IDENTIFYING SUITABLE LOCATIONS FOR MANGROVE PLANTATION USING GEOSPATIAL INFORMATION SYSTEM AND REMOTE SENSING

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ABSTRACT:

Mangroves provide numerous environmental benefits, such as carbon sequestration, water purification, climate change mitigation, and flood and Tsunami impact reduction. Despite these unique advantages, mangroves are threatened by the combined adverse impacts of human activities and climate change. Therefore, it is essential to implement reasonable practices to avoid further degradation of mangroves and provide efficient workflows to increase their extent. Accordingly, better plantation policies are principally required for their conservation and rehabilitation. In this study, we desired to detect suitable locations for mangrove plantation in coastal areas of Hormozgan Province, Iran. We considered a relatively new Multi Criteria Decision Making (MCDM) technique to combine ten criteria derived from remote sensing in a GIS environment. The Best Worst Method (BWM), as an MDCM technique, was implemented to determine the relative importance of each criterion. Afterward, all criteria were aggregated using the Weighted Linear Combination (WLC) method to produce a mangrove plantation suitability map. Statistical measures, including Overall Accuracy (OA = 95%), Kappa Coefficient (KC = 87.9%), and Area Under Curve (AUC = 98.79%), indicated the high applicability of the implemented method for mangrove plantation site allocation. The produced map could give managers a profound insight into finding optimal spots to plant mangroves.

1. INTRODUCTION

Mangroves include a group of woody vegetation that exist mostly in tropical and semi-tropical areas (Bihamta Toosi et al., 2020; Estoque et al., 2018; Syahid et al., 2020). This type of evergreen flora, a mixture of tree and shrub species, can survive in severe saline environments (Osei Darko et al., 2021; Vaghela et al., 2018). These ecosystems offer a variety of environmental services, including storm protection, water purification, and carbon sequestration (Devaney et al., 2021; Yancho et al., 2020).

Regardless of their significance, mangroves' survival is endangered and threatened by both human-induced actions and natural phenomena (e.g., climate change and natural hazards) (Omo-Irabor et al., 2011), which could have a massive impact on achieving Sustainable Development Goals (SDG) for the future (Chakraborty et al., 2019). Unfortunately, roughly 20-30% of these ecosystems have disappeared globally during the last five decades (Giri, 2021). Therefore, temporal and spatial observation and mapping of mangroves are mandatory steps that should be taken into account to halt their degradation (Ghorbanian et al., 2021). By doing these, suitable locations for mangrove plantation can be detected, which provides decision-makers and managers with strategies to save and increase their extents (Hu et al., 2020).

In order to establish an effective framework to map and detect suitable regions for mangrove plantation, various criteria, such as meteorological, topographical, and vegetation conditions, should be considered (Chakraborty et al., 2019). Remote Sensing (RS) can provide the mentioned criteria, which is more convenient than field-based data collection in extensive area investigations (Baloloy et al., 2020; Kamal et al., 2015). A combined framework consisting of RS satellite data and Geospatial Information System (GIS) technology is the most practical approach for mangrove vegetation mapping (Maurya et al., 2021). Also, GIS, as a flexible tool, allows many criteria to be aggregated via Multi Criteria Decision Making (MCDM) methods (Kanani-Sadat et al., 2019).

Therefore, in this study, a GIS-based MCDM method named Best Worst Method (BWM) combined with RS satellite data obtained from Google Earth Engine was applied to map mangrove forests in Hormozgan province, Iran. After identifying the affecting criteria (i.e., meteorological, topographical, and vegetation conditions) on mangrove ecosystems, the BWM method was implemented to calculate the weight of each criterion. Then, these criteria were aggregated in a GIS environment using Weighted Linear Combination (WLC) approach to obtain a mangrove suitability map. Finally, statistical measures were calculated to assess the reliability of the implemented method.

