

Improving the livelihoods of local communities in degraded desert regions through afforestation with *Moringa peregrina* trees to combat desertification

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Abstract: Climate change and human activities have led to desertification and decreased land productivity, significantly affecting human livelihoods in desert regions. Identifying suitable areas for cultivating economic and native plants based on ecological capacity, biological restoration, and risk management can be valuable tools for combating desertification. In this study, we identified suitable areas for the growth of economic and medicinal *Moringa peregrina* trees in desert regions of Sistan and Baluchestan Province, southern Iran, using library research and field methods. We also assessed the economic involvement of local communities in areas under different topographic conditions (namely flat area, undulating area, rolling area, moderately sloping area, and steep area) in the study area. Financial indicators such as the net present value (NPV), benefit-cost ratio (BCR), internal rate of return (IRR), and return on investment (ROI) were calculated for areas under various topographic conditions in the study area. The rolling area with results of NPV (6142.75 USD), IRR (103.38), BCR (5.38), and ROI (in the 3rd year) was the best region for investing and cultivating *M. peregrina*. The minimum economic level varied from 0.80 hm² in the flat area to 21.60 hm² in the steep area. Also, approximately 5,314,629.51 hm² of desert lands in the study area were deemed suitable for *M. peregrina* cultivation, benefiting around 1,743,246 households in the study area. Cultivating *M. peregrina* in southern Iran can positively affect local communities and help preserve land from erosion. Our study will provide theoretical support for planting native species in other degraded desert regions to enhance ecosystem services and the well-being of indigenous populations.

Keywords: desert afforestation; *Moringa peregrina*; CRITIC method; minimum economic level; local communities; degraded desert regions

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1 Introduction

Desertification is widely acknowledged as one of the most critical environmental hazards on a global scale, exerting a profound impact on arid and semi-arid areas (Millennium Ecosystem Assessment, 2005). It not only leads to ecological degradation, but also influences socio-economic conditions and threatens the livelihoods of millions of people who depend on vulnerable ecosystems (Karmaoui et al., 2022). Iran is located in the world's arid belt, with more than 75% of its land area classified as arid and semi-arid regions. This extensive aridity has a profound effect on the livelihoods of local communities, posing significant challenges to sustainable development and resource management (Kavandi et al., 2014). A large portion of Iran's desert regions are located in Sistan and Baluchestan Province, part of which is currently experiencing degradation due to a drastic reduction in vegetation cover caused by previous droughts (Hosseini et al., 2013). The desert regions of Sistan and Baluchestan Province are highly vulnerable to desertification, and vegetation cover serves as a crucial indicator of land sensitivity to desertification within these regions (Rigi et al., 2017).

There are various methods to combat desertification. Techniques such as mulching, windbreaks, and afforestation are among the most significant projects implemented in Iran, emphasizing community participation and socioeconomic aspects (Amiraslani and Dragovich, 2011). These efforts are considered essential for combating desertification (Li et al., 2007). The sustainability of these measures requires the participation of beneficiary communities and creation of benefits from the project (Ghoohestani et al., 2022). The most effective solution to this issue is sustainable utilization of desert lands (Atspha et al., 2019; Liu and Wang, 2019; Law et al., 2020). Afforestation and restoration of native species in degraded desert regions can enhance ecosystem service performance and foster a harmonious relationship between humans and land resources (Smith et al., 2019; Law et al., 2020). The use of plant species, such as *Moringa peregrina*, contributes to sustainable services in fragile ecosystems, promoting community development and land restoration (Moradi et al., 2021). This plant species is distributed sporadically along the Red Sea coast, extending northward to Somalia and around the Arabian Peninsula to the mouth of the Persian Gulf, including regions such as the United Arab Emirates, Saudi Arabia, and Palestine (Mozaffarian, 2005). *M. peregrina* is a native plant species found in the arid and semi-arid areas of southern and southeastern Iran (Gad El-Hak et al., 2018). This species is valuable for aiding the preservation of water and soil in mountainous and desert regions. Some of the economic benefits of this plant species include livestock feed, seed production, honey production, bird feeding, wildlife nutrition supply, edible and industrial oil production, wood fuel supply, and water purification (Mansour et al., 2019; Elsergany, 2023). In addition, the plant species possesses medicinal properties that can be used to treat infections and produce cosmetics (Al-Khalasi et al., 2024; Mashamaite et al., 2024). *M. peregrina* is capable of thriving under various harsh conditions, including high temperatures, poor soil quality, and limited water availability, demonstrating significant adaptation to drought. This resilience can be effective in combating desertification (Al-Khalasi et al., 2024).

Previous research has indicated that the identification of suitable land for the growth of multipurpose trees at risk of extinction has a positive impact on community economies (Tshabalala et al., 2020). For example, the multipurpose plant *Moringa oleifera* significantly affects food security, climate change mitigation and adaptation, agricultural system resilience, and the livelihoods of people in developing countries, such as South Africa, Nigeria, Egypt, and Ghana (El Bilali et al., 2024). This plant species not only improves the economic income of residents, but also plays a crucial role in creating live windbreaks and controlling erosion (Maroyi, 2006). *M. peregrina* plays a key role in combating desertification in southern Iran, and humidity is a major factor in its distribution (Moradi et al., 2021). Areas near the Oman Sea represent potential habitats for planting this species (Piri Sahragard and Zarrin Karami, 2024). Furthermore, an elevation of less than 1000 m and an annual precipitation between 80.0 and 225.0 mm are necessary for the optimum growth of *M. peregrina* (Farahat and Refaat, 2021).

