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GIS Weighted Suitability Analysis as Decision Support Tool for Mangrove Rehabilitation in Oriental Mindoro, Philippines

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ABSTRACT

A weighted suitability analysis was conducted in predicting suitable areas for mangrove rehabilitation in Oriental Mindoro, Philippines. There were six thematic maps utilized in the study obtained from reliable agencies. The thematic map layers were projected in WGS 84 / zone 51N, rasterized, and reclassified. The weighted overlay technique was implemented using a precise score class ranging from 1-3. Weight influences were assigned to mangrove areas (30%), land cover (20%), rivers (15%), roads (15%), soil types (10%), and slope (10%). The entire workflow was made to run in the ModelBuilder feature of the ArcMap. A mangrove suitability map was generated for the entire study area in three suitability classes. The area covered by each suitability class was extracted using the zonal geometry tool of the spatial analyst extension. There were 10 out of 15 municipalities in the province detected with effective suitable areas. The predicted suitable areas had a total of 75,433.20 km². The municipality of Mansalay gave the highest in low suitability (13,549.26 km²), Calapan City for mid suitability (15,321.13 km²), and Naujan (891.11 km²) for high suitability areas. Overall, Calapan City has the highest computed suitability areas with 19,847.28 km² regardless of the categories. The generated data could be efficiently utilized in the effective planning and management of mangrove resources. It can be integrated with information on biodiversity assessments to draw a robust plan and execute significant actions. The study demonstrated the applicability of a geographic information system (GIS) framework as a decision support tool for potential mangrove rehabilitation initiatives.

Keywords: *weighted suitability, mangroves, zonal geometry, GIS, Oriental Mindoro*

1 Introduction

Mangrove cover in the Philippines suffered a considerable degradation because of its long history of conversion to aquaculture ponds (Primavera 1998). The Philippine mangrove cover was almost 500,000 hectares in 1918 (Brown and Fisher 1918). It was reduced to about 130,000 hectares in 2000 (FAO 2003). Much of the decline happened during the 1960s to 1970s when government policies favored aquaculture expansion (Baconguis et al. 1990; White 1998). It was examined that the conversion of mangrove areas into aquaculture ponds was pinpointed as the single biggest threat to mangrove decline (Baconguis et al. 1990; Primavera 1995). Rapid urbanization, industrial complexes, and human settlements were considered other factors which further depleted the mangroves

(Garcia et al. 2013). These occurrences have significantly reduced the mangroves in the country, amounting to 70% total loss from the original forest cover (Walters 2004). The history of mangrove denudation promoted rehabilitation initiatives across the country to protect and restore the remaining mangrove forest into its functional state.

In the past decade, the Philippine government launched programs to improve the degrading mangrove conditions. Reports indicated that mangrove cover in the country slightly recovered from continuous decline (Junio-Mendez and Toribio 2010). However, rehabilitation efforts also have some negative repercussions. The replanting primarily of mono-specific culture had high mortality (Pomeroy et al. 1996; Ellison 2000; Samson and Rollon 2008). Planted seedlings in unsuitable lower intertidal sites were questioned about replacing seagrass beds (Melana et al. 2000; Primavera and Esteban 2008). The National Greening Program of the Department of Environment and Natural Resources (DENR) targeted 38,411 ha of mangroves from 2011- 2016 (Salmo et al. 2015). The Bureau of Fisheries and Aquatic Resources (BFAR) under the Philippine National Aquasilviculture Program (PNAP) provided PhP 6.00 incentive per surviving propagule (Dieta and Dieta 2015). Replanted seedlings proved to be costly in the long run as they required about USD400 to over USD 500 ha-1 (Primavera and Esteban 2008; Samson and Rollon 2008; Walters et al. 2008). Suitable areas must be identified to effectively reduce the cost in the implementation of mangrove rehabilitation activities.

To provide implications in suggesting suitable areas, other ecological components of mangrove habitats were suggested (Salmo et al. 2013; Mullet et al. 2014). The fundamental research approaches generated vegetation structure as part of data inventory for rehabilitation (Sinfuego and Buot 2008; Jumawan et al. 2015a; Natividad et al. 2015). These can be utilized as vector and raster data inputs as which can be manipulated using geospatial techniques. It was utilized to detect mangrove cover changes influenced by typhoons (Buitre et al. 2019), mapping small patches of mangroves (Altamirano et al. 2010), and determining optimal locations for planting (Syahid et al. 2020). The geospatial analysis has been a valuable tool for mangrove rehabilitation and management (Omar et al. 2019). The GIS as a new and emerging platform has been suggested as a reliable method in generating suitable areas of mangrove habitats.

Geographic information system (GIS) is an effective decision-support system that can be integrated into planning and managing mangrove rehabilitation programs (Densham 1991; Goodchild 2010). These techniques were extensively used to detect mangrove Spatio-temporal distributions with management implications (Cohen and Lara 2003; Kuenzer 2011; Kamal et al. 2014). Advancements in GIS applications provided procedures to identify, categorize and map suitable sites for a specific objective (Davis 1996; Lagro Jr. 2001). The combination of remotely sensed data and select landscape variables provided an excellent framework in a GIS environment for selecting suitable areas (Nishanth 2010).

