

Original Research

# Investigating Environmental Factors for Locating Mangrove Ex-situ Conservation Zones Using GIS Spatial Techniques and the Logistic Regression Algorithm in Mangrove Forests in Iran

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## Abstract

Along the coastal strip of tropical and subtropical regions, mangrove forests extend as one of the most productive coastal ecosystems. Iran is considered one of the most western coastal habitats of these communities in Asia. Unfortunately, in recent years, despite their economic and ecological importance, these forests have been threatened mainly due to human activities, which necessitate the need for protecting and developing these ecosystems. Ex-situ conservation, which aims to transfer a species to right place for preservation and development, is one of the most effective ways of protecting these forests. It is obvious that the successful transfer of a species in order to protect it as ex-situ conservation requires a comprehensive environmental assessment. The present paper employs a spatio-statistical methodology to delineate areas enriched with environmental parameters and weather factors necessary to support a mangrove ex-situ conservation plan in Hormozgan Province, Iran. With extensive effort in reviewing the related studies in the literature, we elicited a collection of 14 environmental and weather indicators critical to maintaining mangrove stands in a sustainable ecological environment. For screening the number of indicators to environmental variables with highest importance in our research, we used the Delphi method to quantify expert attitudes in order to develop a suitability index collection. Accordingly, an integrated application of GIS spatial analysis and a logistic regression algorithm were used to build an explicit spatial predictive model that evaluates the targeted area in terms of identified factors, thereby quantifying the potential of suitable zones for locating mangrove ex-situ conservation sites. Predictive performance of the developed model was evaluated based on Kappa index and omission error rate. According to our results, land proneness to a mangrove plantation has a high positive correlation with environmental attributes such as temperature fluctuation, land form, and mean tidal level, and has a negative correlation with slope and wave height. Our results should be considered advantageous for decision makers and planners in the field of mangrove ecosystems.

**Keywords:** mangrove forest, *Avicennia marina*, Hormozgan Province, Delphi, logistic regression

## Introduction

Forested wetlands of mangrove ecosystems are the main vegetative cover of tropical coastlines. These places are rich and complex in ecology and are good primary locations for different types of birds and fish, as well as valuable areas for providing food and wood. Moreover, these ecosystems provide protection from typhoons and tornados [1].

In addition, as a pool of diversity, mangrove wetlands provide nursery habitats for a wide variety of prawns, shrimp, fish, crabs, and other crustaceans. Mangrove ecosystems are witnessing an astonishing rate and unprecedented scale of deforestation, mainly due to anthropogenic activities like expansion of aquaculture, wood overexploitation, and land use transformation [1-2]. Accordingly, it is estimated that during the next three decades unrestricted clear-cutting, aquaculture, and overexploitation of fisheries will be the greatest threats [2-3]. Taking diverse services of mangrove ecosystems into account, depletion of mangrove reserves should be prohibited and the remaining mangroves need to be managed sustainably [3]. Indonesia, Australia, Brazil, and Nigeria possess the largest mangrove reserves, accounting for 43% of the world's mangrove forests [2]. According to the Iranian agriculture bureau report in 2002, 93.37 km<sup>2</sup> of Iranian shorelines are covered by mangrove forests [4] located at between 25°19'-27°84' E. This area spans the three southern provinces of Iran (Bushehr, Hormuzgan, and Sistan and Baluchestan) and includes coastal boundaries of the Persian Gulf and Oman Sea. *Avicennia marina* (grey mangrove) is a dominant mangrove species in Iran [3].

Iran mangrove reserves have experienced a noticeable temporal decline in their distribution in recent decades [3]. The ongoing shrinking process of mangroves necessitates effective management in terms of mangrove forest rehabilitation. Mangrove forests occur as a function of several environmental parameters as well as climatic factors. These attributes can be processed as statistically explanatory variables in a spatial database. Their importance and degree of contribution in mangrove forest occurrence can be investigated through the integrated application of spatio-statistical modeling techniques. In this regard, statistical algorithms such as the logistic regression modeling approach in conjunction with GIS spatial techniques is of potential importance for estimating occurrence probability of mangrove stands. The implementation of spatially explicit probabilistic models has attracted noticeable research interest in recent years [5-7], in which the land is evaluated in terms of environmental and climatic factors (explanatory variables) that are necessary to support the establishment and maintenance of a mangrove plantation program. Integration of GIS spatial analysis and statistical modeling techniques can help managers and decision-makers in identifying suitable sites for mangrove plantations at minimum possible cost [8]. For example, Alongi stated

that “people will continue to misuse mangrove forests with the present speed up to 2025 if the value of these forests as unique natural resources are not recognized, and plans for protecting them are not performed” [2].

