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Article

Aquaculture Site Selection of Oncorhynchus Mykiss (Rainbow Trout) in Markazi Province Using GIS-Based MCDM

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Abstract: The production of seafood, particularly in areas far from coastlines, makes aquaculture an optional farming alternative. Case research from the semi-arid Markazi province, Iran, is examined as a viable aquaculture location for Oncorhynchus mykiss (rainbow trout). ArcGIS Version 10.6.1 and Super Decision Version 3.2 software are utilized for the zoning and assessment of criteria maps. All criteria, i.e., sub-criteria and limitations, were gathered through the academic literature, qualitative interviews via expert opinion, national data, and guidelines. By imposing constraints on the premier aquatic potential map, the final map of the aquaculture potential of Markazi province was obtained. The results indicated that 40.79% of Markazi province has a high potential for aquaculture development. According to the sensitivity analysis, changes in criterion value (i.e., increase or decrease) in weight corresponded with the rate of change. Aquaculture development would require large-scale investment and make Markazi province a major seafood producer in the region.

Keywords: offshore aquaculture; multi-criteria; analytic network process; suitability mapping; semi-arid area; Iran

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1. Introduction

When taking into consideration the significant decline in marine fisheries catchments, aquaculture is believed to be a suitable substitution to globally supplying fish and seafood protein [1–3]. Aquaculture is one of the fastest-growing activities worldwide. The strong and rapid development of the sector tends to reflect significant environmental impacts and challenges [4]. Despite the immense potential of aquaculture for food and livelihoods, "new aquaculture initiatives are often dominated by donor-driven projects instead of local entrepreneurships" [5], which can be highly affected by aquaculture governance and production-related incentives. Nonetheless, aquaculture is one of the fastest-growing protein production systems, supplying approximately 47% of the world's protein demand [6]. Aquaculture activities have been significantly improved in recent years with a continued increase in its production targets. The socioeconomic gains obtained from aquaculture development provide nutritive food, improve the lives of the impoverished, diversify fish production, generate capital and employment opportunities, and allow for high-value export earnings [7]. A key challenge for aquaculture development is the sharing of water, land, and other alternatives, such as agriculture and tourism. Spatial planning for aquaculture—including zoning, land evaluation, and the design of aquaculture management areas—should consider the balance between the environmental, social, economic, and governance objectives of local communities, in-line with sustainable development theory [8,9] and the ecosystem system approach [10].

Site selection is the initial critical factor in beginning the "process, expansion, or relocation of businesses of all kinds" [11]. Land evaluation is a multifaceted practice. Scientifically, it is commonly resolved using utility theory, e.g., a simple linearity weighted method, analytic network process (ANP) method, and technique for order preference by similarity to an ideal solution [12]. Hence, several solutions and valuation criteria should be considered beforehand [13]. First, the location of aquaculture is very specific and must consider climate, establishment, and facilities needed [14]. Effective land evaluation can improve aquaculture efficiency and lower the environmental impact [15]. Geography-based software such as geographic information systems (GIS) [16] are frequently used for spatial planning (e.g., aquaculture), in which different sets of feasible and local-oriented evaluation criteria are designed and optimally identified—with alternative locations considered [17–19]. The ability to create territorial information strengthens the use of spatially-based analyses in combination with multi-criteria decision-making (MCDM) techniques [20–23]. Traditionally, land evaluation was centered on technical and economically oriented criteria; however, presently, more sophisticated methods are demanded. Selection criteria must take into account several environmental and social requisites that must be administered by legislative bodies and government regulations [24]. The implementation of GIS models can aid in resolving a number of these problems [25,26]. Selecting a location that is suitable can lower distribution costs, minimize environmental impacts, and reduce transport activities [27]. Various MCDM approaches have been utilized in the site selection of such facilities [28,29]. ANP, a MCDM ranking approach, is used to evaluate locations by using key decision criteria to reduce such costs and the associated negative effects. The development of a model that can identify the optimal locations for aquaculture facilities is designed on a hybrid GIS-based criteria approach that uses empirical findings from each criterion, i.e., by limiting uncertainty and simplifying a decision support system's approach, to obtain the suitability of a location [30]. The resulting models can be used to obtain ecological insight or predict distribution, with applications in spatial management, biosecurity, climate change, and theoretical ecology [31].

GIS, a digital database management system, is designed to manage large volumes of spatially distributed data from a multiplicity of sources [32]. These systems are ideal for land evaluation as they efficiently catalogue, retrieve, analyze, and exhibit application-specific data [33]. The practice of GIS modeling for the selection of marine aquaculture sites is commonly used, with varying socioeconomic, logistic, and environmental criteria [34–38]. Generated modelled maps—labeled with the descriptor classes (i.e., variables of interest), factor layers (i.e., converted descriptors), and constraint layers—are weighed and put through a multi-criteria analysis [39]. GIS site selection has been utilized throughout the literature for a variety of aquaculture applications, including hard clam culture in Florida [40], shrimp farming development in northwest Mexico [29], land suitability of aquaculture of rainbow trout in Peru [41], brackish site selection for water aquaculture in India [42], land-based shrimp farming along the Australian coast [43], shrimp farming in Vietnam [44], marine fish cages within the tourism industry in Tenerife [45], oyster culture-based single-use site selection in Venezuela [34], cage culture marine fish in Tenerife [46], and site selection of Japanese scallop in Japan [36,47], as well as assessing suitable carp farming areas, shrimp and crab farming, urban aquaculture development, tilapia farming areas, and modeling of land suitability for giant prawn in Bangladesh [48–50].

Recently, GIS integrated with MCDM was found to be a near best practice for aquaculture site selection and land evaluation [14,50–53]. In tangent, these methods improve the decision-making and planning processes [54]. A number of studies, specific to land evaluation and site selection, support MCDM approaches in the GIS environment [54–59]. This study presents a GIS-based MCDM that uses ANP to identify the most suitable places for aquaculture development in Markazi province, found geographically on the central plateau of Iran. Two study-specific points are important to this study, namely: (1) water quality in terms of aquaculture land evaluation in Iran is not an important factor as it is internally controlled and adjusted by the government prior to any site implementation, and (2) increasing land evaluation parameters can improve the accuracy of the location selection, e.g., by increasing layers and data. As such, when conducting land capability assessment that requires large-scale government investment to create or expand current facilities, as in Markazi province, the potential to develop aquaculture facilities in Iran is a top-down process. The most important and compatible type of edible farmed fish species in the province is Oncorhynchus mykiss (rainbow trout), which is classified as a cold-water fish and has been pilot bred with success in a few farming pools throughout Iran's central plateau area. A breakdown of the paper is structured as follows: Section 2 contains the methodology, Section 3 illustrates the results, and Section 4 elucidates a discussion and conclusion with suggestions for future research.

