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ORIGINAL ARTICLE

Multi-criteria analysis in Artemia farming site selection for sustainable desert ecosystems planning and management (case study: Siahkouh Playa, Iran)

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Abstract Arid environments and desert ecosystems which contain several potential resources such as unconventional water sources are remarkable areas for developing projects. To prevent undesirable consequences caused by desert conditions, it is necessary to determine which areas are suitable. The current study identified suitable areas for the development of Artemia farming in the Siahkouh Playa, Yazd, Iran using the multi-criteria decision-making method based on the TOPSIS technique. The decision-making group was determined, and then, the most important criteria in determining a suitable area in the study region were identified. The second questionnaire was designed to determine the rate of each criterion in choosing the best alternative. The results showed that three main factors are effective in determining a suitable area for Artemia farming units in a desert ecosystem, which, according to their importance were environment, technology, and socioeconomics. Results also indicated that the best choice among the three alternatives is to consider the geomorphological faces as the assessing and monitoring unit of other criteria in arid regions and desert ecosystems. In the current research area, clay pan geomorphological features were found to be suitable for Artemia farming.

Keywords Desert ecosystems · Sustainable development · Multi-criteria analysis · Artemia farming

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Introduction

Estimations show that if the world's population reaches 9.1 billion by 2050, the world's food production will need to increase by 70 %, and developing countries will need to double their food production (FAO 2013).

Fisheries and aquaculture, the fastest growing food-producing sector, currently support about 10–12 % of the world's fish demand (FAO 2014), and production is predicted to dominate by the year 2030 (Brugere and Ridler 2004; Silva et al. 2011). The high growth rate of aquaculture has created important environmental and management issues such as eutrophication (Holmer et al. 2005; Islam 2005; Kalantzi and Karakassis 2006; Mantzavrakos et al. 2007), chemical pollution from various sources (Antunes and Gil 2004; Cabello 2006; Calvi et al. 2006; Hamilton et al. 2005; Hites et al. 2004; Holmstrom et al. 2003; Lai and Lin 2009; Sapkota et al. 2008), and biodiversity changes in endemic populations (Pusceddu et al. 2007; Soto et al. 2001; Tomassetti and Porrello 2005; Vezzulli et al. 2008). The expansion of the world's aquatic industry requires that suitable food be provided for aquatics in different growth stages (Atashbar et al. 2010). The brine shrimp Artemia has obtained a good position in aquaculture systems and supports over 85 % of cultured species around the world as live feed. Artemia thrive in natural seawaters and saline well waters; they are able to tolerate salinity ranging from 3 to 300 ppt (Soundarapandian and Saravanakumar 2009).

Iran, like many arid countries, is facing the critical issue of inland salinity. This problem has caused a noticeable degradation in the quality of surface waters. In recent years, arid environments and desert ecosystems which include several potential resources such as unconventional water sources were pinpointed as remarkable areas for economic projects such as inland saline aquaculture and Artemia farming (Keshtkar et al. 2014). Unsuitable aquaculture development can result in the over-utilization and unsustainability of natural resources (Nyoman Radiarta et al. 2008). The persistence of the unresolved stabilization of these fragile environments and the substantial decrease in providing ecosystem services as a result of intensive use of resources, incapacity of widespread suitable technologies for providing a sufficient supply of food, forage, and fuel, water scarcity, and climate change make desertification, a major environmental challenge today and a serious impediment to the provision of human needs.

Thus, in order to guarantee both richness and sustainability and prevent undesirable consequences of these economic projects, stock enhancement must be carried out in harmony with the environment and obviously reflected in the grown product (Uki 2006). Moreover, finding suitable areas for aquaculture is a vital consideration in any aquaculture activity, influencing its success and sustainable development (Gavine and Bretherton 2007; Nyoman Radiarta et al. 2008). A suitable location for aquaculture development will decrease the risk of environmental effects and social conflicts, increase the total economic return, and guarantee sustainable development (GESAMP 2001; Kapetsky and Aguilar-Manjarrez 2007; Silva et al. 2011).