According to the results of Elsebaie, although many worldwide projects have been developed to protect mangrove ecosystems, there has not been much success in performing these plans [6]. One of the reasons for these failures is wrongly locating areas suitable for mangrove plantations because locating the proper place for mangrove natural forests is an important factor in protecting and developing natural mangrove forests. Based on a study conducted by Abd-El Monsef et al., using satellite imagery interpretation, topographic maps, and soil maps for locating suitable sites for mangrove plantations, they indicated that “mangrove occurrence is correlated with environmental parameters, including air temperature, water temperature, salinity, tidal, wave energy, land proneness to flash-flooding, and soil suitability” [5]. In order to determine factors affecting mangrove forest occurrence, we investigated related studies on mangrove occurrence indicators in the literature (Table 3).

The purpose of this study is to achieve the following objectives:

1. Modeling the linkage between environmental attributes and mangrove presence on the basis of probability prediction values generated by the logistics regression model.
2. Identifying the explanatory variables linked to the possibility of mangrove occurrence.
3. Development of a spatial predictive model to detect suitable mangrove sites for ex-situ conservation programs.

## Material and Methods

### Study Area

We considered coastal boundaries along the northern Persian Gulf and Oman Sea Coast in Hormozgan Province as the study site. The surface area is approximately 1,000 km<sup>2</sup>, 1,950 km long (parallel to the shoreline), and 500 m wide (Fig. 1). Mangrove forests along the Hormozgan coastal line occur between 25°25'51" to 27°18'55" N and 52°39'41" to 59°14'2" E coordinates and dominated by *A. marina* species [3]. Table 1 shows the position of *A. marina* forests in Hormozgan.

### Indicator Screenings

The Delphi method was applied to selected indicators with better performance in the study area. The Delphi technique is in essence a series of sequential questionnaires, or ‘rounds’, interspersed by controlled feedback and that seek to gain the most reliable consensus of opinion of a group of experts. It is a technique that is useful for situations where individual judgments must be tapped and combined in order to address a lack of agreement or incomplete state

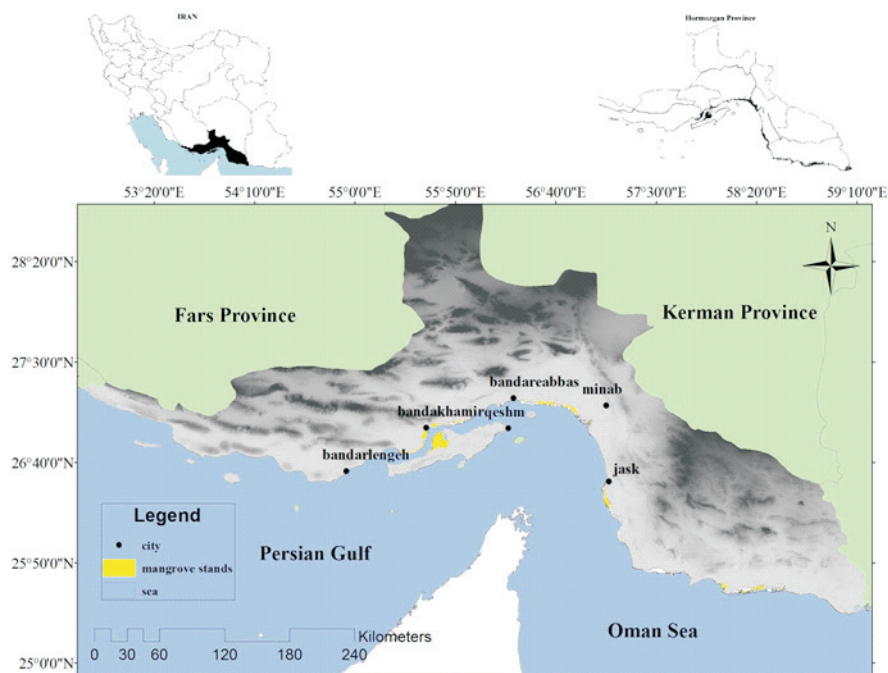


Fig. 1. Study area.

of knowledge [9]. In this study, 15 series of sequential questionnaires were analyzed in this way (15 experts).