However, a key issue remains unclear: how can decision makers fairly and systematically utilize suitable land with community participation? Previous studies have not effectively integrated environmental and economic issues to engage local communities. For this purpose, calculating the minimum land area required per household with the help of financial valuation can contribute to ecosystem conservation, in addition to managing natural resource projects by creating benefits for residents (Ghoohestani et al., 2022). To improve environmental conditions and address management changes, financial indicators such as net present value (NPV), benefit-cost ratio (BCR), and internal rate of return (IRR) can be used to increase land value. Financial evaluation plays an important role in identifying the minimum economic level required for each household, ensuring equitable use of limited land, and strengthening the active participation of local communities. Accordingly, this study aims to achieve the following objectives: (1) employing the CRITIC statistical weighting method for assessing parameters influencing the selection of suitable areas for *M. peregrina* growth; and (2) combining financial evaluation with location identification for *M. peregrina* habitats to determine the minimum requirement per household.

2 Materials and methods

2.1 Study area

The study area is located in Sistan and Baluchestan Province, southern Iran. This region is located between latitudes of $25^{\circ}03'–27^{\circ}02'N$ and longitudes of $26^{\circ}11'–58^{\circ}47'E$, with elevations ranging from -27 to 3916 m (Fig. 1). It covers an area of 180.73 km² and is home to a population of 2,775,014 people residing in 705,000 households (National Portal of Statistics, 2016). The north of Sistan and Baluchestan Province has less than 65.0 mm of annual precipitation and an annual evaporation of more than 5000.0 mm. The southern region of the province experiences a different climate due to its proximity to the Oman Sea and the influence of seasonal winds. This region is known for its high average temperatures and small temperature fluctuations. With low precipitation level and scarce mountain snow resources, most river flows in the region are temporary and seasonal. Limited underground water resources serve as the primary water supply in most parts of Baluchestan. According to data from local meteorological stations, the study area receives an average annual precipitation of 139.8 mm, and has an average annual temperature of $22.6^{\circ}C$ (National Meteorological Organization, 2019).

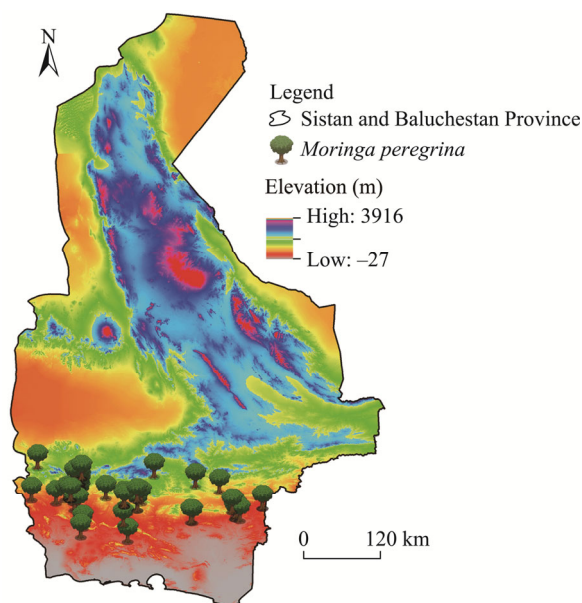


Fig. 1 Overview of the study area and distribution of 56 occurrence points for *Moringa peregrina*

In the study area, numerous valuable plants are existing, such as *Capparis decidua* (Naraghi et al., 2012), *Tecomella undulata* (Jahantighi et al., 2019), *Salvadora persica* (Ghanbarzahi et al., 2018), *Ziziphus spina-christi* (Ameri and Keneshloo, 2014), *Prosopis cineraria* (Ameri and Keneshloo, 2014), and *M. peregrina*, which serve soil conservation and medicinal and industrial purposes. Among these species, *M. peregrina* is particularly noteworthy due to its numerous properties and high value for cultivation and propagation; all parts of the plant can be used, earning it the name "miracle tree". This plant species is distributed along the Red Sea coast from northern Somalia to Egypt, throughout the Arabian Peninsula from the Persian Gulf to the Red Sea shores, and also in the Sinai Mountains (Boulos, 1999). Observations have also indicated that this plant species has a wide range from Sudan to Jordan and Palestine (Zaghloul et al., 2010). In southern Iran, it thrives in parts of Sistan and Baluchestan Province as well as Hormozgan Province (Mozaffarian, 2005). Despite its importance and extensive distribution in southern Iran, this species is one of the forgotten plants that has been overlooked and adequate efforts have yet to be made regarding its identification, development, and scientific utilization.

2.2 Data collection and processing

First, by combining studies from the literature and field surveys, we determined the growth conditions and distribution range of *M. peregrina* (Hegazy et al., 2008; Keshlo et al., 2012; Farahat and Refaat, 2021) and identified various factors that affect species growth, including climatic, soil, geological, topographical, and land use criteria (Moradi et al., 2021; Wang et al., 2021). Then, we prepared maps of the precipitation and temperature indices (average, minimum, and maximum values), relative humidity, evapotranspiration, and wind speed based on the climate data from the Iranian National Meteorological Organization (<https://data.irimo.ir>). We obtained some soil parameters (soil texture, soil pH, and soil classification) and geological formation information based on the soil data (<https://soilgrids.org/www>). Based on the topographical data (<https://www.search.asf.alaska.edu/>) and land use data (<https://iransdi.ncc.gov.ir/>), we determined the elevation, aspect, slope, and land use type (Hu et al., 2020; Farahat and Refaat, 2021). Table 1 shows the details of these data. The geographical positions of 56 occurrence points for *M. peregrina* (Fig. 1) were recorded in the desert regions of Sistan and Baluchestan Province using a GPS device. The value of each environmental variable at each point was extracted using ArcGIS 10.7 software. The growth range of *M. peregrina* determined in the study area was subsequently used in location planning and this location planning served to the financial evaluation of the *M. peregrina* cultivation project.