In selecting a suitable area, several factors traditionally grouped as water quality, soil quality, topography, infrastructure, and socioeconomics which must be particular to the appropriate culture system should be examined (Kutty 1987; Giap et al. 2005; Salam et al. 2005; Hossain et al. 2007). Multi-criteria decision-making (MCDM) includes the concepts, approaches, models, and methods that make possible the assessment of such a multi-dimensional task according to a number of criteria (Ozelkan and Duckstein 1996; Herath 2004; Mendoza and Martins 2006; Prato and Herath 2007; Ananda and Herath 2009; Hossain et al. 2009; Weng et al. 2010; Daliri et al. 2013; Keshtkar et al. 2013; Sadeghiravesh et al. 2014) which results in the making of better decisions. There are many MCDM techniques such as analytic hierarchy process (AHP), analytic network process (ANP), elimination and (Et) choice translating reality (ELECTRE), multi-objective programming (MOP), goal programming (GP), technique for order performance by similarity to ideal solution (TOPSIS), etc. TOPSIS was first developed by Hwang and Yoon (1981) for use in solving multi-criteria decision-making (MCDM) issues (Jahanshahloo et al. 2006; Aryanezhad et al. 2011). TOPSIS, also known as a classic MCDM technique, is based on the idea that the selected option should have the shortest and farthest distance from the positive and negative ideal solution, respectively (Abo-Sinna and Amer 2005; Jahanshahloo et al. 2006).

The main objective of MCDM methods is to analyze several options consisting of multiple criteria and conflicting purposes (Voogd 1983). Although, as the researchers point out, there is still a necessity for assessment of criteria selection in the context of Artemia farming site selection, since the relative advantages of every criterion also depend on the characteristics of the issue domain. To fill this gap, current study identified suitable sites for the development of Artemia farming in Siahkouh Playa using MCDM and emphasizing environmental impacts.

Materials and methods

The study area

Siahkouh Playa is about 2791 km^2 and is located in the center of the Iranian central plateau. It extends from 32°43′ to 33°18′N latitude and between 53°44′ and 54°47′E longitude (Fig. 1). Because of its topography, sunny weather, and huge saline water resources, this area was earmarked for Artemia farming. The topography of Siahkouh Playa is not very different from other desert environments in the country, being a part of the flat regions that branch off from the Iranian central plateau. The geographic environment of Siahkouh Playa encompasses various geomorphological faces, plains, lakes, and agricultural lands because of changes in the land use pattern in recent years. Because Siahkouh Playa is located at the outlet of the Yazd-Ardakan river basin, floods, surface and subsurface waters flow through and end there; therefore, some of its geomorphological features include remarkable surface and subsurface saline water sources, even during the dry period of the year, which are visible as saline lakes and marsh land. The north part of the study area is wet, even during July and August, but the south part is dry during this period and becomes wet in the middle of September. Soils are generally clay loam. The nearest population centers to the area are Chah Afzal village and Ardakan city. It is 60 km