2. Materials and Methods

2.1. Study Area

Markazi province is found in central Iran (i.e., east of Zagros) and south of the capital (i.e., Tehran; Figure 1). Examination of long-term climate statistics in Markazi province indicates that, in general, the climate is dry and cold, with long-term average rainfall slightly higher than the national average at 281.5 mm [60]. The existence of a surface water network in conjunction with its centralized location and proximity to densely populated cities make the province relatively suitable for the growth and development of aquaculture. Examples of breeding ponds in Iran are divided into two categories: mechanized and traditional. In the case of Markazi province, small-scale traditional fishponds have been trialed using water construction (Figure 2) and using barriers (i.e., small dams) along rivers.

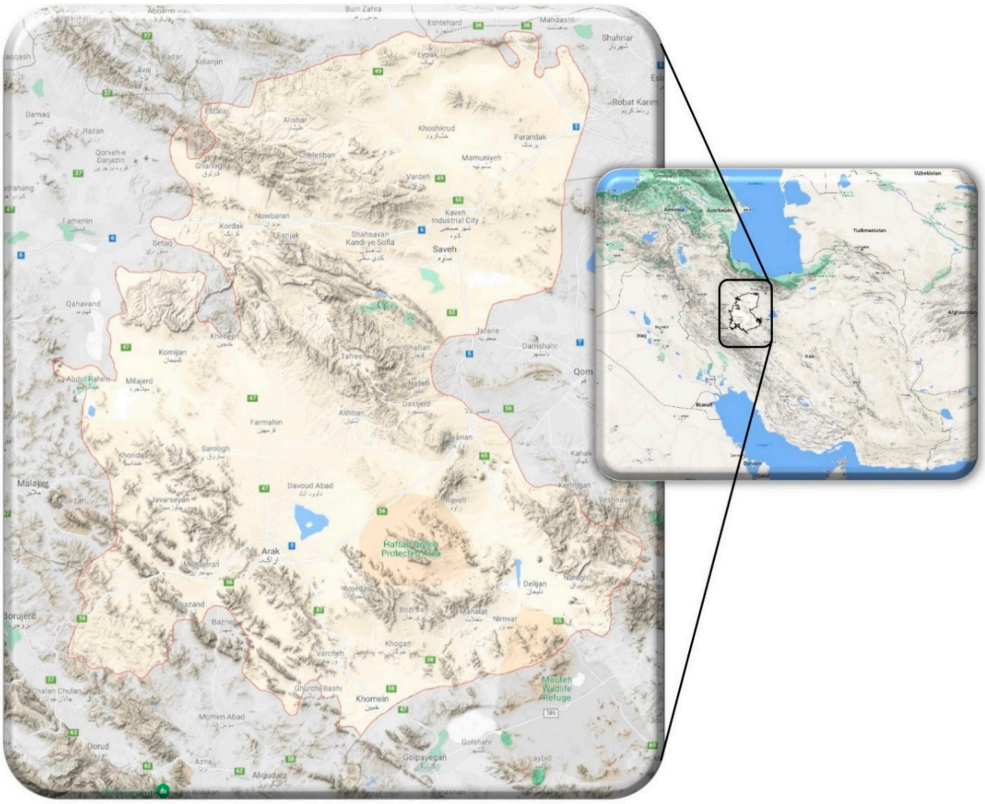

Figure 1. Geography and location of Markazi province in Iran; maps sourced from Google Earth [61].

Figure 2. Example of traditional fish breeding pond in Markazi province. Photography taken by Amir H. Aghmashhadi on 17 July 2019.

2.2. Methods

This study uses a GIS-based MCDM to identify the suitability of sites for the development of aquaculture via ANP. The research comprises spatially oriented datasets and decision-making preferences, as well as their combination. The study combines the flexibility of GIS to appraise geographical information and determine whether MCDM can integrate the information properly. The premise of the research is to identify suitable sites and model output based on hybrid techniques of suitable options for integrated assessment in conjunction with correct decision-making when an area is selected for aquaculture development. The framing of the GIS-based MCDM uses six stages, namely, (1) identify decision criteria for the selected location based on guidelines by Makhdoum [62], (2) determine the criteria weighing using ANP-based responses from experts, (3) construct map layers for decision criteria using GIS analytical tools (i.e., to determine values for each grid in the study area), (4) perform land suitability analysis of the study area to generate a location suitability map and identify candidate sites, (5) remove the areas with constraints from the production map and classification of the final output map, and (6) sensitivity analysis (i.e., by using Super Decision Version 3.2 software). A robustness test was also utilized by using the fault injection testing method. This was performed to check the robustness by injecting faults (i.e., errors) in the software and observing the system's resilience [63]. We explored various contrasting randomization faults and found through a training simulation for the map outputs, convergence curve (i.e., threshold) was reached where the parameters provided one number for each parameter, instead of multiple numbers. The framework incorporates spatial-based evaluation modeling, societal aberrations and concerns, and local infrastructure (Figure 3). ArcGIS Version 10.6.1 software was used to create criteria mapping via the grid-based technique and weights were applied, using Equation (1), to each of the factors.

$$grid_{result(basic\ criteria-limitations)} = \sum_{i=1}^{n}(grid_i * W_i) \quad (1)$$

where n = summation upper limit, i = summation index, and W = weight.