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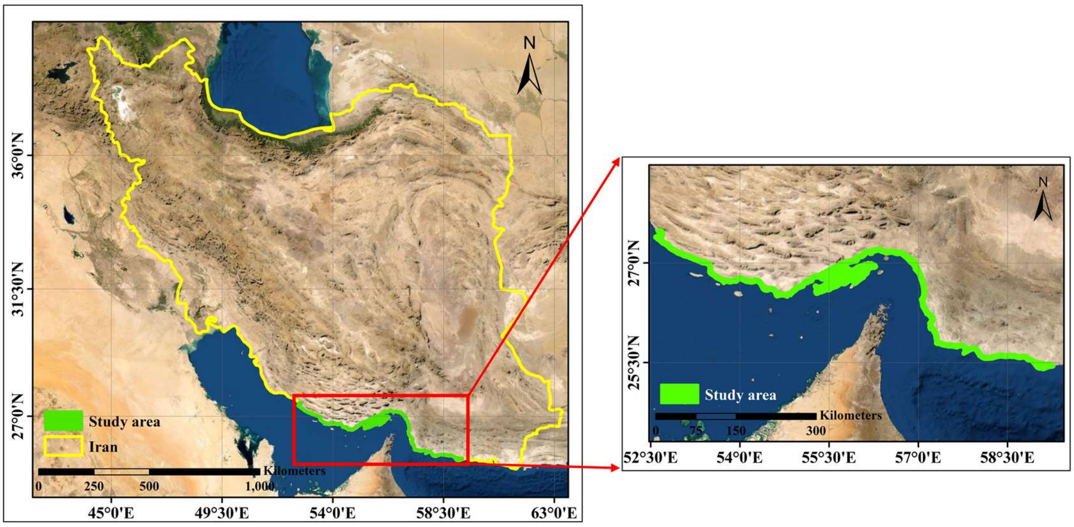

Figure 1. The geographical location of the study area in southern parts of Iran, along the coastal area of the Hormozgan province.

2. STUDY AREA

The study area is located on the northern coast of the Persian Gulf and Oman Sea along Hormozgan province (900 km) in the southern part of Iran, which is also home to the vastest mangrove forests in the country. *Avicennia marina* and *Rhizophora mucronata* are those mangrove species that encompass the area dominated by the earlier and are reported to be great sources of carbon sink (Amiri, 2021). Unfortunately, tourism and fishing industries affect the mangrove ecosystem adversely. Also, oil leakage is another issue that is affecting this ecosystem due to oil tanker transportation nearby, like the Hormuz strait (Dadashi et al., 2018).

3. MATERIALS AND METHODS

In the current study, a GIS-based MCDM method was utilized to identify regions suitable for mangrove plantation. Figure 2 shows the applied framework for generating the mangrove plantation suitability map, including 1) data preparation (e.g., input criteria) based on literature review and accessible data (Chakraborty et al., 2019), 2) criteria weight calculation using BWM, 3) criteria aggregation based on BWM weights and WLC, 4) suitability mapping generation and validation using several statistical measures, which are explained in details in the following subsections.

3.1 Data Preparation

Ten criteria were chosen to be investigated in this study, and the selection was based on a literature review and the accessibility of the criteria. The considered criteria included precipitation (C1), elevation (C2), wind (C3), Normalized Difference Salinity Index (NDSI) (C4), Normalized Difference Moisture Index (NDMI) (C5), Normalized Difference Vegetation Index (NDVI) (C6), slope (C7), temperature (C8), solar radiation (C9), and Land Use/ Land Cover (LULC) map (C10). These criteria were obtained from the Google Earth Engine (GEE) platform with a 100 × 100 m pixel size spatial resolution and were inserted into a GIS environment to generate raster maps with the same pixel size (Figure 3). In the next step, all the obtained criteria were normalized in the GIS environment to eliminate the inhomogeneity of the criteria. Generally, if the higher value of a criterion is more suitable for mangrove plantation, it is normalized by $y = \frac{x - x_{min}}{x_{max} - x_{min}}$ (direct), otherwise $y = \frac{x_{max} - x}{x_{max} - x_{min}}$ (inverse); where x and y are un-normalized and normalized values of each criterion, respectively. x_{min} is the lowest, and x_{max} is the highest value of each layer. Accordingly, NDVI, NDMI, solar radiation, and precipitation were normalized using the direct equation, and the remnant criteria were normalized using the inverse equation.