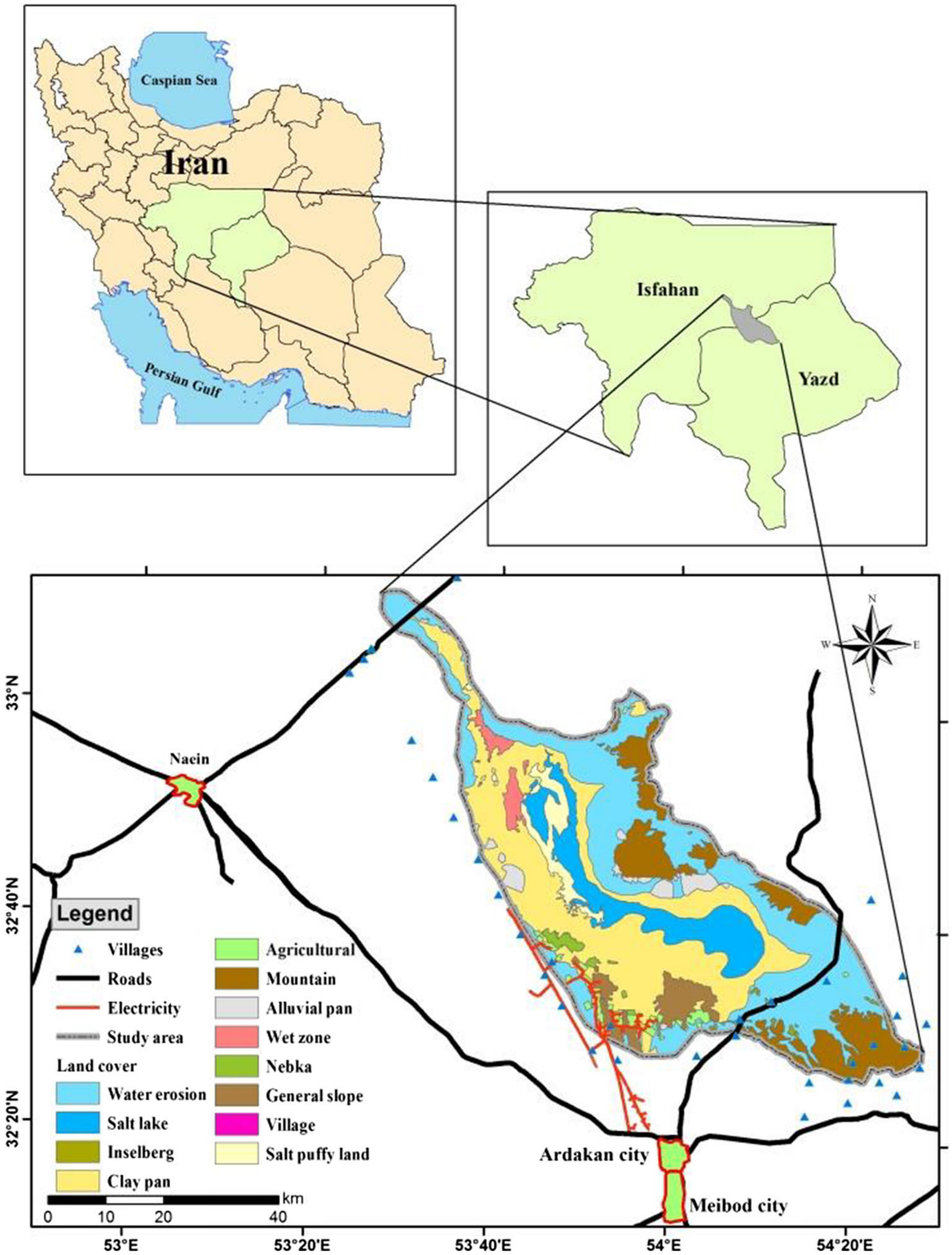

Fig. 1 Geographic location of study area in Iran

from Yazd, the center of Yazd province. The area has been extremely affected by seasonal winds, like other deserts in the country. Average annual precipitation in the study area is 70 mm, and average annual temperature is 19 °C. Annual sunshine hours are about 3280.

Methodology

There are many established methods that are widely applied for area suitability evaluation and site selection (Elaalem et al. 2010). In this research, the analytic hierarchy process (AHP) and the technique for order performance by similarity to ideal solution (TOPSIS) were applied to determine suitable areas for Artemia farming. The research methodology was divided into four steps.

Identification of factors and data collections

Most important factors such as water, topography, soil, climate, infrastructure, and socioeconomic issues which also are included in current research have been used by farmers for developing Artemia cultures (Triantaphyllidis et al. 1995; Kulasekarapandian and Ravichandran 2003; Soundarapandian and Saravanakumar 2009), but environmental factors as well as other effective parameters have not been considered. The sources of data were field measurements, social survey, range and watershed management projects (such as geomorphology, vegetation, hydrology, climatology, soil erosion, and administrative maps), and topographic maps with a 1:25000 scale. Regarding the desert ecosystem conditions, the geomorphological faces were considered for evaluating indices and sampling locations and were determined to be land management units. Soil samples were collected from 11 locations to determine soil pH and texture.

Availability to transportation facilities, electricity, and marketing was considered as criteria for desert aquaculture development. Roads and market locations were extracted from 1:25,000-scale topographic maps, and the electricity supply line was produced using a 1:20,000-scale administrative map of the Yazd province electricity company. All information was used to determine adequate geomorphological faces for the development of Artemia farming. ArcGIS software was applied in this research. All maps were prepared based on the Universal Transverse Mercator (UTM) projection coordinate system. One meter was identified for the software system as the unit of scale (Hossain et al. 2009).

The selection of parameters that identify area suitability for Artemia farming in a desert environment was particularly related to the environmental consequences of performance which can be destructive to this fragile ecosystem during those months when water bodies are dry, and saline-deposited sediments can be transported by wind erosion to surrounding areas. Therefore, 14 parameters were chosen, prioritized, and developed into a series of criteria and indices according to the method of Aguilar-Manjarrez and Ross (1995), Kapetsky and Nath (1997), Giap et al. (2005), Salam et al. (2005) and Hossain et al. (2009).