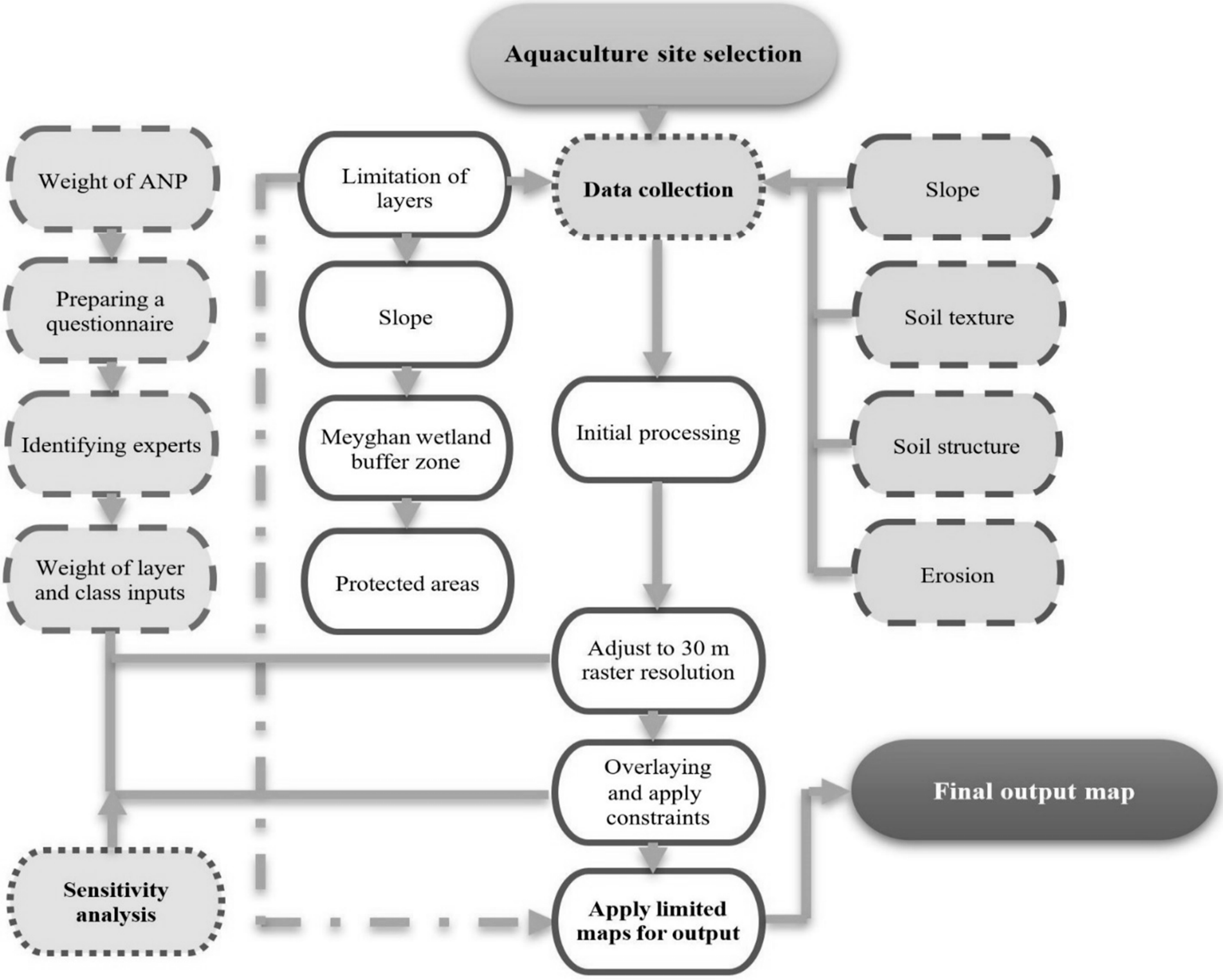

Figure 3. Methodology flowchart.

The ecological potential for aquaculture development in Markazi province was pieced together using datasets from different sources. Table 1 presents the raw list of data layer resources and references.

Table 1. Raw data in the study.

Raw	Layer	Reference	Year of Dataset Layer
1	Political areas of the country and province	Iran National Cartographic Center	2016
2	Digital elevation model (DEM)	DEM Shuttle Radar Topography Mission with 30 m raster resolution	2020
3	Slope	DEM data obtained from ArcGIS	2020
4	Soil texture	Office of Planning and Budget Organization, Markazi province	2009
5	Soil structure	Office of Planning and Budget Organization, Markazi province	2009
6	Soil erosion layer	Office of Agriculture Organization at Jahad, Markazi province	2012
7	Wetland and environmentally sensitive areas	Department of Environment, Markazi province	2020

After preparing the initial layers, i.e., in Table 1, the required processing was performed. Initially, the layers are divided by their political boundaries around the province's layer. Follow this, the coordinate system for the layers is interfaced with the World Geodetic System (i.e., WGS_1984_UTM_Zone_39N). Then, using ANP, the weight of each layer and their classes were obtained using the Super Decision Version 3.2 software environment. Within this structuring, three soil-related datasets (i.e., soil texture, soil structure, and erosion) were transformed into a raster format with a 30-m block size by assigning the weight obtained through ANP to their classes using the raster feature tool. Then, the slope layer was prepared from the province's DEM and classification (i.e., via the reclassify tool) and class weight were applied to it. The prepared criteria were overlaid by applying the weight of each, using the raster calculator tool in GIS software. Using the reclassify tool, it was classified into five categories, i.e., ranked from very low to very high suitability. Then the restriction layer was prepared and applied in the final map. To this end, the area of the classes was formulated using the calculate geometry tool. The layers are then integrated according to up-to-date datasets from Markazi province, and the according weights are allocated. Using GIS, the area of layer class is considered on its own. The data layers are overlaid to show the aquaculture-friendly area. Then, using the raster approach, the resource layers which allocate all primary data to raster layers of 30 m of resolution are assigned weight. Each layer's weight and associated class is determined using expert opinion in the form of ANP.

2.3. Determining Criteria

Suitable site selection and zoning is used to develop aquaculture areas using an MCDM process via a considered set of criteria. All the criteria were compiled by assessing the state of the art (i.e., the academic literature), qualitative interviews via expert opinion, local conditions of Markazi province, and Iran's national standards and laws [62]. The snowball procedure was utilized to find the experts for the study [64]. In the procedure of administering the qualitative interviews, 75 experts from Arak university—i.e., 15 experts, Islamic Azad University Arak Branch—i.e., 10 experts, and the province's fisheries establishments—i.e., 50 experts, participated in the study in October 2020.