### Preparing Maps

Maps of the most important parameters that are assumed to make significant contributions to our study area were prepared as follows:

- Topographical data

The digital elevation model (DEM) of the study area obtained from the Maritime Organization of Iran (MOI) (with 30-m resolution) was interpreted through ArcGIS 9.3 package software to determine some important parameters, including slope (percent) and elevation maps for the backshore area of the coastline (Fig. 5).

- Landform data

We obtained a landform map of the study area from MOI. This map illustrated three different landforms of mud, sand, and rock in coastal regions of the province (Fig. 3).

- Climatology data

Climatology indices of the study area were extracted through data processing of five synoptic stations of weather monitoring that are located close to mangrove forests (Table 2 and Fig. 6)

- Wave height

Data of daily wave forecasts obtained from nine points were used to analyze wave height. We acquired these data from the MOI. The analyzed wave records belonged to a 10-year period from 2001 to 2014 (Fig. 7).

- Water Salinity

Water salinity data were provided from documents including national Iranian mangrove forest in 2012 and monitoring the coastal zone of Hormuzgan Province in 2011.

- Mean tidal levels

Data of 12 selected sites were obtained based on the tide forecast table issued by the National Cartography Center (NCC) of Iran (Fig. 4).

- Soil properties

Table 1. Geographic position and area of Hormuzgan Province mangrove forests (Zahed et al. 2010).

No	Province	Region	Area (Km <sup>2</sup> )	Geographical position	
				East longitude	North latitude
1	Hormuzgan	Khamir Port	10.5	56°77'-56°83'	26°77'-26°93'
2	Hormuzgan	Qeshm Island	67.5	55°63'-55°80'	26°75'-26°93'
3	Hormuzgan	Koulegghan Areas	1.00	56°51'-56°58'	27°16'-27°18'
4	Hormuzgan	Tiyab Area	1.30	56°77'-56°83'	27°11'-27°14'
5	Hormuzgan	Sirik	4.86	57°06'-57°12'	26°30'-26°44'
6	Hormuzgan	Jask Area	2.00	57°80'-57°82'	25°69'-25°70'

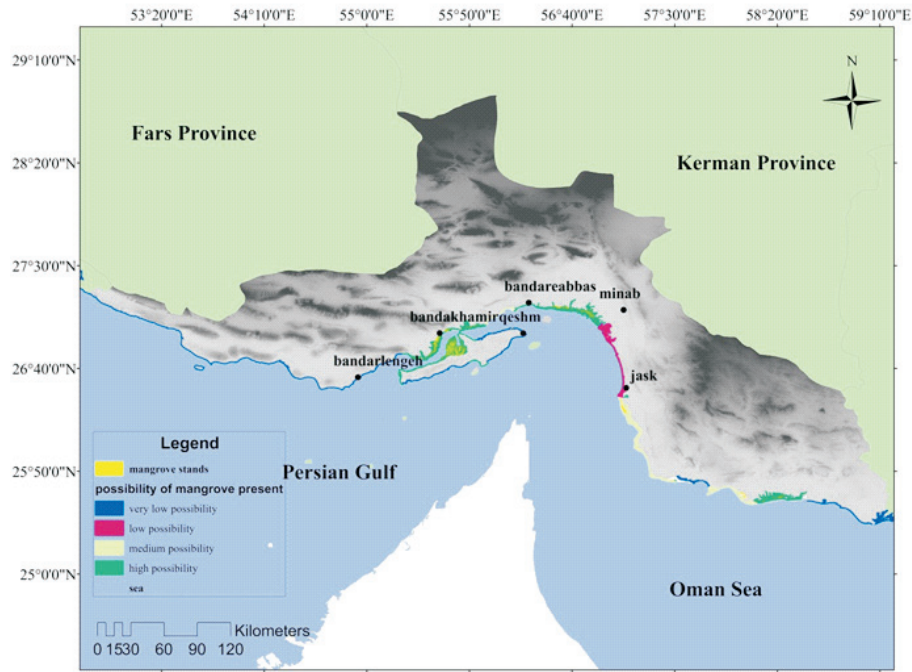


Fig. 2. Results of logistic regression.