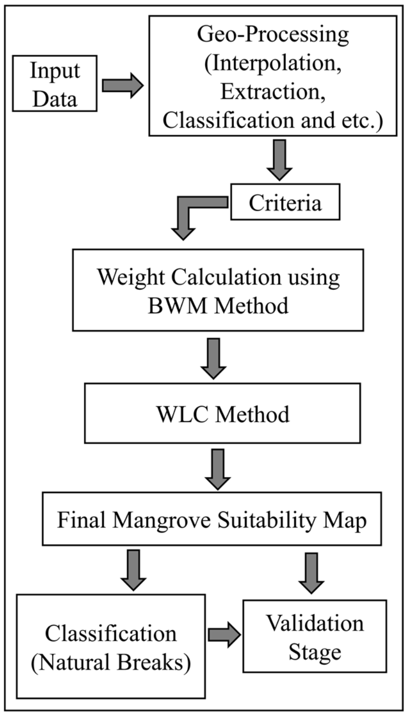

Figure 2. Flowchart of the implemented method for mangrove plantation suitability mapping.

3.2 Best Worst Method

BWM, a relatively new MCDM method, was proposed by (Rezaei, 2015). BWM is said to be a more convenient and trustworthy MCDM method due to several justifications. First, it provides consistent results by applying pairwise comparisons in a structured way. Second, it is not time-consuming and requires less data for decision-makers to fill the questionnaire since it only includes two vectors compared to the whole pairwise comparison matrix in other methods. Third, this method not only calculates the weights of criteria but can also be merged with other MCDM

Criterion	Description
Precipitation	Changes in precipitation patterns have a significant effect on both the growth of mangroves and their areal extent. Precipitation raster was an annual average precipitation using CHIRPS precipitation products (Funk et al., 2015).
Elevation	Very low or very high elevation is not appropriate for mangrove growth. The elevation raster was generated from SRTM digital elevation data (Jarvis et al., 2008).
Wind	Low and moderate wind speeds are appropriate criteria for mangrove vegetation suitability (Chakraborty et al., 2019). The wind raster was generated from ERA5 reanalysis data (Alpert, 2004; Hersbach et al., 2020).
NDSI	This index uses NIR and Red spectra to examine the salinity condition of the salt-affected area. The NDSI raster was generated using Landsat-8 optical data.
NDMI	There is a positive correlation between NDMI and mangrove suitability. The NDMI raster was generated using Landsat-8 optical data.
NDVI	A numerical parameter that examines the existence and condition of healthy green vegetation. The NDVI raster was generated using Landsat-8 optical data.
Slope	Slope affects the frequency of tidal inundation and the impact strength of the waves. The slope raster was generated from SRTM digital elevation data.
Temperature	High and low temperature values are inappropriate for mangrove ecosystems (Syahid et al., 2020). The temperature raster was generated using Landsat-8 thermal data.
Solar radiation	There is a positive correlation between solar radiation and mangrove growth. The solar radiation raster was generated from ERA5 reanalysis data.
LULC	The LULC layer for the study area has seven classes, each of which has a specific weight. The LULC raster data was generated from Copernicus Global Land Cover data (Buchhorn et al., 2020).

Table 1. Summary of sources and preparation descriptions of all considered criteria for mangrove plantation suitability mapping.

methods (Liu et al., 2020; Rezaei et al., 2016). To implement this method, first, experts compare criteria and give preferences of the best criterion toward other criteria, and then, other criteria will be compared to the worst one (Munim et al., 2020). The optimal weights and consistency ratios will simply be calculated using a linear model based on these two sets of comparisons (Rezaei et al., 2016). The following steps are taken to implement BWM:

1) Detection of criteria [c_1, c_2, …, c_n] involved in the problem.

2) Identifying the best and worst criteria, the most preferable and least preferable, respectively.

3) Calculating the best-to-others (BO) vector, which is the relative importance of the best criterion toward the other criteria.