2.3 Fuzzy layering

Figure 2 gives the flow chart of this study. The first step was to prepare layers of factors affecting the growth of desired plant species using GIS. Next, a numerical value was assigned as the weight of each layer, and the combination of input data helps to predict suitable growth areas for the desired plant species (Tshabalala et al., 2020). To select suitable growth areas for a specific species, several factors need to be considered using fuzzy logic tools in ArcMap 10.7 software (Zoghi et al., 2017). Fuzzy logic, based on the theory of fuzzy numbers, operates on a continuous scale from 0 to 1, unlike Boolean logic that is binary (0 and 1) (Zadeh, 1965). In fuzzy logic, membership is characterized by a spectrum of values between 0 and 1, indicating levels of ambiguity and numerous constituents (McBratney and Odeh, 1997).

2.4 Layer weighting

Not all factors that affect location selection are equally important. To conduct a more precise assessment, it is necessary to assign appropriate weights to each factor. The CRITIC method is an accurate approach for weight assigning based on the correlation between criteria that can reduce human errors (Diakoulaki et al., 1995). In this method, weights are determined by evaluating the correlation, overlap, and conflict between criteria, which helps minimize the influence of expert opinions. Initially, it is assumed that there is a set of variable alternatives A_i (where $i=1, 2, \dots, m$)

Table 1 Ranges of effective parameters for natural growth of *Moringa perigna*

Parameter type	Time	Indicator	Range	Data source
Climate	1999–2019	Maximum temperature (°C)	30.0–35.0 (monthly average)	Presence points
		Minimum temperature (°C)	17.0–21.0 (monthly average)	Presence points
		Precipitation (mm)	120.0–200.0 (annual average)	Kenshloo et al. (2012); Farahat and Refaat (2021); Hegazy et al. (2008); presence points
		Wind speed (m/s)	2.5–3.5	Presence points
		Relative humidity (%)	20.0–50.0 (monthly average)	Presence points
Soil	2020	Soil texture	loam-sand and clay-sandy loam	Presence points
		Soil pH	6.9–8.1	Kenshloo et al. (2012)
		Soil classification	Stony lands; Entisols and Aridisols	Presence points
Geology	2020	Geological formation	Eocene flysch, shale, Marl, sandstone, conglomerate, and limestone	Kenshloo et al. (2012); presence points
Land use	2020	land use type	Various land use types were recorded including lands with poor vegetation cover and no vegetation, rocky lands, and forests.	Presence points
Topography	2020	Elevation (m)	200–800	Kenshloo et al. (2012); Farahat and Refaat (2021); presence points
		Aspect	Mostly in the southern direction	Presence points
		Slope (%)	0.0–30.0	Presence points

and evaluation criteria C_j (where $j=1, 2, \dots, n$) relevant to the research problem. Then, the decision matrix X can be created using Equation 1 to illustrate the performance of various variable alternatives with different evaluation criteria. In addition, the decision matrix was normalized using Equation 2.

$$X = \begin{bmatrix} x_{11} & x_{12} & \dots & x_{1n} \\ x_{21} & x_{22} & \dots & x_{2n} \\ \vdots & \vdots & \dots & \vdots \\ x_{m1} & x_{m2} & \dots & x_{mn} \end{bmatrix}, \quad (1)$$

$$x'_{ij} = \frac{x_{ij} - x_{j\min}}{x_{j\max} - x_{j\min}}, \quad (2)$$

where x_{mn} represents the performance of the m^{th} alternative on the n^{th} criterion; x'_{ij} is the normalized performance value of the i^{th} alternative on the j^{th} criterion; x_{ij} represents the performance of the i^{th} alternative on the j^{th} criterion; and $x_{j\min}$ and $x_{j\max}$ are the minimum and maximum data on the j^{th} criterion, respectively. It is important to note that normalization does not consider the criteria type.

When establishing the criterion weights, both the standard deviation of each criterion and its correlation with the other criteria were considered. Consequently, the weight of the j^{th} criterion (W_j) was calculated using the formulas as follows:

$$W_j = \frac{C_j}{\sum_{j=1}^n C_j}, \quad (3)$$

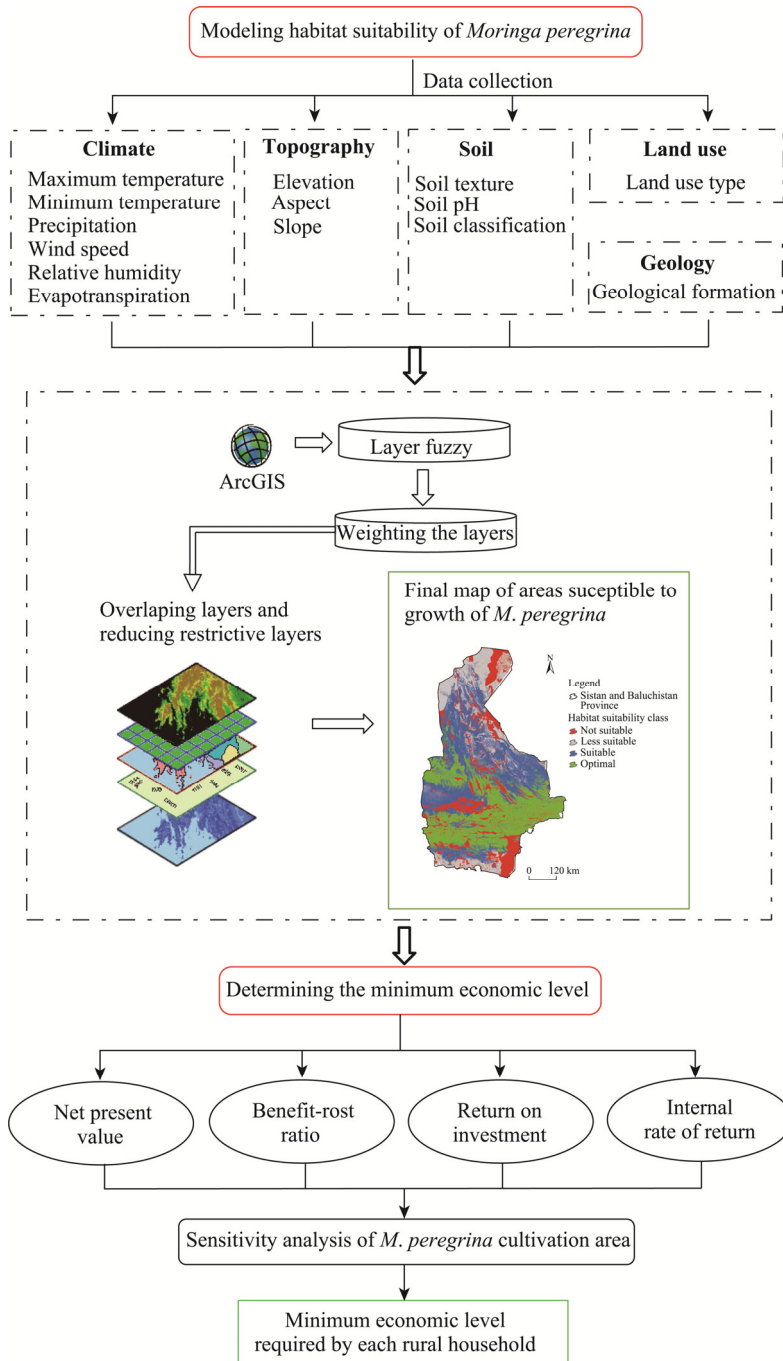


Fig. 2 Flow chart of the study

$$C_j = \sigma_j \sum_{j'=1}^n (1 - r_{jj'}), \tag{4}$$

where C_j represents the amount of information contained in the j^{th} criterion; σ_j represents the standard deviation of the j^{th} criterion; and $r_{jj'}$ denotes the correlation coefficient between the j^{th} and j'^{th} criteria. This method assigns greater weights to criteria that exhibit a high standard deviation and low correlation with other criteria (Aznar Bellver et al., 2011). In other words, a higher C_j value indicates that more information can be derived from the criterion, thereby

enhancing its relative importance in the decision-making process.

Finally, the final layers were obtained incorporating the weights of the obtained layers (Table 2) and fuzzy layers. The formula is as follows:

$$S = \sum_{j=1}^n W_j Y_j, \quad (5)$$

where S represents the final layer; W_j represents the weight of criterion j ; and Y_j represents the performance of target layer on the criterion j .

Table 2 Weights of criteria used to identify suitable areas for the cultivation of *M. peregrina*

Layer type	Layer	Amount of information	Final weight
Topography	Aspect	4.70	0.07
	Height	6.47	0.10
	Slope	4.38	0.06
Climate	Evapotranspiration	6.64	0.10
	Wind speed	5.72	0.08
	Precipitation	5.09	0.08
	Maximum temperature	4.96	0.07
	Minimum temperature	5.20	0.08
	Relative humidity	4.66	0.07
Geology	Geological formation	3.75	0.06
Land use	Land use type	3.44	0.05
Soil	Soil texture	4.26	0.06
	Soil classification	4.25	0.06
	Soil pH	3.98	0.06

2.5 Model validation

In this study, logistic regression was used to validate the habitat modeling of *M. peregrina* in the study area. This method assessed the model validity by presenting a receiver operating characteristic (ROC) curve. Specifically, the logistic regression model utilized 56 collected points for *M. peregrina*, assigning a value of 1; subsequently, ten times as many random points as the existing ones were generated in ArcMap 10.7, with a value of zero in the regression model (Tshabalala et al., 2020). The 56 collected points obtained by GPS were used as model testing points (30%) and model training points (70%). In the subsequent step, the actual and random point values were extracted from the final map and analyzed using logistic regression. The performance of the model was assessed by calculating the area under the curve (AUC) of the ROC curve (Tshabalala et al., 2020). The ROC curve is a graphical representation used to assess the performance of binary classification models. It illustrates the sensitivity between 0 and 1 across various threshold settings. Sensitivity (True Positive Rate) measures the proportion of actual positives correctly identified by the model. Specificity (False Positive Rate) represents the proportion of actual negatives that are incorrectly identified as positives. AUC values equal to or less than 0.50 signify random prediction, whereas values exceeding 0.50 and approaching 1.00 indicate accurate model prediction (Tshabalala et al., 2020). The XLSTAT software was used to conduct this analysis.