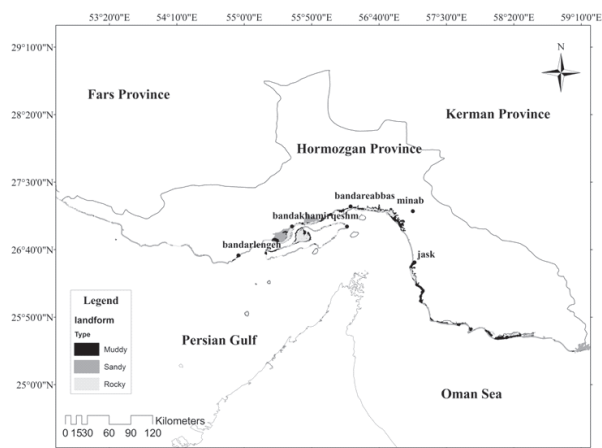


Fig 3. Land form types in study area.

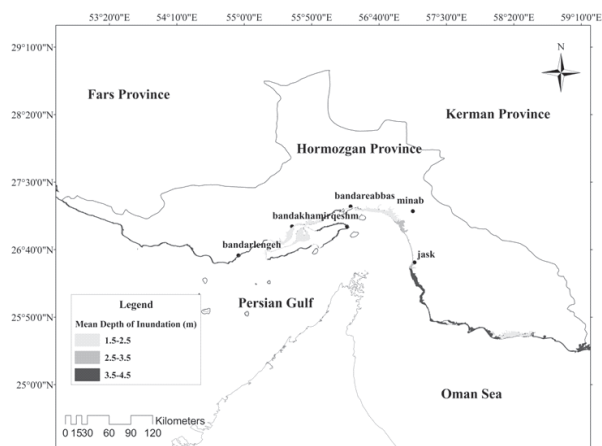


Fig 4. Mean tidal level in study area.

Data of salinity of soil was obtained from previous studies such as the Iranian mangrove forest document in 2012 and monitoring and modeling of the Hormozgan Province coastline in 2011.

All input data layers were imported into a GIS environment and then an inverse distance weighting (IDW) algorithm was used for data interpolation [10]. The input layers were transformed into 100 m × 100 m 1:25000-scale grid and co-registered to the same extent by the source of Universal Transverse Mercator datum and a WGS 84 projection system.

### Statistical Analysis

– Random Sampling

From the total available cells, 5% of random sampling

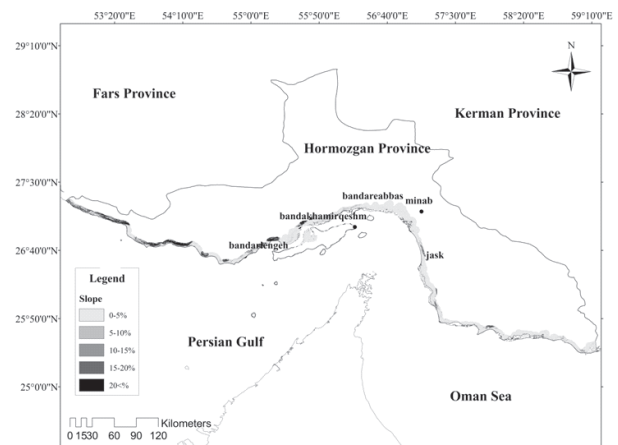


Fig. 5. Slope parameter in study area.



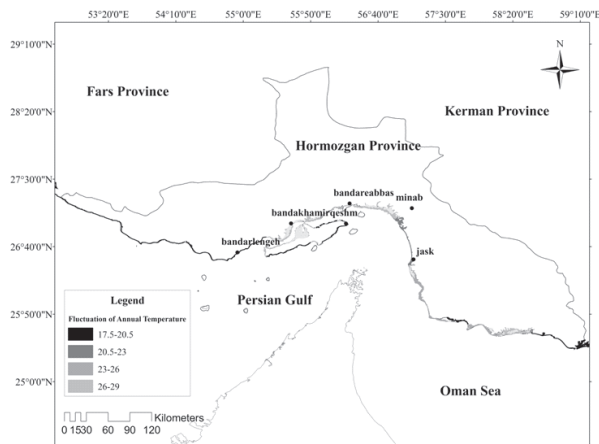


Fig 6. Fluctuation of annual temperature in study area.