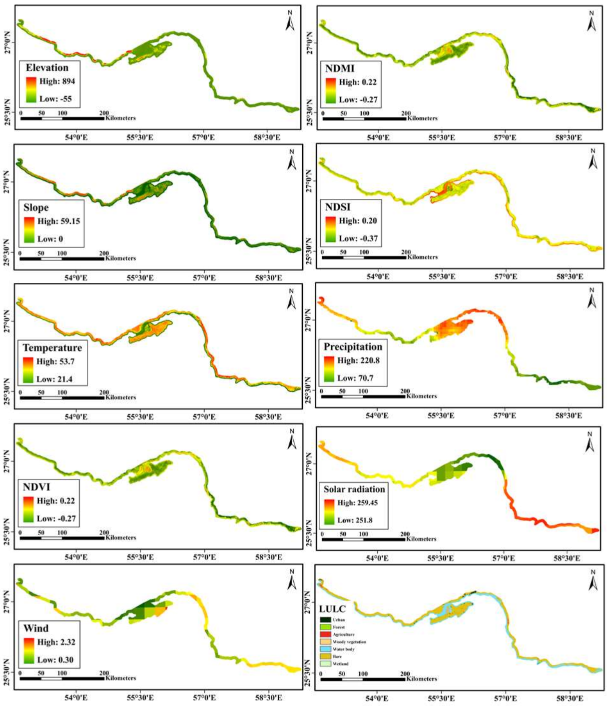

Figure 3. Raster Maps of the considered criteria for mangrove plantation suitability mapping.

$$A_B = (a_{B1}, a_{B2}, \dots, a_{Bn}) \quad (1)$$

where a_{Bj} =the priority of the best criterion B toward criterion j. It is obvious that $a_{BB} = 1$.

4) Obtain the others-to-worst (OW) vector, which is the priority of all the criteria toward the worst one.

$$A_w = (a_{1w}, a_{2w}, \dots, a_{nw})^T \quad (2)$$

where a_{jW} = the importance and priority of criterion j toward the worst criterion W. It is evident that $a_{WW} = 1$.

5) Calculate the optimal weights ($w_1^*, w_2^*, \dots, w_n^*$) by applying a Linear Programming (LP) model on BO and OW vectors according to the below equation.

$$\begin{aligned} &\text{Min } \xi \\ &\text{s.t.} \\ &|w_B - a_{Bj} w_j| \leq \xi; \\ &|w_j - a_{jw} w_w| \leq \xi; \\ &\textstyle\sum_j w_j = 1,\ w_j \geq 0, \text{ for all } j \end{aligned} \quad (3)$$

Where ($|w_B - a_{Bj} w_j|$, $|w_j - a_{jw} w_w|$) = the absolute deviation from the expert-determined values. The maximum of this value should be minimized for each j. w_B and w_w = the weights of the best and the worst criteria, respectively. Also, the value of ξ (the consistency ratio) has to be a proper value. which results in a non-empty solution space. The comparison system is more consistent when ξ is closer to zero (Rezaei et al., 2016; Zolfani and Chatterjee, 2019).

Expert	Best Criterion	Other Criteria									
		C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
1	NDVI	3	3	3	1	1	1	5	4	6	2
2	NDVI	4	4	6	2	2	1	5	4	6	3

Table 2. Pairwise comparison matrix between best criterion and other criteria based on two experts' knowledge. The values show the relative importance of the best criterion to other criteria

Expert	Worst Criterion	Other Criteria									
		C1	C2	C3	C4	C5	C6	C7	C8	C9	C10
1	Solar radiation	5	3	1	4	3	6	3	4	1	6
2	Solar radiation	6	3	1	5	5	6	4	4	1	4

Table 3. Pairwise comparison matrix between other criteria and the worst criterion based on two experts' knowledge. The values show the relative importance of other criteria to the worst criterion.

3.3 Weighted Linear Combination (WLC)

After determining the weight of each criterion, Equation 4 was used to aggregate all criteria in a GIS environment (e.g., ArcMap).

$$MSM = \sum_{i=1}^{n} W_i * C_i \quad (4)$$

where MSM = Mangrove Suitability Map,
Wi = the importance,
Ci = the normalized raster layer of each criterion.

Based on Equation 4, each normalized criterion is multiplied by its weight, and the final mangrove plantation suitability map is produced as the summation of all criteria. Finally, to visually simplify the comprehension of the generated map and identify appropriate areas for mangrove plantation, it is classified into five classes such as "Very Low", "Low", "Medium", "High", and "Very High".