Weighting method

Extracting weights for the determined criteria and indices is the fundamental requirement for utilizing AHP and TOPSIS techniques (Malczewski 1999). The weight for each factor was determined by pairwise comparisons in the context of a decision-making process known as the analytical hierarchy process (Saaty 1977, 1990) recommended by Pereira and Duckstei (1993) and Malczewski (1999). The AHP was used to weight and score each factor, as also suggested by Pereira and Duckstei (1993) and Malczewski (1999). Based on the AHP technique, a pairwise comparison matrix was used to develop the weights (Saaty 1980). The comparisons of the relative importance of two criteria or indices were related to identifying suitability for the determined purpose. In this method, the summation of the weights must be equal to 1. Ratings are systematically scored from 1/9 (minimum importance) to 9/9 (maximum importance) (Saaty 1977). Water and soil factors, road network, markets, and electricity were weighted and prioritized in terms of significance for Artemia culture.

The relative prioritization of the parameters was carried out before completing the pairwise matrix. Scores were determined in rank order according to importance of the factors involved in the assessment for Artemia culture without repetition. Based on Saaty (1977), in order to show minimum probability in developing the weights by chance, the recommended consistency ratio is less than 0.1, which was good for the current study.

The questionnaire method was applied to verify the weights generated and to reach an agreement for the weights (Aguilar-Manjarrez 1996). An important way to learn about local conditions and resources is to ask local residents (Pelto and Pelto 1978). ArcGIS and MS Excel software packages were applied to digitize and analyze all the classified maps.

Model structure and identification of suitable areas using AHP and TOPSIS

In this research, AHP and TOPSIS approaches were applied to develop area suitability analyses for Artemia farming in a desert environment. To develop an Artemia culture model, the three criteria were multiplied by the expert's weights, and then, these values were added. The selection of areas suitable for Artemia farming in a desert environment was carried out based on AHP (Saaty 1977) and TOPSIS techniques (Lai et al. 1994). The steps of AHP and TOPSIS techniques have been widely explained in the literature (such as Wang and Elhag 2006; Kahraman et al. 2007; Lin et al. 2008; Onut and Soner 2008; Shih 2008; Boran et al. 2009; Chamodrakas et al. 2009; Gumus 2009; Wang et al. 2009; Amiri 2010; Sun 2010; Büyüközkan and Çiftçi 2012; Chou et al. 2012; Latinopoulos et al. 2012; Oros 2014).

Results and discussion

In the process of evaluating the possibility of Artemia culture in the Siahkouh Playa, based on the main objective which is the same as sustainable development in arid and desert environments, research criteria and related indices were determined according to importance and priority. As mentioned regarding desert ecosystem conditions, 112 geomorphological faces were determined as base land management units for assessing indices (Table 1).

To achieve the goal of the present research using questionnaires, the main criteria were determined to be environment, technology, and infrastructure and socioeconomics (Table 2).

Table 1 Geomorphological units of Siahkouh Playa

Geomorphology			
Unit*	Type**	Face***	Description
Mountain	Mountain	Volcanic	Area including volcanic stone with slope more than 20 %
Piedmont	Covered piedmont	Agricultural lands	Adjacent lands to playa unit where dominant land use is agriculture
Playa	Alluvial fan (AF)	Alluvial fan	A triangle-shaped deposit of gravel, sand, and even smaller pieces of sediment, such as silt
Playa	Fluvial clay pan (Delta)	Clay pan	Dense, compact, slowly permeable areas where the subsurface layers have a much higher clay content than the surface material
		General slope	Features without erosion and including deep soil profile
Playa	Salt pan	Wet zone	Regions that are seasonally flooded and always wet at or near the surface, but may be superficially dry in drier seasons like summer
		Salt puffy land	Features with a thin layer of pure salt (mainly sodium chloride) which decreases surface layer resistance to soil erosion
Playa	Inselberg	Inselberg	Single and isolated rock outcrops that stand out abruptly from surrounding plains
Playa	Nebka	Nebka	Small sandy dunes (including some degree of soil) around the large plants formed as a result of wind deposits accumulating at the base of vegetation
Playa	Water erosion	Water erosion	Feature with water erosion
Playa	Salt lake	Salt lake	Landlocked water bodies that have a concentration of salts