2.4. Analytical Process

ANP is employed to define the weight of criteria via expert opinion as well as their importance in terms of decision criteria. ANP is a MCDM method that transforms the decision process into a decision criteria network [65]. Using this approach, the two-pair comparison system aided in determining the weight of the structural conditions followed by the prioritization of the criteria in the MCDM process [12,15,64,66,67]. Many researchers have used ANP approaches in selecting locations and evaluating and analyzing land [12,15,64,67–71]. Steps for applying ANP are pieced together in four-step process. Details of the compiled data are available as Supplementary Tables S1–S5.

- *Step 1.* Show the significance and value of the factors based on the criteria. Utilize pairwise comparison to consider the impact of each element versus other elements. Conceptually, an example of the pairwise comparison used to evaluate the suitability of land in can be seen in Figure 4.

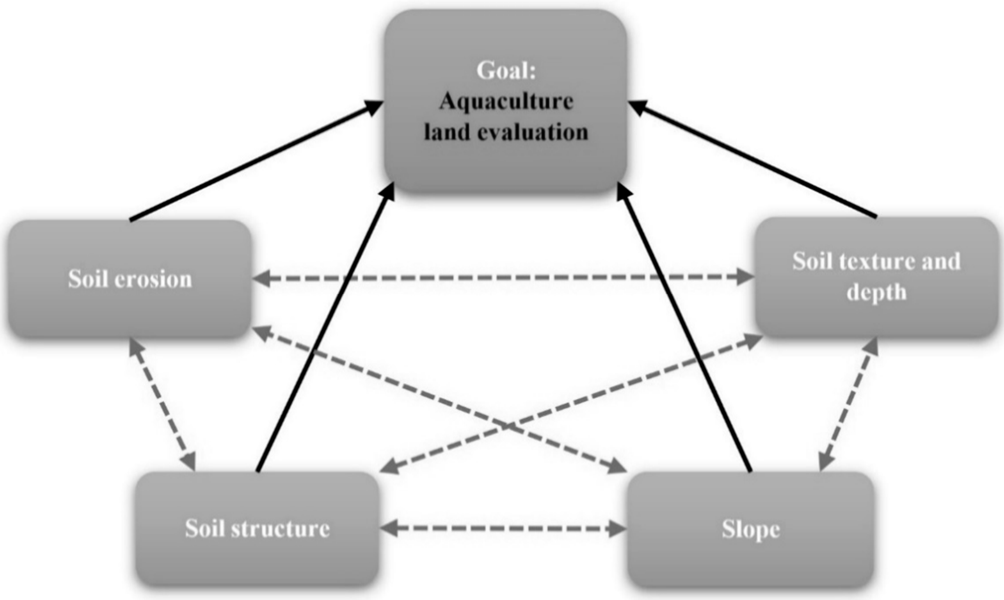

Figure 4. Conceptual model of aquaculture land evaluation in Markazi province.

- *Step 2.* Scale sub-factors of the elements. To compare elements in each cluster, scales in discrete intervals are chosen (i.e., 1–9 where scale 9 shows the absolute significance of an element in comparison with others and scale 1 shows the equal significance of the elements). Note the a_{ij} indicates the importance of the i^{th} element with respect to the j^{th} element [72,73].
- *Step 3.* Calculate the super matrix that is partitioned and based on the cluster (i.e., factors) and its elements (i.e., from the pairwise comparison). The super matrix, i.e., Equation (2), consists of N clusters is presented as follows:

$$W = \begin{array}{cc} & \begin{array}{ccccc} C_1 & \cdots & C_k & \cdots & C_n \\ e_{11}\, e_{12} \cdots e_{1m1} & \cdots & e_{k1}\, e_{k2} \cdots e_{km1} & \cdots & e_{n1}\, e_{n2} \cdots e_{nm1} \end{array} \\ \begin{array}{cc} C_1 & \begin{array}{c} e_{11} \\ e_{12} \\ \vdots \\ e_{1m1} \end{array} \\ \vdots & \vdots \\ C_k & \begin{array}{c} e_{k1} \\ e_{k2} \\ \vdots \\ e_{kmk} \end{array} \\ \vdots & \vdots \\ C_n & \begin{array}{c} e_{n1} \\ e_{n2} \\ \vdots \\ e_{nm1} \end{array} \end{array} & \begin{bmatrix} W_{11} & \cdots & W_{k1} & \cdots & W_{1n} \\ \vdots & & \vdots & & \vdots \\ W_{k1} & \cdots & W_{kk} & \cdots & W_{kn} \\ \vdots & & \vdots & & \vdots \\ W_{n1} & \cdots & W_{nk} & \cdots & W_{nn} \end{bmatrix} \end{array} \quad (2)$$

where: C_k = the kth cluster (i.e., k = 1, 2, . . . , n) and each cluster k consists of mk items displayed by $e_{k1}, e_{k2}, \ldots, e_{kmk}$. Each column of W_{ij} = the priority vector acquired from the identical pairwise comparison, indicating the significance of the elements in the i^{th} cluster with respect to an element in the j^{th} cluster.

- *Step 4.* Compute the weight of the super matrix by multiplying the matrix by priority factors, creating a limited super matrix, and raising the weighted super matrix to the appropriate limit. The limited super matrix is obtained using Equation (3).

$$\lim_{\varphi \to \infty} = (W^a)^{\varphi} \tag{3}$$

where: W^a = weighted super matrix, a = element, and φ = limit of the function.

After distributing the questionnaire among the experts, the results of their comparison and weighting are determined, by Super Decision Version 3.2 software. Among the effective criteria in the assessment of potential aquaculture facilities in Markazi province, slope is the most important criterion with a weight of 0.449, followed by soil erosion with a weight of 0.265, soil structure with a weight of 0.145, and soil texture and depth with a weight of 0.141. These weights are the aquaculture land capability (i.e., priority) criteria results for the study and are used to determine the development potential of aquaculture in the region. After determining the weight between the criteria, the weight of the classes of each criterion is determined.