2.6 Suitable areas for *M. peregrina* growth

Based on the final layer, the distribution of suitable areas for *M. peregrina* growth was categorized into four classes (not suitable, less suitable, suitable, and optimal) using the natural

break classification method in ArcGIS 10.7 (Tshabalala et al., 2020; Moradi et al., 2021; Li et al., 2023).

2.7 Financial evaluation of *M. peregrina* planting pattern

To evaluate the economic feasibility of cultivating *M. peregrina* in the study area, it is crucial to determine the minimum economic level required for such cultivation. This requirement is determined based on the cultivation strategy proposed for *M. peregrina* in Iran, as detailed by Riahi and Khodarahimi (2008). This study determined the minimum economic level needed for households in the *M. peregrina* cultivation plan during the financial evaluation stages of the project. The average annual cost per household was factored into the project's annual expenses, assuming that rural households' annual expenses were solely covered by participating in the *M. peregrina* cultivation plan. According to the Iran National Statistics website (<https://www.amar.org.ir>), the average annual cost for a rural household with an average of four persons in Sistan and Baluchestan Province was 289.96 USD. These costs were then integrated into the annual expenses of the *M. peregrina* cultivation plan for 2021–2041. The annual costs and revenues for the base year were calculated using a discount rate of 25% (considering Central Bank's 16% rate for 2021 and a 9% confidence interval in Iran). A sensitivity analysis was conducted on the proposed land area with a 20% decrease and increase under different topographic conditions (Table 3) to assess the financial indicators such as NPV, IRR, BCR, and ROI. The minimum economic level required for each region was determined. Additionally, 10% of the total costs were added as unforeseen expenses, in addition to existing costs.

Table 3 Definitions and area proportions of different topographic conditions in the study area

Topographic condition	Definition	Area proportion (%)
Flat area	Area with slope of 0%–2%	33
Undulating area	Area with slope of 2%–8%	36
Rolling area	Area with slope of 8%–15%	14
Moderately sloping area	Area with slope of 15%–30%	11
Steep area	Area with slope of 30%–60%	6

3 Results

3.1 Accuracy validation of the habitat modeling of *M. peregrina*

Figure 3 indicates that the generalization capability of the model was 0.80, reflecting its good predictive power. Additionally, the learning capacity of the model, as measured by the predicted areas, was 0.89, indicating a better prediction by the model.

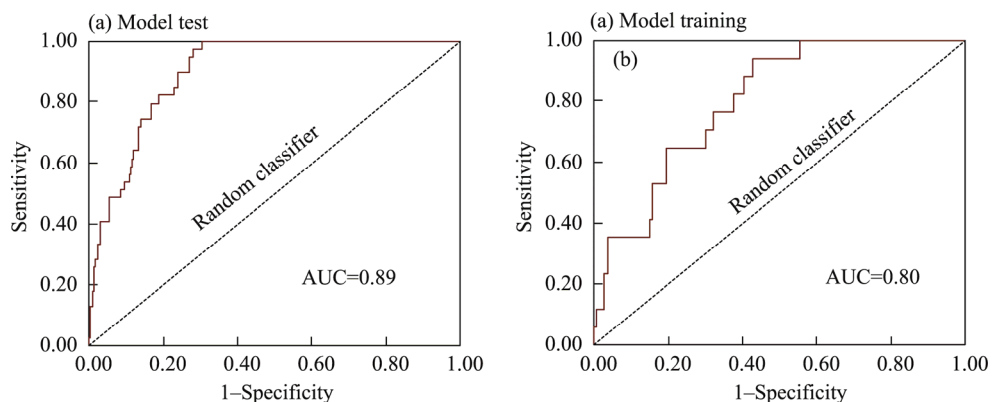


Fig. 3 Receiver operating characteristics (ROC) curves based on model test points (a) and model training points (b) for *M. peregrina*. AUC, area under the curve. The red curve represents the mean response.

3.2 Suitable areas for *M. peregrina* growth

The optimal areas for *M. peregrina* growth covered 31% of the study area, totaling 5,314,629.51 hm^2 , and was therefore prioritized for cultivation (Fig. 4). Areas deemed suitable and less suitable for *M. peregrina* growth accounted for 34% and 17% of the study area, respectively, indicating their recommendation for secondary priority planning. About 18% of the study area was unsuitable for this species. These unsuitable areas were basically urban areas, rural areas, lakes, salt flats, wetlands, roads, railways, rivers, and nature reserve, posing challenges for restoring vegetation. Therefore, these areas were typically excluded from cultivation planning because of either private ownership or a lack of growth potential.

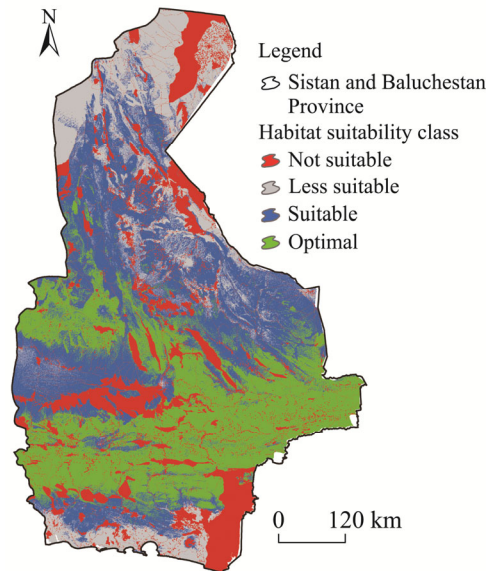


Fig. 4 Spatial distribution of four classes of suitable areas for *M. peregrina* growth

3.3 Minimum economic level required for the cultivation of *M. peregrina*

After identifying suitable areas for *M. peregrina* growth and considering the limited land available to farmers, it is crucial to determine the amount of land required per household. The required financial evaluation information for effectively utilizing the land is shown in Table 4. This table shows the benefits that will be obtained from the implementation of the project along with the economic area of the land. The data in Table 4 will be used in the following economic calculations. In the flat area, profitability can be achieved with the smallest area of land.