* Geomorphological units classified based on lithology

** Geomorphological types classified based on geomorphic process

*** Geomorphological faces classified based on erosion features

Table 2 Main criteria and related indices of Siahkouh Playa

Criteria	Index	Description
Environmental	Vegetation cover	Natural vegetation cover percentage
	Soil erosion	Wind or water erosion rate
Technology	Water	Water quality and quantity
	Topography	Slope percentage
	Climate	Precipitation and evaporation rate
	Soil	Soil texture and pH
Infrastructure and socioeconomic	Distance from electricity	Geomorphological faces distance from electricity lines (km)
	Distance from road	Geomorphological faces distance from roads (km)
	Stakeholders participant	Rate of stakeholders' participation and propensity

The relative weights of the chosen criteria and indices are the priorities as extracted from the AHP questionnaire evaluation. In the next step as in previous stages, indices were compared with each other. Normalized weights of the criteria and indices are shown in Tables 3 and 4.

According to the results of Table 3, the environmental criteria and its indices are the most important. The results showed that the environmental criterion is strongly dependent on soil erosion. Technical and socioeconomic criteria and their related indices contributed only 18.1 and 7 %, respectively. These results refer to the priority of environmental issues, even compared with economic criteria in desert and arid environments for making decisions and implementing developing projects.

After estimating the weights for all criteria, the TOPSIS technique numerical priorities were computed for each of the geomorphologic features and decision options. As mentioned, priority determination and ranking of alternative scenarios were carried out in various geomorphology features as land management units. Then, the relative

Table 3 Normalized weights of criteria for Siahkouh Playa

Criteria	Environmental	Technology	Infrastructure and socioeconomic	Criteria weight vector
Environmental	0.789	0.848	0.615	0.751
Technology	0.113	0.121	0.308	0.181
Infrastructure and socioeconomic	0.099	0.030	0.077	0.069

Table 4 Normalized weights of indices for Siahkouh Playa

Indices	Erosion	Veg.	Water	Slope	Soil	Prec.	Evap.	Elec.	Road	Stak.	Weight vector
Soil erosion	0.46	0.65	0.33	0.33	0.37	0.30	0.21	0.21	0.17	0.61	0.36
Vegetation cover	0.09	0.13	0.19	0.16	0.19	0.17	0.12	0.12	0.10	0.20	0.15
Water	0.05	0.02	0.04	0.04	0.02	0.07	0.01	0.12	0.10	0.02	0.05
Slope	0.06	0.03	0.04	0.04	0.02	0.03	0.12	0.12	0.10	0.01	0.06
Soil	0.08	0.04	0.11	0.16	0.06	0.17	0.12	0.16	0.13	0.01	0.11
Precipitation	0.05	0.03	0.02	0.04	0.01	0.03	0.01	0.07	0.10	0.02	0.04
Evaporation	0.05	0.03	0.15	0.01	0.01	0.10	0.02	0.07	0.10	0.02	0.06
Electricity	0.05	0.03	0.01	0.01	0.01	0.01	0.12	0.02	0.06	0.01	0.03
Road	0.05	0.03	0.01	0.01	0.01	0.01	0.12	0.01	0.02	0.01	0.03
Stakeholders participant	0.05	0.03	0.11	0.20	0.31	0.10	0.16	0.12	0.13	0.07	0.13

closeness and distance of each option to the ideal solution, the average relative closeness of each option to the ideal solution, and the priority of each option were estimated.

Analysis of the results, according to the weighted sum method, identified the priority levels of the options as related to the overall objective. The relative closeness values were 0.952 for clay pan (land management unit number two) as the maximum option, and 0.219 for Inselberg as the minimum option. Regarding the ecosystem conditions, field measurements and expert evaluation, land management units with $Ci^{+} > 0.75$, $0.5 < Ci^{+} < 0.75$, and $0.5 < Ci^{+}$ were determined to be suitable, medium, and unsuitable areas for Artemia farming, respectively. The results indicated that the geomorphological feature known as clay pan located in the west-southwestern part of the study area near Chah Afzal village with an area of 77,850 ha was the only suitable land for Artemia culture in the study area.