A noteworthy point to this method is that to locate the aquaculture locations in the study area as accurately as possible, in addition to weighing the criteria in the location selection, the classes of each criterion are weighted according to the experts and prioritized accordingly. As such, the ANP method utilized determines the weight of the criteria according to expert opinion and their importance aids in determining decision criteria outputs. It is important to point out that the solving of problems, using a network that largely depends on modeling and network design, does not follow a certain rule. Therefore, problem solving has its complexity, of which, it is not possible to generalize an overall rule or formula to solve them [69]. ANP can be a very useful framework for analyzing development issues, as it can be used to study internal and external relations, mutual relations of elements and variables, application of quantitative and qualitative criteria, adaptability in judgments, the possibility of paired comparison of variables in decision making, the possibility of final prioritization of proposed options, and overcome the problems of hierarchical relationships from top to bottom or from bottom to top by ignoring the concept of feedback. This process is a flexible way of helping decision makers analyze complex issues whose elements are to be decided; altogether, it is a comprehensive and powerful way to make accurate decisions. The ANP model can also be combined with other models, e.g., the FANP model in combination with ANP and fuzzy in which language estimations are converted into fuzzy numbers—as suggested by Malmir et al. [65], Zarei et al. [69], Yunna et al. [71], and Seyedmohammadi et al. [66]. Finally, the Ethical Committee of University of Gdansk, in cooperation with Arak University, has verified that this study complies with the ethics of scientific research described in the Ethical Principles of the Declaration of Helsinki and other applicable ethical principles and legislation in the European Union conforming with Directive 2010/63/EU.

3. Results

Using Makhdoum's [62] ecological land capability potential assessment model, the land area for aquaculture uses and natural conditions of the region are assessed using different classes of layers to establish via expert assigned weights (Table 2). The results illustrate that the classes with higher utility should receive a higher weight. For example, traditionally slope classes of up to 5% and above 65% have been of equal importance, while for this study slope classes weighted from 0–5% are more than 17 times the weight of a slope class above 65%.

Table 2. Class and the associated weight of each layer in the aquaculture land evaluation of Markazi province.

Raw	Layer	Properties									
1	Slope (%)	Class	0–5	5–8	8–12	12–15	15–20	20–30	30–50	50–65	>65
		Weight	0.325	0.233	0.165	0.111	0.078	0.059	0.048	0.036	0.026
2	Soil erosion	Class	Low	Medium	High						
		Weight	0.670	0.201	0.129						
3	Soil texture and depth	Class	Deep loam clay	Semi-deep sandy loam clay	Semi-deep clay loam	Deep sandy	Shallow sandy	Shallow sandy loam	Semi-deep sandy loam	Semi-deep loam clay	
		Weight	0.331	0.231	0.156	0.106	0.071	0.048	0.033	0.024	
4	Soil structure	Class	Fine-grained sediment	Semi-transformed	Flooded soil	Frost soil	Flat and calcareous	Low-transformed	Without evolution and rocky	Without evolution and coarse texture	Often salty
		Weight	0.313	0.223	0.152	0.108	0.074	0.051	0.036	0.025	0.018

After establishing criteria weight and criteria classes and applying them, removal of the constraints (i.e., controls) (Table 3 and Figure 5) from the base maps was performed (Figure 6). The limitation factors of slope (%), protected area, and Meyghan Wetland buffer zone (presented in Figure 5) were combined to make-up the limitation map and were integrated into the data collection process as illustrated in the methodology framework. As a final finding, the modeled maps were all overlaid on each other to illustrate a final map of suitable places aquaculture development could be done in Markazi province (Figure 7).

Table 3. Imposed limitation of land use for aquaculture.

Raw	Layer	Limitation
1	Slope (%), Makhdoum (2015)	15
2	Protected area, Makhdoum (2015)	Protected area
3	Meyghan Wetland buffer zone (m), Department of Environment [74]	1500

