodiversity loss, they should also account for the livelihoods and economic stability of local communities, ensuring that environmental policies are not perceived as restrictive, but rather as integrated with broader developmental objectives. Collaboration among government agencies, NGOs, and local stakeholders is essential for designing conservation strategies that acknowledge negotiated outcomes openly. Recognizing the social and economic dimensions of biodiversity protection fosters solutions that preserve ecosystems while supporting human well-being, preventing conflicts between conservation mandates and local needs. By balancing ecological sustainability with socio-economic stability, this study underscores the need for strategic conservation policies that promote long-term success through transparent decision-making and inclusive governance. The future of biodiversity conservation in Almabolaq depends on translating this framework into concrete actions. The three recommended initiatives are establishing local rangeland management committees, launching an organic transition subsidy and certification program, and forming an inter-ministerial task force for policy coordination. By implementing these specific institutional reforms and incentive structures, policymakers can ensure that the balance between ecological integrity and socio-economic resilience is not just theoretical but operationalized, securing the long-term sustainability of the Almabolaq Protected Area for both nature and people.

Based on the findings of this study, future research should focus on empirically testing the proposed ISM hierarchy to quantitatively validate the perceived relationships between strategies over time. Furthermore, applying this integrated Fuzzy Delphi-ISM methodology to other protected areas with different ecological and socio-economic contexts would enable for valuable comparative analysis, helping to distinguish universal principles from location-specific dynamics. Additionally, integrating these socio-economic models with spatial analysis (GIS) could identify precise geographic hotspots for intervention, while in-depth ethnographic studies are needed to fully understand local economic dependencies and willingness to engage in alternative livelihoods. Finally, investigating the contextual factors that led to the dismissal of certain threats (e.g., illegal hunting) in Almabolaq could provide transferable insights for managing those same threats elsewhere, ultimately contributing to more robust and adaptable conservation frameworks.

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Authors Contribution

Aminollah Sahab Mahmoodi: Conceptualization (equal), data curation (lead), formal analysis (lead), methodology (equal), investigation (lead), visualization (lead), writing original draft (lead). Mohammad

Reza Gili: supervision (Equal), conceptualization (equal), investigation (equal), Methodology (equal), writing review and editing (equal), project administration (equal).

Iman Saeedi: supervision (Lead), project administration (equal), methodology (Lead), conceptualization (equal), writing review and editing (Lead).

Availability of data and materials

The data that support the findings of this study are available on request from the corresponding author.

Conflict of interests

The authors have no conflicts/competing interests.

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