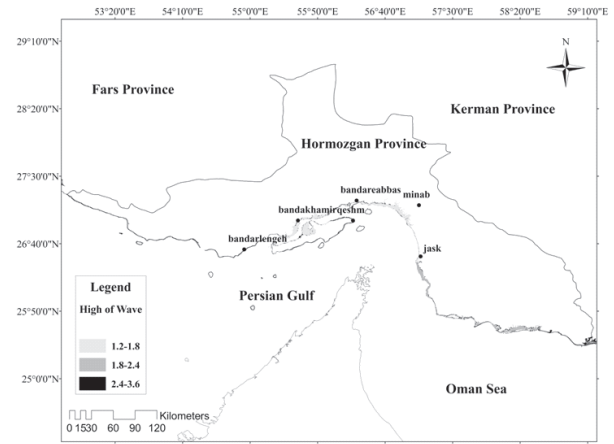


Fig 7. Wave height in study area.

points were overlaid with all selected index layers (distributed across the entire region). Only those sampled grid cells that appeared to retain 100% of their natural forest cover were classified as mangrove forest presence (1). Otherwise, they were classified as mangrove forest absence (0). Accordingly, digital values of environmental settings in terms of the presence and absence of locations of mangroves were extracted.

– Correlation analysis

In order to identify predictive variables with most predictive value for developing a logistic regression model, parameters were examined in terms of correlation and dependency. The correlation analysis was performed because the overlaid data can lead to exaggerated results, and an insufficient number of variables can result in missing information. Therefore, simple correlations were established between each pair of variables. When the correlation value exceeded 0.8, only one variable was used for further analysis [11].

– Logistic regression-based model building

The purposes of model development are: 1) to assess the relative influence of 14 explanatory variables on probability [12] of mangrove forest occurrence, and 2) to predict the probability of mangrove occurrence for the future. Therefore, we developed a logistic regression model in order to model the linkage between dependent variables (the presence and absence of mangroves) and independent variables (environmental parameters).

Formula 1: Logistic regression model for binary data.

$$Y = \frac{Exp(b_0 + b_{1x_1} + b_{2x_2} + \dots + b_{nx_n})}{1 + Exp(b_0 + b_{1x_1} + b_{2x_2} + \dots + b_{nx_n})} \quad (1)$$

...where: *Y* Is the expected probability that the outcome is present, *X*<sub>1</sub> through *X*<sub>p</sub> are distinct independent variables, and *b*<sub>0</sub> through *b*<sub>p</sub> are the regression coefficients.

– Model performance evaluation

For evaluating model performance we used methods that included Kappa index and classification table methods.

## Results and Discussion

### Literature Review

Considering the results of investigating 20 studies from Iran and other parts of the world, three effective criteria and 23 indices were identified for detecting suitable sites for developing *Avicennia marina* forests (Table 3).

### Indicator Screening Results

According to the results of the Delphi method, maximum annual precipitation, average temperature in the hottest month, maximum temperature, evaporation, water

Table 2. Synoptic stations.

Synoptic station	Elevation from sea level	Period of information (years)	Geographical position	
			East longitude	North latitude
Jask	5	21	25°38'	57°46'
Minab	27	21	27°07'	57°06'
Bandar Abbas	10	22	27°13'	56°22'
Gheshm	6	10	26°55'	55°55'
Bandar Lenge	12	22	26°32'	54°50'

Table 3. Criteria and indices that extract from studies.

Criteria	Indices	References
Climate	Mean annual perception	[26-30, 3]
	Minimum annual perception	[31-32, 3]
	Maximum annual perception	[32, 3]
	Average temperature in the coldest month	[30-29, 3]
	Average temperature in the hottest month	[30, 5, 3]
	Mean annual temperatures	[27, 29, 33, 30, 3]
	Minimum and Maximum temperatures	[34, 3, 32]
	Varying of annual temperatures	[3, 35]
	Evaporation	[26, 29]
	Kind of Climate	[28, 33, 26, 35, 3]
Sea water feature	Tidal range	[28, 16, 26, 34, 5]
	Mean depth of tidal inundation	[20, 33, 36]
	Wave height	[20, 16]
	Water salinity range	[31, 34-37, 34, 35, 39, 20]
	Water pH	[34, 37, 38, 20, 36]
	Water EC	[37-38]
	Water temperature	[35, 39]
	Elements of water	[26]
Land feature	Slope	[16, 20]
	Topography	[26]
	Landform	[33, 31, 20, 28, 38, 40, 41]
	Soil salt content	[33, 37, 38, 20, 36, 42, 5, 19]
	Soil pH	[37, 38, 40-42, 20, 35, 5]