Based on the findings in Tables 4 and 5, the BCR exceeded 1.00 for areas under different topographic conditions in the study area. Additionally, the IRR surpassed the Central Bank's 16% rate for 2021 and the NPV was positive, suggesting the appropriateness of the assessed metrics.

3.4 Sensitivity analysis of areas under different topographic conditions

Initial studies showed that the flat area, undulating area, rolling area, moderately sloping area, and steep area with 2.00, 5.40, 11.20, 27.70, and 54.00 hm^2 of cultivated area of *M. peregrina*, respectively, could have similar performance (Table 4). However, the financial indicators studied indicated that they performed very well (Table 5). Therefore, with the help of sensitivity analysis at a 20% reduction rate in the proposed areas, the minimum area of land that is economically justified can be determined. Finally, the minimum economic area for the flat area, rolling area, moderately sloping area, and steep area with 60% reduction in their area was 0.80, 4.48, 11.08, and 21.60 hm^2 , respectively, and for the undulating area with 40% reduction in the area, it was 3.24 hm^2 .

Table 4 Assumptions and benefits of the *M. peregrina* cultivation project for areas under different topographic conditions in the study area

Topographic condition	Projected economic area (hm ²)	Benefits of the project				
		Time	Product performance (kg/hm ²)	Income (USD)	Cost (USD)	Benefit (USD)
Flat area	2.00	1 st year	-	0.00	1797.00	-1797.00
		2 nd year	-	0.00	760.89	-760.89
		3 rd year	652.50	2584.16	622.05	1962.10
		4 th year onwards	652.50	2584.16	604.46	1979.88
Undulating area	5.40	1 st year	-	0.00	1909.87	-1909.87
		2 nd year	-	0.00	974.69	-974.69
		3 rd year	240.00	2566.33	752.80	1813.52
		4 th year onwards	240.00	2566.33	731.41	1834.92
Rolling area	11.20	1 st year	-	0.00	997.75	-997.75
		2 nd year	-	0.00	203.65	-203.65
		3 rd year	116.25	2578.21	282.10	2296.11
		4 th year onwards	116.25	2578.21	257.54	2320.67
Moderately sloping area	27.70	1 st year	-	0.00	1655.81	1655.81
		2 nd year	-	0.00	330.99	-330.99
		3 rd year	46.78	2566.33	406.67	2159.66
		Fourth year onwards	46.78	2566.33	372.44	2193.89
Steep area	54.00	1 st year	-	0.00	1900.00	-1900.00
		2 nd year	-	0.00	490.51	-490.51
		3 rd year	24.00	2566.33	522.21	2044.12
		4 th year onwards	24.00	2566.33	479.40	2086.91

Note: "-" indicates no data.

Table 5 Calculation of financial evaluation indicators for areas under different topographic conditions in the study area

Topographic condition	NPV (USD)	IRR	BCR	ROI
Flat area	3826.74	55.50	2.43	In the 5 th year
Undulating area	3083.80	48.05	2.05	In the 5 th year
Rolling area	6142.75	103.38	5.38	In the 3 rd year
Moderately sloping area	4976.75	69.48	3.47	In the 4 th year
Steep area	4261.24	58.96	2.79	In the 4 th year

Note: NPV, net present value; IRR, internal rate of return; BCR, benefit-cost ratio; ROI, return on investment.

3.5 ROI of the *M. peregrina* cultivation project in areas under different topographic conditions

The ROI indicates the amount of time required to recoup a project's investment cost. Table 5 shows that the ROI will be achieved in the 3rd year for the rolling area, the 4th year for moderately sloping and steep areas, and the 5th year for flat and undulating areas. After these years, households can benefit from net returns (Fig. 5). Taking into account the average household expenses in project implementation, participants will begin deriving net benefits in the 14th year in the flat area (94.26 USD), the 10th year in the undulating area (413.85 USD), the 4th year in the rolling area (1020.67 USD), the 7th year in the moderately sloping area (USD 683.63), and the 10th year in the steep area (268.06 USD).

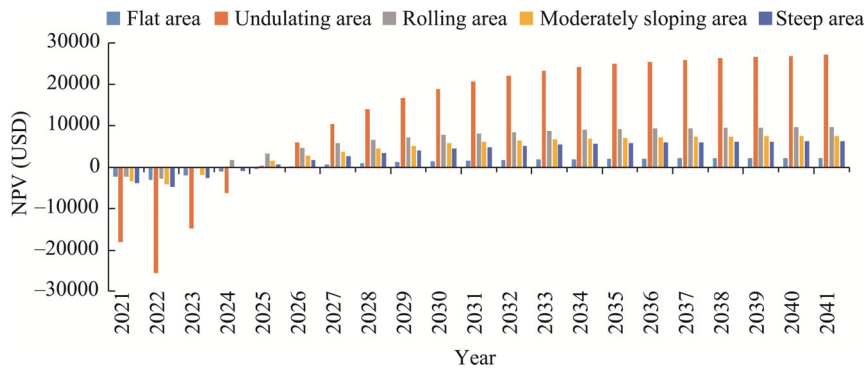


Fig. 5 Annual changes of net present value (NPV) from the *M. peregrina* cultivation project from 2021 to 2041 in areas under different topographic conditions

3.6 Benefits of *M. peregrina* cultivation

In the study, the habitat suitability classes were defined separately for areas under different topographic conditions (Fig. 6). The rolling and moderately sloping areas had the most extensive regions of optimal suitability. The flat area had the smallest area proportion of optimal suitability and the largest area proportion of suitable suitability.