4. RESULTS

In the current study, ten criteria, including topographical, vegetation, meteorological, and geomorphological criteria, were aggregated to generate a mangrove plantation suitability map of the study area. According to the five steps of the BWM method described in Section 3.2, experts compared criteria and chose the best and the worst ones affecting mangrove plantation suitability. Then, two vectors (i.e., BO and OW) were obtained, which were the comparisons between the best criterion toward the other and the other criteria toward the worst one, respectively, shown in Table 2 and Table 3.

After obtaining these vectors, the weight of the criteria was calculated using Equation 3. Obtained weights are represented in Figure 4 and Table 4. According to Figure 4 and Table 4, NDVI, NDSI, NDMI, and LULC had the highest weights among the criteria. As a result, areas with a higher level of these four criteria would be more suitable for mangrove plantation. The final mangrove suitability map was generated by aggregating the ten investigated criteria. Based on Equation 4, each criterion layer was normalized and multiplied by its weight, and the sum of these values resulted in the final suitability map, illustrated in Figure 5.

Moreover, to evaluate the implemented approach, Area Under Curve (AUC), Kappa Coefficient (KC), and Overall Accuracy (OA) as statistical measures were calculated (Table 5). The result indicated the efficiency of the implemented approach.

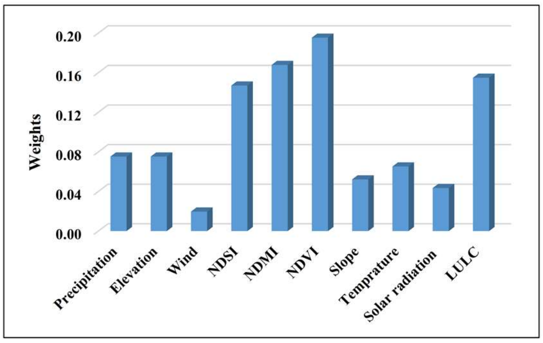

Figure 4. Weights of the considered criteria calculated based on the Best Worst Method (BWM) for mangrove plantation suitability mapping.

Criterion	Weight
Precipitation	0.075
Elevation	0.075
Wind	0.020
NDSI	0.014
NDMI	0.168
NDVI	0.195
Slope	0.052
Temperature	0.065
Solar radiation	0.043
LULC	0.155

Table 4. Weights of the considered criteria calculated based on the Best Worst Method (BWM) for mangrove plantation suitability mapping.

Validation measure	Value (%)
Sensitivity	91.91
Specificity	93.42
Overall Accuracy	95.00
Kappa Coefficient	87.90
Area Under Curve	98.79

Table 5. Validation results of the implemented approach for mangrove plantation suitability mapping.

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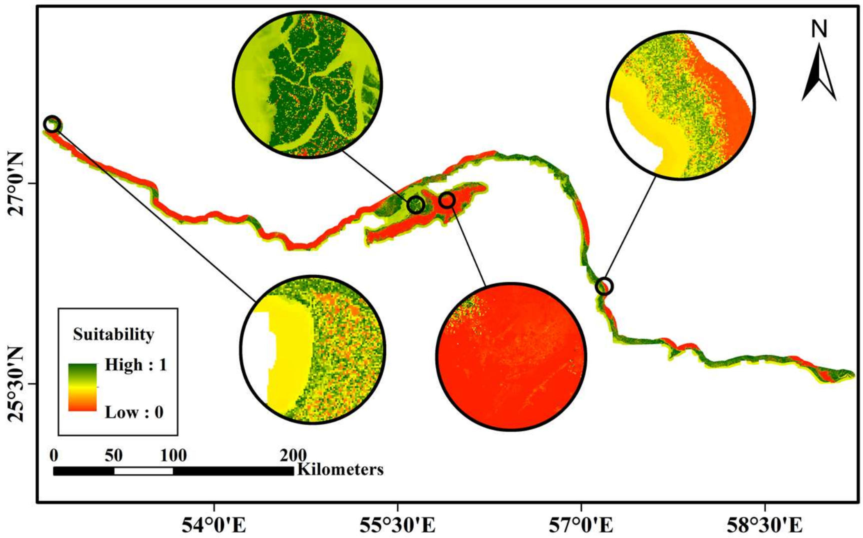

Figure 5. The mangrove plantation suitability map of the coastal area of the Hormozgan generated using the Best Worst Method (BWM) based on ten criteria.