pH, water EC, elements of water, water temperature, and soil pH must be eliminated, and mean annual precipitation, minimum annual precipitation, average temperature in the coldest month, mean annual temperatures, minimum temperatures, variation of annual temperatures, climate type, tidal range, mean depth of tidal inundation, wave height, water salinity range, slope, topography, and landform are selected variables to choose suitable areas for developing mangrove forests.

Below we present the most important parameters extracted from the mentioned articles and range of each of these parameters in the mangrove forests along the coasts of the Persian Gulf and Gulf of Oman (Hormozgan Province).

Table 4. Effective model development.

Variable	Value	P-Value	Standard error
Intercept	-7.7	0.001	0.311
Fluctuation of annual temperature	0.56	0.003	0.069
Landform	2.2	0.03	0.062
Slope	-1.2	0.009	0.018
High of wave	-5.3	0.013	0.2
Mean depth of tidal inundation	0.6	0.002	2.1

#### Description of the Selected Parameters

##### – Climatic Criteria

These criteria include the sub-criteria of precipitation, temperature, evaporation, and climate type, which are discussed below.

##### – Precipitation

Amount, duration, and distribution of rainfall influence on the development of flora and fauna. While mangroves are not directly affected by rainfall, rainfall indirectly has an important effect on the establishment of mangroves [5]. Rainfall washes excess salt from the soil and improves the growth of mangroves. In this study, the indicators of mean annual rainfall and minimum annual rainfall were identified as two significant indicators influencing rainfall. Mangrove communities along the Hormozgan coastline occur in an area with mean annual rainfall ranging from 126 to 204 mm (160 mm in average), and in the last 22 years received at least 16 mm of rainfall.

##### – Air temperature

Areas with high annual temperature and temperature fluctuations less than 10°C are suitable sites for mangroves. At lower temperatures, tree size, leaf area index, and compounds synthesized by plants decrease [13]. *Avicenia* has a high tolerance to temperature fluctuations, and this is reflected by their distribution at high and low latitudes worldwide [14]. Five indices of mean minimum temperature of the coldest month, annual temperature fluctuations, absolute minimum temperature, mean monthly temperature, and climate type are among the identified indices in this study. Based on the long-term mean monthly temperature index, this temperature ranges from 26.71 to 28.65°C (with an average of 27.5°C) along the Hormozgan coastline.

In Hormozgan coasts, mangrove communities tolerate mean minimum temperature in the coldest month, ranging from about 12 to 14°C (the mean minimum temperature in the coldest month along the coastline is 13.76°C) and the absolute minimum temperature recorded in the area is about 2.8°C. Temperature fluctuations serve as an important factor in the distribution of mangrove forests,

Table 5. Areas of suitable zones for planting *A. marina* variables.

Township	Areas(ha)
Bandar Abbas	5,600
Sirik	5,500
Jask	2,800
Sirik	2,300
Gheshm	840
Bandar Lenge	20
Sum	17,060

as the majority of mangrove species only grow in areas where temperature fluctuation is less than 10°C [13]. Temperature fluctuations in the range of the distribution of mangroves along the Hormozgan coastline range from 17 to 50°C, with an average of 29°C.

– Climate type

One of the most important factors in distributing and establishing mangroves is climate [15], so that mangroves are limited to the coastal areas of tropical and subtropical regions and are not present in other climatic conditions [3].

– Criteria of seawater characteristics

Sub-criteria of his criteria effective in distribution of mangroves include wave, tidal zone, the amount of flooding during tide, and the salinity range of sea water.

– Waves

Mangroves are located in areas protected from the effects of waves, so the first condition for the growth of mangroves is the existence of an area with minimum water movement [16]. Maximum wave height recorded in the Hormozgan coastal area in a 21-year period between 1992 and 2013 ranges from 2.1 m to 6.3 m.