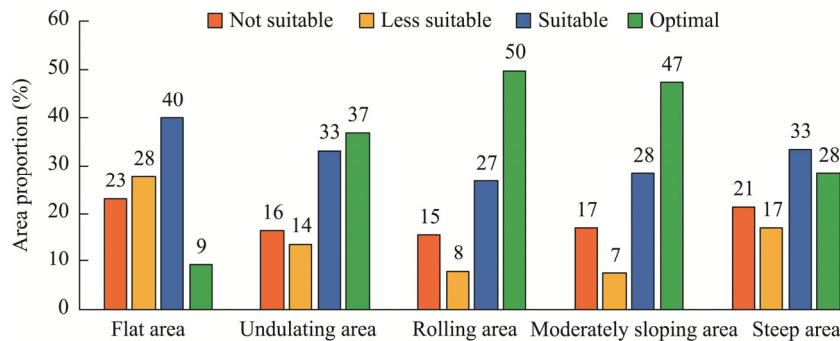


Fig. 6 Area proportions of four habitat suitability classes in areas under different topographic conditions

The priority for cultivating *M. peregrina* was given to areas with optimal growth potential. The most suitable areas for *M. peregrina* cultivation, with optimal growth potential, were in the undulating area with a minimum economic level of 3.24 hm² (Table 6). Approximately 712,021 households in these areas could benefit from cultivating *M. peregrina*. The lowest benefits from *M. peregrina* cultivation were obtained from the steep area with a minimum economic level of 21.60 hm² and 14,888 households. Overall, land with a total area of 5,314,629.51 hm² (31% of the study area) had an optimal growth potential for cultivating *M. peregrina*, which can result in economic benefits for around 1,743,246 rural households.

Table 6 Benefits of *M. peregrina* cultivation in areas under different topographic conditions

Topographic condition	Area of land susceptible to priority cultivation (hm ²)	Area proportion of land susceptible to priority cultivation (%)	Minimum economic level (hm ²)	Number of households
Flat area	535,328.19	10	0.80	66,160
Undulating area	2,306,948.04	43	3.24	712,021
Rolling area	1,190,950.29	22	4.48	265,837
Moderately sloping area	959,801.40	18	11.08	81,339
Steep area	321,601.59	6	21.60	14,888
Total	5,314,629.51	100	-	1,743,246

Note: "-" means no data.

4 Discussion

One of the main obstacles to achieving sustainable development in degraded regions is the low income of residents, which leads to the increased exploitation of nature and further degradation of land. Optimizing land use by enhancing ecological performance and preserving native plant species not only enhances the overall performance and ecosystem potential but also boosts the income of residents in degraded regions (Atsbha et al., 2019; Liu and Wang, 2019; Law et al., 2020). Identifying areas suitable for cultivating economically viable plants for local communities and integrating them into development initiatives plays a crucial role in improving livelihoods and conserving biodiversity. This fosters a harmonious relationship between humans and the land, promoting sustainable land management (Smith et al., 2019). Additionally, enhancing the ecological performance and increasing income in regions vulnerable to desertification by cultivating multipurpose plants with high economic value can increase the economic status of residents in desert regions (Urzedo et al., 2020). Based on our findings and previous research, cultivating *M. peregrina* could be a valuable asset for this purpose (Gad El-Hak et al., 2018).

4.1 Layer weighting in habitat modeling of *M. peregrina*

In this study, the parameters of elevation and evapotranspiration (each weighed at 0.10), along with precipitation, wind speed, and minimum temperature (each weighed at 0.08), had the most significant impact on the modeling outcomes, which is consistent with the findings of Farahat and Refaat (2021) and Moradi et al. (2021). Additionally, the minimum temperature is a critical parameter because of the plant's sensitivity to frost, a fact corroborated by experts from the Department of Natural Resources in the study area and by research conducted by Piri Sahragard and Karami (2024). Furthermore, Bezzi et al. (2022) found that in Sistan and Baluchestan Province, elevation, temperature, and wind speed significantly influenced evapotranspiration in the region. Given the presence of 120-d winds and high temperatures in this region, evapotranspiration plays a vital role in the growth of *M. peregrina*. Ultimately, considering the weights assigned to these parameters complicates the decision-making process regarding the areas more suitable for *M. peregrina* cultivation; thus, influencing factors must be considered.

4.2 Suitable areas for the cultivation of *M. peregrina*

In the present study, 18% of the land in the study area exhibited limited growth conditions for *M. peregrina*. Based on spatial analysis, 17% of the areas were deemed unsuitable for growth, while 34% showed moderate potential, and 31% (equivalent to 5,314,629.51 hm²) demonstrated the highest potential for cultivating this species. The areas showing optimal suitability were found in undulating, rolling, and moderately sloping areas with slopes of less than 30%. These areas were primarily located within an elevation range conducive to the desired plant growth.