The highest priority of clay pan is directly related to the environmental indices, especially soil erosion in which sediments that are stabilized during dry seasons cannot be removed by wind erosion. Also, subsurface flow and runoff volume, low vegetation cover (mostly without vegetation or less than 10 %), slope (between 2 and 5 %), clay soil, and closeness to village were advantages of this land management unit which made it as the first and only priority for Artemia farming.

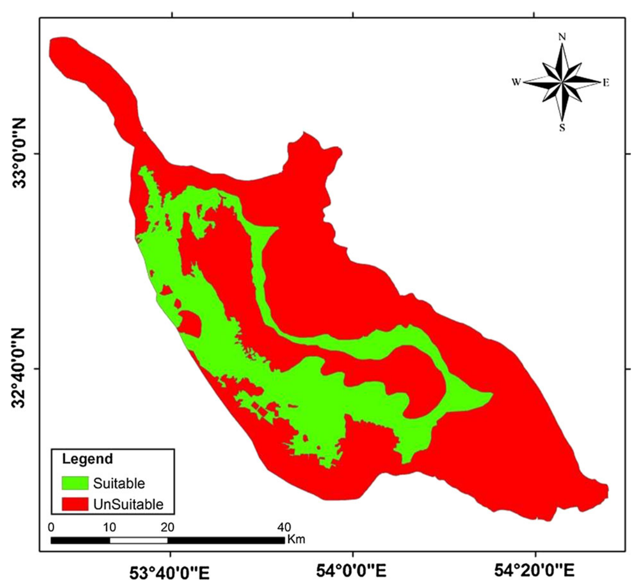

Fig. 2 Location of suitable and unsuitable areas for Artemia farming in Siahkouh Playa

Regarding the last option, the final priority ranking differed in technical issues. The low priority of Inselberg is mainly related to technical criteria including high slope (more than 30 %), clay soil (without clay), low water volume, and vegetation cover (25–30 %). All of these characteristics are disadvantages of this land management unit and are what made it the last priority. Figure 2 illustrates the final ranking of suitable and unsuitable areas for Artemia farming in Siahkouh Playa.

Conclusion

The results of the current research, which applied multi-criteria analysis to assess the feasibility of using saline water resources in the Siahkouh Playa for Artemia farming with the goal of sustainable development in arid regions and desert ecosystems, indicated that considering the fragile desert ecosystem conditions for any project implementation in these areas should be prioritized by the specific environmental conditions of the region. Then, with purpose decreasing possible damage, any implementation of a development project in such environments should be based on sustainable development. Other experiences related to aquaculture showed that most of these projects dominated all technical and economic points of view. Obtaining positive results in such projects requires that in addition to the technical aspect, environmental conditions, stakeholders' participation, and all effective factors on the decision-making process should be considered.

Multiple criteria analysis (MCA) has been widely applied to find solutions for real-world decision-making issues. Results indicated that multi-criteria decision-making techniques have great potential to reduce costs and time and to improve the accuracy of decision-making, and could provide an appropriate framework for solving problems. In fact, this method can be used in resource management that in fact, multi-criteria decision-making method can be used when there are various conflict criteria in decision making and it's difficult for decision maker to choose one of them. In such cases, including more than one criteria and conflict criteria are prerequisite and sufficient condition, respectively.

Results of the current study indicated that concerning the desert ecosystem condition, geomorphologic features were the best options that determined land management units for the evaluation criteria and related indices in arid and desert environments. In the research area, clay pan geomorphological features were suitable areas, because they receive enough runoff, the water table is less than three meters, and more importantly, because of sediment and salts stabilization after saline water evaporation. They are also the base land management unit in arid regions where other criteria and indices can be evaluated. In addition to having suitable environmental conditions for Artemia farming, the expansion of the clay pan geomorphological feature in the study area, and the evaluation criteria of technology and socioeconomics, this geomorphological feature located in the west-southwestern part of the study area near Chah Afzal village was determined to be an adequate area in which to implement Artemia farming development.

Finally, because of the unsuitable development of agricultural lands within rangelands (especially pistachio planting), and the reduced rainfall and intensified drought in adjacent catchments, the uncertainty regarding the shallow saline water supply will increase. Therefore, in order to decrease investment risk rate, it is necessary to measure saline water quantity and quality annually or even seasonally. Consequently, for any future planning decisions related to Artemia farming in Siahkouh Playa, the specifications provided by the existing regulative framework, with less intensive farming techniques emphasized, are likely to constitute a useful starting point.

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