– Tidal zone

In almost all definitions for mangroves, these forest are considered plants belonging to the tidal zone. The results of this study show that Hormozgan mangrove communities are distributed in the coastal areas with minimum tidal zones of at least 150 m, and these forests are not capable of growing in narrow coats of widths less than 150 m.

– Salinity range of seawater

Mangroves generally are more dense in areas with low salinity, as studies have shown that in high salinity mangroves consume more energy to maintain water and proper concentrations of ions, with energy allocated for growth and primary production. The salinity range in Hormozgan estuaries vary from 38 to 48 mg/l.

– Maximum flooding during tide

When the amount of flooding habitats is not proportional to species tolerance, the species cannot distribute. Studies of tide height in tidal stations showed that the highest mean annual tide occurs in the central Hormozgan coasts with the highest and the lowest heights recorded as 4.5 and 1.8 m.

### Criterion of Land Characteristics

– Texture

Soil texture is an important factor affecting the mangrove ecosystem. In terms of particle size distribution, mangroves demand fine-grained soils [6]. The majority of the study area is characterized by sandy and silty-textured soils.

– Slope

Mangroves generally grow in low-slope and flat areas with large tidal range and low activity of waves, and the structure of the forests is affected by the effect of slope on tidal range [17]. Obviously, as the slope decreases, tide encompasses wider areas and leads to increased distribution of mangroves [18]. Bed slope of the study area ranges from 0% to 15/5.

– Soil salinity

Salinity plays an important role in the distribution of the species, production, and growth of mangrove forests. Soil salinity affects the growth of plants through photosynthesis and respiration, and high salinity causes plants to be dwarf-sized [19]. Soil salinity in this province varies from 60 to 70 ppt.

### Results of Spatial Analysis

Fourteen raster maps of continuous surfaces were generated using the IDW interpolation method. Four-thousand six-hundred random samples (from presence and absence locations of mangrove forests) were selected to extract information from raster maps of our driving forces. The values were entered into the Minitab 16 software and the correlations between each pair of variables were investigated.

### Results of Correlation

Correlation analysis revealed that there is a strong correlation among mean annual precipitation, minimum annual precipitation, average temperature in the coldest month, minimum temperatures, and fluctuation of annual temperatures. Consequently, we eliminated correlated variables from the model development process, and only fluctuation of annual temperatures as a highly contributing factor in predicting the probability of mangrove occurrence was included. Finally, climate type with invariable attributes across the entire study area were also omitted from logistic model building.

### Results of Logistic Regression Modeling

A logistic regression model was created according to 14 attributes of predictive variables related to the locations of sampling points. In this regard, the dependent variable was either a presence or absence event (1 = mangrove forest presence and 0 = mangrove forest absence), and environmental parameters serve as independent variables. The relative importance of each variable was assessed through regression coefficient.

*P-values* of predictive variables, fluctuation of annual temperature, landform, slope, wave height, and mean depth of tidal inundation were less than 0.05; therefore, these indicators can estimate the occurrence of *A. marina*. Table 4 and Formula 2 represent the significant variables with their *p-values* for predicting mangrove occurrence.

Formula 2

$$Y = \frac{\text{Exp}(-7.7 + 0.56FT + 2.2L - 1.2S - 5.3HW + 0.6DT)}{1 + \text{Exp}(-7.7 + 0.56FT + 2.2L - 1.2S - 5.3HW + 0.6DT)} \quad (2)$$

...where:

*Y* – Probability of mangrove occurrence  
*FT* – Fluctuation of annual temperature parameter  
*L* – Landform parameter  
*S* – Slope parameter  
*HW* – Height of wave parameter  
*DT* – Mean depth of tidal inundation parameter

### Model Performance Evaluation

Model performance evaluation indicated 0.801 and 2% for Kappa index and omission error, respectively.

### Running the Logistic Regression Model

In this study we executed our predictive model based on GIS data layers (Fig. 2). The result showed that only 17% of the Hormozgan coastline (with probability of 60 to 90%) was suitable for planting *A. marina*. In addition, most of the suitable areas are located in the Sirik and Bandar Abbas townships coastline. Table 5 presents areas of suitable zones in different parts of the province.