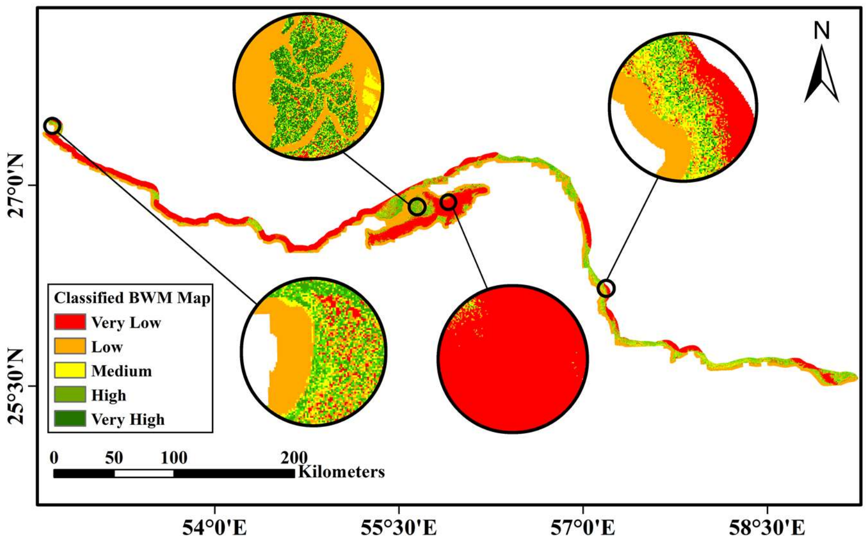

Figure 6. The classified mangrove plantation suitability map of the coastal area of the Hormozgan generated using the Best Worst Method (BWM) based on ten criteria.

To simplify the analysis of the generated mangrove plantation suitability map, it was categorized. The suitability classes included five suitability classes: "Very Low", "Low", "Medium", "High", and "Very High". The classified map is illustrated in Figure 6. Also, the distribution of the classified map is demonstrated in Figure 7.

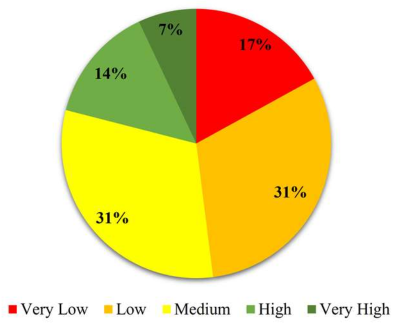

Figure 7. The percentage of suitability classes for mangrove plantation in the study area.

5. CONCLUSION

The present study aimed to investigate suitable locations for mangrove plantation in southern parts of Iran. In this regard, experts were first asked to express their ideas and preferences regarding chosen criteria. After choosing the Best and Worst criteria, they filled out a questionnaire to compare the Best one with other criteria and compared all criteria toward the Worst one, which resulted in two vectors. The final weights were obtained by incorporating these two vectors in an LP model. After this stage, each criterion was multiplied by the corresponding weight, and the sum of these values resulted in the final mangrove plantation suitability map. NDVI gained the highest weight value among the criteria, and the NDMI and NDSI had the next ranks. To simplify the interpretation of generated mangrove plantation suitability map, it was categorized into five classes. By classifying the generated map, the proposed method acknowledges 17%, 31%, 31%, 14%, and 7% of the study area as Very Low, Low, Medium, High, and Very High suitability. Furthermore, the evaluation process was executed to ensure the robustness of the BWM method, and Statistical measures indicated that the results were reliable. Therefore, the result of this study could be beneficial to be considered by decision-makers and managers in upcoming planning programs. Having a reliable knowledge of suitable areas for mangrove plantation leads to seedling mortality reduction. Also, authorities are able to take action to halt mangroves' degradation by having appropriate strategies and boosting social awareness. It is worth mentioning that one of the drawbacks of this study is the fact that experts express their idea and opinion about criteria using crisp numbers. This issue might lead to some uncertainty in the result. Therefore, one of the suggestions for future works is to combine it with fuzzy logic.

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