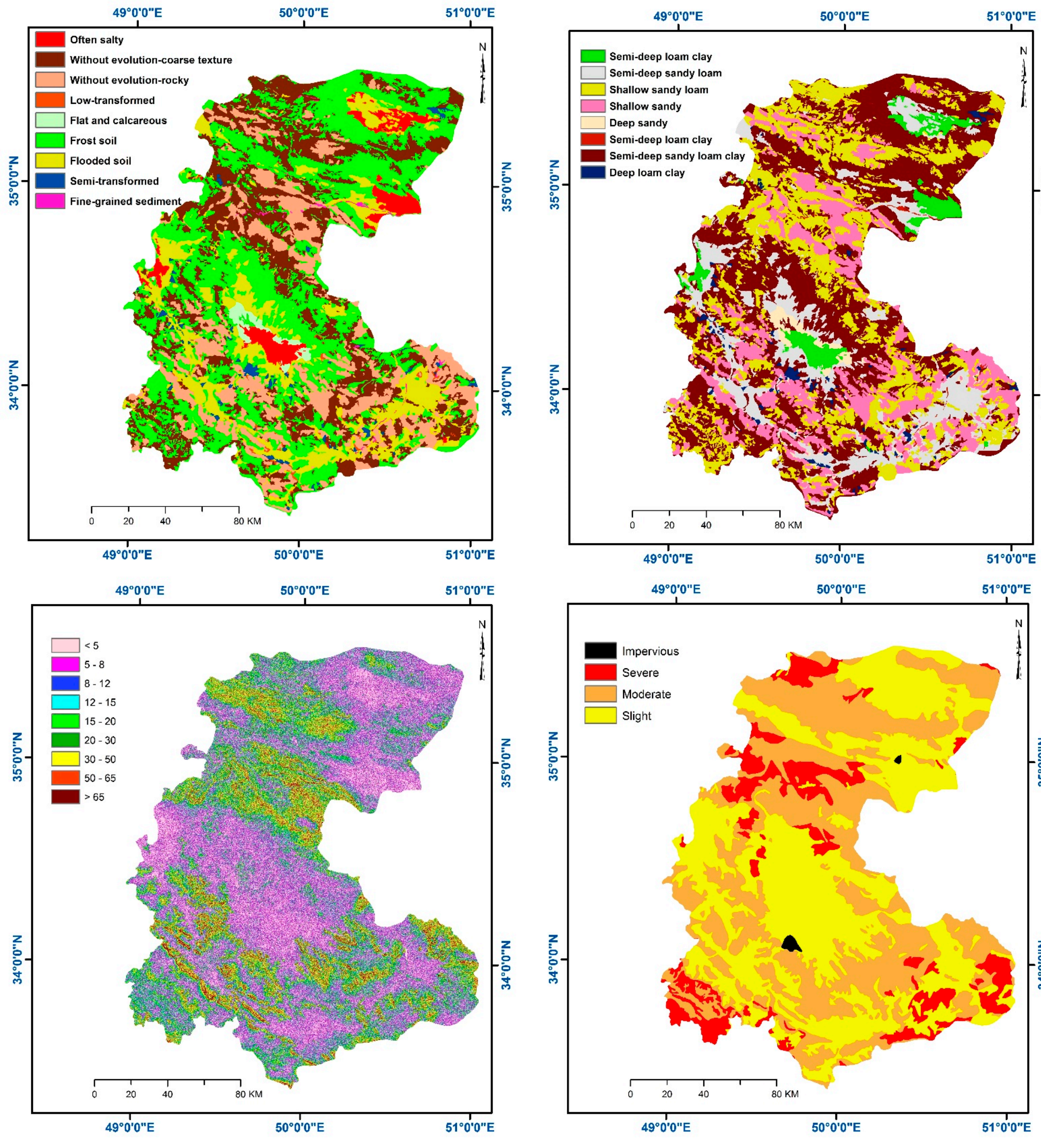

Figure 5. Classification map of each criterion: soil structure—top left; soil texture and depth—top right; slope (%)—bottom left; soil erosion—bottom right.

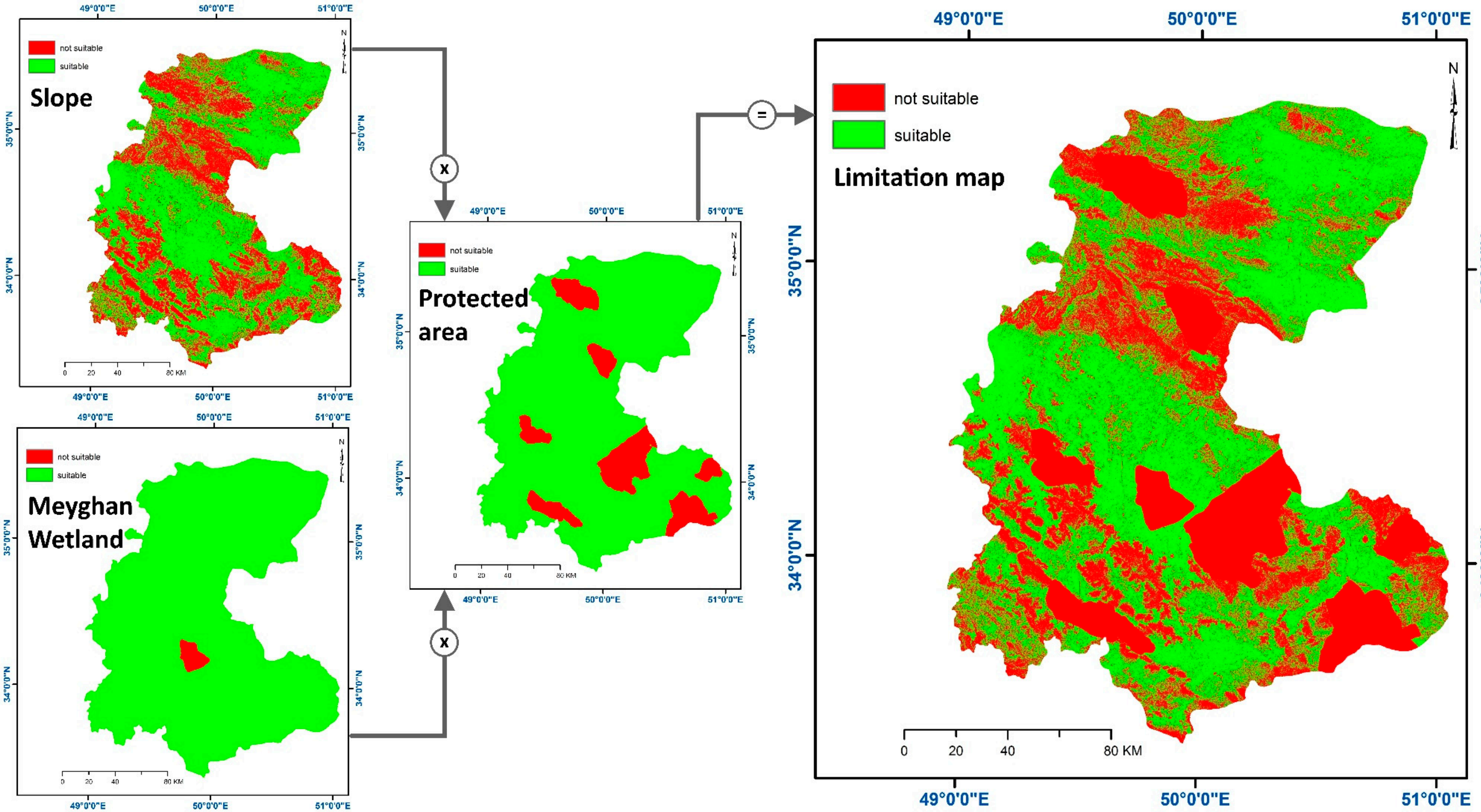

Figure 6. Restriction maps used to determine aquaculture land use in Markazi province: slope (%), protected area, Meyghan Wetland buffer zone, and combined limitation map.