Based on results, wave height was an indicator with the highest predictive power for mangrove forest presence, which is negatively correlated with mangrove occurrence probability. This means that the probability of *A. marina* occurrence increases as wave height decreases. This finding is compatible with the study of Kamali and Hashim, who concluded that “wave action and erosion were among the most important factors influencing the possibility of mangrove seed survival.” Also, Kamali and Hashim considered surges to be the only reason to convert Malaysia’s west coast, which was covered with mangrove forests [16]. If the mangrove seeds are not planted in suitable places, they might be uprooted or washed away by strong waves, rain, or waterflow. Low wave energy is better for the mangrove to root strongly in the soil. Gilamn and his colleague have reported that “in rehabilitation and restoration sites, wave action should be regarded as an important mangrove uprooting cause, which ultimately can prohibit mangrove seedlings” [20]. Neinavaz and her colleague concluded that “severe waves and extreme tidal action can uproot mangroves and decrease growth” [21].

In addition, Zahed and his colleague also determined severe waves to be the main cause for the absence of *Avicennia marina* in many mangrove habitats of Iran. It

is recommended, if necessary, to create structures such as breakwaters in planting areas to protect the seedlings [4].

Fluctuation in annual temperature was scored as the second contributing factor and represented a direct relationship to *A. marina* existence probability. Data analysis of coastal weather stations showed that temperature fluctuation in the coastal province of Hormozgan is about 24°C. This result is also verified by other studies, including Morrissey and his colleague [22], Krauass and his colleague [23], Petrosian and her colleague [3], and Balachandran [24], who confirmed the importance of temperature for mangrove distribution, productivity, and reproduction.

Fluctuations in annual temperature in the coastal province of Hormozgan is high, and higher than fluctuations in annual temperatures of most of the mangrove habitats in the world, which represents the high tolerance of *Avicennia marina* against temperature changes and drought. So this species is among the most suitable species in terms of Iran’s climatic conditions, and introducing other mangrove species for planting to this region will likely fail due to an inability to withstand temperature changes.

Muddy landform is the third factor linked to mangrove occurrence likelihood, which had been reported as an effective factor in similar studies, including Zahed and his colleague [4] and Monsef and his colleague [5]. One reason for the development of mangroves on muddy soil is the ability of these soils to absorb phosphates, and since soil phosphorus is one of the major factors in the growth of mangrove forest, mangrove forests prefer muddy soils as regions for their development [18].

Hinterland slope has not been regarded as an important variable in the majority of studies conducted in other parts of the world, but it was considered an influential variable in this study. Slope indicated a negative relationship with *A. marina* existence probability. Areas with a low percentage of backshore slope are correlated with increased river stream and low speed, which create appropriate conditions for mangrove seedlings [3].

Areas with high slope cause a return to breaking waves with higher force, while the waves in areas with low slope (which generally constitute important areas of biological communities) distribute and lose their power [2].

The forth factor is the mean depth of tidal inundation, which demonstrated a positive correlation with the likely presence of mangroves. In general, if the tidal range of the coast is high, the possibility of a mangrove forest will increase because greater tidal range reduces the possibility of sediment formation [5]. This parameter prevents coastal salinity to the death threshold and this mechanism is vital for mangrove forests, which are arbitrary halophytes [3].

Model performance was evaluated and calculated using Kappa and omission error. The results were 0.801 and 2% for Kappa index and omission error, respectively, which denoted high accuracy of the developed logistic model in successfully predicting mangrove occurrences [11]. Predicted probabilities of mangrove occurrence in the study indicated that highly potential lands for a



mangrove plantation are located in Bandar Abbas and Sirik townships. Consequently, the priority of these areas in establishing new mangrove plantation programs is evident. In addition, the cost of mangrove restoration and planting projects can be considerable. Therefore, these projects should be designed in advance to achieve success and to avoid wasting large amounts of money [17]. In most cases, direct human disturbance is the cause of mangrove degradation, so the risk of human-induced disturbance in the restoration and development sites must be eliminated before commencing plantation programs [25].

### Conclusions

In our study, spatial analysis techniques and a logistic regression model provided a valid predictive model of mangrove occurrence as a function of several environmental and weather parameters. The results of our study are advantageous for mangrove management plans and can be beneficial for decision makers to identify suitable lands for mangrove existence at minimum expense.

### Acknowledgements

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