Although the flat area exhibits low slopes, water infiltration is reduced due to the heavy soil texture and sediment accumulation in low-lying lands. The high rates of evapotranspiration in Sistan and Baluchestan Province exacerbate this limitation. Furthermore, overlaying the flat area map with soil classification and land use maps reveals that the presence of saline lands, marshes, sandy soils, and arid soils contributes to the minimal optimal suitability in the flat area. Identifying areas suitable for *M. peregrina* cultivation can help protect the species and prevent its extinction in native habitats, including southern Iran. Furthermore, conducting a location analysis could provide a valuable solution to reduce the time and costs associated with cultivating this species, which may be of interest to desert land managers. The significance of this analysis was also emphasized in the study conducted by Keshavarz and Dabiri (2018). Areas suitable for plant growth present an excellent opportunity to prevent sand movement through sedimentation and reduce wind speed. This study employed the AUC method to evaluate the performance of the location analysis. The resulting AUC range was suitable for this modeling, and the generated map had an accuracy of 80%, with 89% learning power to predict suitable cultivation areas. According to Tshabalala et al. (2020) and Moradi et al. (2021), this level of

accuracy was acceptable, reflecting the model of high accuracy and performance in this study.

4.3 Minimum economic level required for the development of *M. peregrina* cultivation

With the increase in global population and the limitation of resources such as land, finding ways to achieve equitable land distribution and sustainable use has become more essential than ever. Land sensitivity analysis leads to the determination of the minimum economic level at which native households with the least available land can meet their annual expenses. Advancing the cultivation of plants can be a significant step in rehabilitating biological areas, preventing land degradation, and preserving the genetic reserves of economically valuable species. This strategy aligns with sustainable development goals and is based on environmental, social, and economic benefits. Local community participation in natural resource management programs and the transfer of these plans to local stakeholders can enhance their involvement and contribute to the economic sustainability of projects. To mitigate environmental degradation, management strategies should focus on empowering local communities to reduce poverty, create job opportunities, and increase their participation in society. The findings of this study indicated that implementing *M. peregrina* afforestation project under various topographic conditions is economically viable, as emphasized in studies of Mansour et al. (2019) and Karimi et al. (2021).

In the flat area and areas with suitable slopes (undulating, rolling, and moderately sloping areas), trees are spaced more closely together, allowing a larger population to benefit from the economic advantages of those while requiring less land to achieve the minimum economic level. The ROI has been observed from the 3rd or 4th year of project implementation across all operational areas. Considering typical household costs incurred during project execution, it is expected that payback will occur after 14 a in the flat area, 10 a in the rolling area, 4 a in the undulating area, 7 a in the moderately sloping area, and 10 a in the steep area. The rolling area was key regions with a payback period of 4 a and 50% of its area classified as optimal.

Finally, this study determined the minimum economic level for each household in areas under different topographic conditions. For instance, in the flat area, a local individual cultivating *M. peregrina* over an area of 0.80 hm² can cover their living expenses. This approach represents a dynamic method that combines economics with spatial analysis of natural resources and can be integrated with updated data and other economically viable crops for further development.

4.4 Benefits from *M. peregrina* cultivation

M. peregrina is a valuable multipurpose plant that contributes to the conservation of water and soil in mountainous and desert regions. This plant species is utilized in the production of livestock fodder, supplying wildlife nutrition, providing shelter for honeybees and birds, and producing medicinal seeds, cooking oil, firewood, and industrial oil with high economic value. Furthermore, the present study indicated that arid lands, as well as uncultivated and unused lands, can be valued in terms of income per hectare through the cultivation of this plant species. The benefits derived from planting *M. peregrina* could lead to a reduction in poverty and environmental degradation (Law et al., 2020).

In this study, the sensitivity analysis of land surface showed that increasing the cultivation of *M. peregrina* leads to enhanced profitability and improved financial indicators. This upward trend was observed across various topographic conditions. Approximately 70% of the study area was undulating area or rolling area, and in total, the optimal suitable areas for *M. peregrina* cultivation will enable about 1,743,246 local households to use degraded land to strengthen their economic situation and benefit from the *M. peregrina* afforestation project in areas prone to plant growth. This assertion is also supported by Tshabalala et al. (2020).

5 Conclusions

The increasing global population requires more efficient use of arid lands, which account for over 40% of the Earth's surface. This study showed that *M. peregrina*, with its adaptations to desert

regions, offers a viable solution for the optimal utilization of these lands. By aligning the interests of local stakeholders and implementing policies to promote vegetation growth, we can reduce land degradation rates in desert regions. With one-third of the Sistan and Baluchestan Province showing enormous potential for the growth of *M. peregrina*, it is evident that a substantial portion of southern Iran's desert regions holds significant economic promise. Through a thorough financial evaluation, we determined the minimum land area necessary for each rural household and the potential economic benefits that can be derived from cultivating *M. peregrina* in the Sistan and Baluchestan Province. As a result, cultivating *M. peregrina* in southern Iran will not only enhance the quality of life for local inhabitants but also safeguard the lands from erosion. By involving the local communities, we can achieve a balanced restoration in arid lands and enhance vegetation cover, leading to enhanced ecosystem services after *M. peregrina* cultivation. This study serves as a critical foundation for the afforestation of *M. peregrina* in Iran, potentially improving the livelihoods of indigenous populations in desert regions and contributing to species conservation efforts.

Conflict of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Author contributions

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