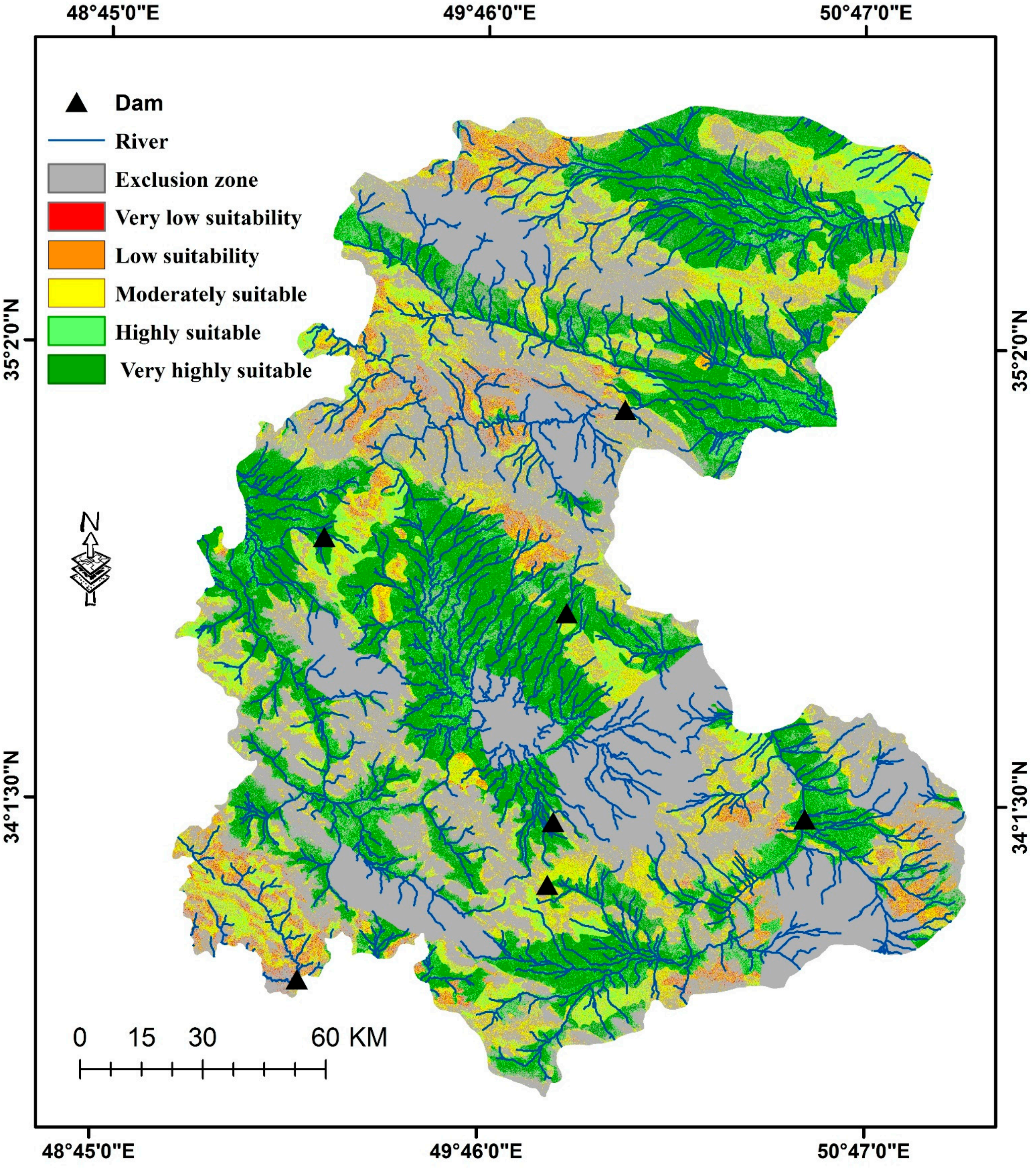

Figure 7. Land potential for suitable aquaculture development of Oncorhynchus mykiss (rainbow trout) in Markazi province integrated with the limitation map findings.

Table 4 illustrates, in terms of the ecological land capability, that even though 43.8% of Markazi province is not suitable for aquaculture, 40% of it is with an economic potential relating to 13.84% as highly suitable and 26.95% as very highly suitable. The results indicate that key areas with high and very high potential are in the central, south, and northeastern part of the province near a water source. As such, most of the capable areas for aquaculture development are located around reservoir dams and dense branches of the hydrological network of Markazi province.

Table 4. Classification of land for aquaculture development in Markazi province.

Land Potential	Area (Ha)	Area (%)
Exclusion Zone	1,275,062	43.8
Very low suitability	19,968	0.69
Low suitability	109,950	3.78
Moderately suitable	320,076	10.99
Highly suitable	402,943	13.84
Very highly suitable	784,656	26.95

The results of the sensitivity analysis show that by increasing or decreasing each of the criteria by 10%, the prioritization of the criteria remained the same (Table 5). However, it was found that if only the soil texture and depth criteria increased by 10%, the prioritization of the criteria changed the slope, soil erosion, soil texture and depth, and soil structure—as illustrated in Figure 8. In general, as the criteria increased or decreased, the weight of the criteria changed according to the rate of change relative to that criterion—their priority, as stated, did not change.

Table 5. Sensitivity analysis to check criteria validity using a ±10% interval.

Interval	Criteria			
Increase by 10%	Slope		Soil erosion	
	slope	0.469	slope	0.440
	soil erosion	0.260	soil erosion	0.280
	soil structure	0.142	soil structure	0.142
	soil texture and depth	0.138	soil texture and depth	0.138
	Soil structure		Soil texture and depth	
	slope	0.441	slope	0.441
	soil erosion	0.260	soil erosion	0.260
	soil structure	0.160	soil structure	0.142
	soil texture and depth	0.138	soil texture and depth	0.156
Decrease by 10%	Slope		Soil erosion	
	slope	0.440	slope	0.452
	soil erosion	0.269	soil erosion	0.260
	soil structure	0.147	soil structure	0.146
	soil texture and depth	0.143	soil texture and depth	0.142
	Soil structure		Soil texture and depth	
	slope	0.451	slope	0.451
	soil erosion	0.266	soil erosion	0.266
	soil structure	0.142	soil structure	0.146
	soil texture and depth	0.141	soil texture and depth	0.138

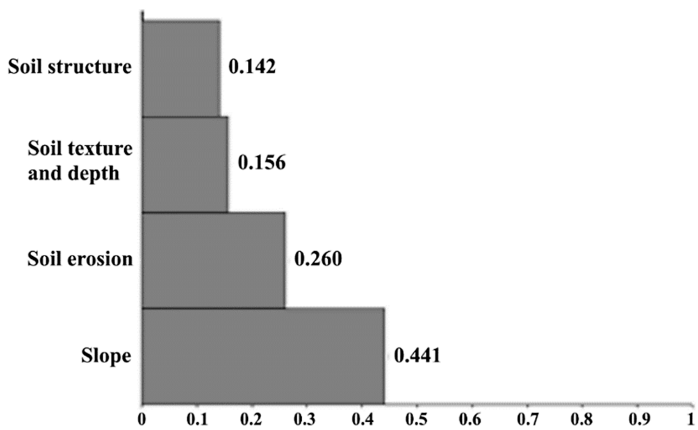

Figure 8. Sensitivity analysis linkage with soil texture and depth.

4. Discussion and Conclusions

The study integrated a GIS-based location selection method with the ANP algorithm to evaluate aquaculture suitability (i.e., land capability) of Oncorhynchus mykiss (rainbow trout). A combined method was used to determine suitable places for aquaculture based on selected conditions. In some situations, it was crucial to use a method that could consider all of the potential characteristics. GIS in combination with ANP applied a sufficient methodological solution to the piecing, together the spatial analysis procedures for the study area. As such, the final output map can assist managers and planners in properly deciding where the most fit location is to develop aquaculture in the province. GIS-based MCDM is a fast and cost-effective method for aquaculture land evaluation purposes, especially in the initial planning stages [75].

A main innovation of the research in comparison with other similar studies can be summarized in two parts. First, this study was conducted in the central parts of the Iranian plateau, where it is very far from the coastline of the north and south of Iran, and, at the same time, it is experiencing climate change issues like other parts of the world, including drought, which can be advantageous as it has created vast opportunities for indigenous people. Second, as mentioned, the research combines GIS and MCDM approaches for a better output, despite the limitations of the data. As such, several studies report the advantages of MCDM methods interfaced with the GIS environment for land evaluation and site selection purposes [54–59]. Given this, recognizing the factors affecting the location and determining the extent of the constraints they create is one of the important issues in valuing aquaculture-prone areas [49]. Therefore, it is essential that researchers in this field in all stages of land evaluation properly review and select these criteria in as much detail as possible. Hence, the location criteria in this study, according to the ecological potential assessment model of the land area for aquaculture [62], using slope, soil texture and depth, soil structure, and soil erosion, proved to be valuable.

To achieve validation of land evaluation and indicators related to aquaculture in Iran, looking at all the studies published to date on the topic, we identified six key papers [15,33,54,69,76,77]. All these studies showed similar climatic and geographical specifications in which the most practical indicators in relation to sustainable aquaculture were slope, soil structure, and soil texture and depth. Moreover, in-line with our study, almost in all of them sourced the importance of these parameters in a similar weighing order to this paper. In addition, according to the Statistical Center of Iran [78], among the counties in Markazi province, Arak (i.e., 31 pools), Saveh (i.e., 18 pools), Tafresh (i.e., 15 pools), and Khomain (i.e., 15 pools) are at the top in terms of aquaculture producing areas province-wide. These counties and pool totals correspond with the 96 hectares of total area of aquaculture in Markazi province, which also highlights another correlation with the results of the study.

Examination of the criteria set using GIS and ANP showed that 43.8% of the studied lands in Markazi province did not have the potential for aquaculture, and nearly 40.79% of them were highly and extremely suitable. This positions the province as very favorable for aquaculture development—especially in the central, south, and northeastern regions in close proximity to the hydrological network. The study showed that a combination of GIS with the applied ANP model can be used effectively in land assessment for aquaculture development. At length, two study-specific points should be considered in aquaculture land evaluation. First, water quality (e.g., DO, NH3, No3-1, No2-1, pH, and temperature) is not very important in terms of aquaculture land evaluation in Iran, as this is an internal governmental factor and such parameters are controlled and adjusted for prior to any site implementation. Second, increasing land evaluation parameters can improve the accuracy of the location selection, e.g., by increasing the layers and data. As such, this will always be an obstacle when conducting land capability assessments that require large-scale government investment to create or expand current facilities.

It should be noted that Iran is divided into five broad geographical regions in terms of vegetation and climate. The Irano-Turanian region, which covers about 28% of Iran, is where the study area is located. With very similar climate and geomorphology, a generalization of the results can be implied for the greater part of this region. Nonetheless, this study is still heavily reliant on the availability of information and data, as this is reserved for the provincial level in the country. From this research, it should also be stressed that Markazi province is one of the most attractive provinces in Iran in terms of investment, due to its proximity to the capital—Tehran—and other large cities such as Isfahan and Qom. As the province acts as a western corridor, which that connects the center of the country to its western parts and neighboring countries, the relatively favorable environmental conditions and industrial nature of the province, i.e., compared to other parts of the country, show promise for many parent industries—including aquaculture. To alleviate and reverse any further negative development from poor planning and management, this study comprehensively considered Markazi province and deduced the option (and challenge) of integrating inland aquaculture into the province's production sector as partially feasible. In this case, the use of inland aquaculture is a problem−solution−resolution type of approach. It is stressed as an advancement to the sustainable development agenda of the country, an asset for local and healthy food (i.e., dietary daily protein intake), and a growth potential for exportation and the economy.

Overall, Markazi province has the potential to develop inland aquaculture facilities and become a key seafood producer in the region. However, a sensible understanding needs to be taken into consideration, as the gap over the last few decades of unplanned growth and development disruptions after the Islamic Revolution and the Iraq war, and considering how these geopolitical problems have stalled development, should be taken into account. Future work, through comprehensive and realistic data analyses, should introduce potential aquaculture development, while still considering (i.e., reviewing) existing conditions and the prospective for change. It seems that most of the susceptible areas in Markazi province have already been occupied either by residential areas or other human activities, and some of them have been developed inappropriately due to the geography and natural limitations of the province's geography. Through GIS-based MCDM, it is hopeful that future development can be better planned and managed for sound and sustainable practice province-wide.

Supplementary Materials: The following supporting information can be downloaded at https://www.mdpi.com/article/10.3390/ijgi11030157/s1. Table S1: Aquaculture land evaluation. Table S2: Comparison and weighting of slope divisions in Markazi province. Table S3: Comparison and weighting of erosion divisions in Markazi province. Table S4: Comparison and weighting of soil texture and depth divisions in Markazi province. Table S5: Comparison and weighting of soil structure divisions in Markazi province.

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