The GIS techniques can be used in identifying suitable sites for mangrove rehabilitation in Oriental Mindoro, Philippines. Mangrove conditions in the area reflected a typical mangrove status in the country. The government and private agencies had mangrove and biodiversity assessments in a move to manage and rehabilitate its mangrove resources (Tabaranza 2014; Alcanices 2017). The GIS applications could be incorporated in identifying and mapping suitable areas for mangrove rehabilitation efforts and thereby reduce monetary inputs. Hence, this study is significant, and the data generated could be effectively used by environmental managers and agencies implementing mangrove rehabilitation in the area.

2 Materials and Methods

The Study area

The province of Oriental Mindoro is located south of Luzon Island, Philippines (13° 24′25″N and 121° 10′40″E). The western section is a rugged mountain with the highest peak in Mt. Halcon at 2,582 m above sea level. The eastern section is characterized from hilly to flood plain with crisscrossing rivers emptying into Lake Naujan and the open sea. Administratively, it is composed of 14 municipalities with Calapan City as the provincial capital (Figure 1). The province has about 26 mangrove species with active rehabilitation activities from various stakeholders in the government and non-government organizations (Alcanices 2017).

Input factors

Available online GIS data format and sourced from reliable institutions were utilized in the study (Table 1). In this aspect, it can be replicated by other agencies and incorporate results effectively in the planning stages of mangrove rehabilitation. The digital elevation model was derived from Aster GDEM downloaded from United States Geological Survey (USGS) Earth Explorer website. The shapefiles consisted land cover, mangrove areas, soil types, rivers, roads, and administrative boundary of Oriental Mindoro were obtained from the PhilGIS website. The input factors were determined after a series of field observations and visual assessments of mangrove areas in the province. The environmental managers were interviewed and consulted on the significant factors which might affect mangrove rehabilitation activities in the area. These were composed of personnel from the provincial agriculture office and the Department of Environment and Natural Resources in Region 4B. Land cover data indicated idle fishponds areas that could be reverted to mangroves. Existing mangrove sites can be augmented with existing rehabilitation initiatives. Mangroves are suitable for low and gradual slope gradients based on field observations. The availability of soil types can affect while the river system provides a channel of freshwater and saltwater essential to the growth and survival of mangroves. The presence of roads facilitate mobility for monitoring and implementation of policies by environmental managers.

Weighted suitability analysis

The identification of mangrove suitable sites for rehabilitation was evaluated using weighted

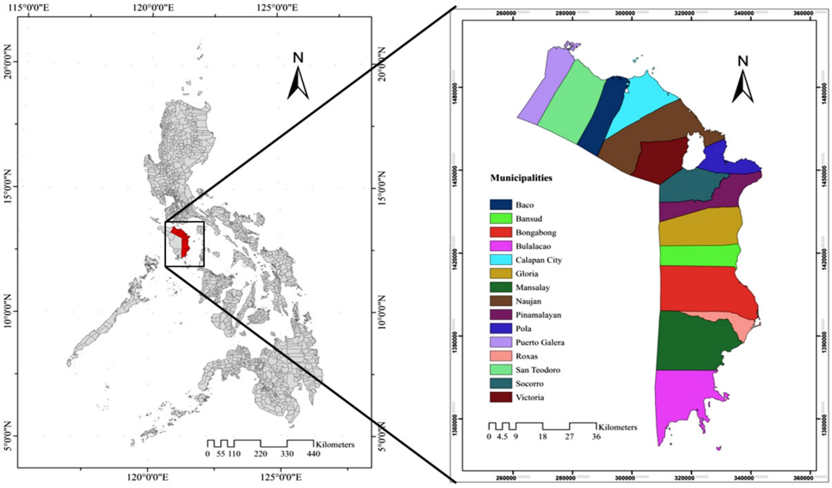

Figure 1. The location of Oriental Mindoro, Philipines showing the administrative municipalities.

Table 1. Data types, format, and sources were utilized as inputs for GIS database in the study.

No.	Description of Database	Data Type and Format	Sources
1	Land Cover	Polygon, Shapefile	PhilGISa
2	Mangrove Areas	Polygon, Shapefile	PhilGISb
3	Soil Types	Polygon, Shapefile	PhilGISc
4	Philippine Rivers	Line, Shapefile	PhilGISd
5	Philippine Roads	Line, Shapefile	PhilGISe
6	Aster GDEM 30m resolution	Raster	earthexplorer.usgs
7	Slope	Raster	Created from Aster GDEM
8	Boundary of Oriental Mindoro	Polygon, Shapefile	PhilGISf

suitability analysis (Wayne 2003). It is a GIS technique that ranks variables and weighs them according to their importance (McCoy 2001). In this aspect, the vector data were rasterized, reclassified, and measured for suitability on a similar scale. Each of the combined raster layers was assigned with a relative importance value. The workflow process was depicted in Figure 2.

The individual thematic map was reclassified into units of suitability and multiplied to a corresponding weight. The relative importance of each thematic map was designated with influence as follows: (a) mangrove areas (30%), (b) land cover (20%), (c) rivers (15%), (d) roads (15%), (e) soil types (10%) and (f) slope (10%). The weight influence is based on the level of significance of each data input for determining suitable mangrove areas.

The thematic layers with their corresponding designated influence were added to derive a suitability value in every site of the map boundary. The formula employed in the analysis was described as follows (Eastman 2001):

(1) $S = \sum w_i x_i$ where: S = suitability index for each pixel in map; w_i = the weight of criterion i; and x_i = criteria score of class i.

The formula depicted above was applied to the actual thematic layers being integrated as a platform for weighted overlay. The final score for the suitability index was converted into suitability classes, namely: low suitability, mid suitability, and high suitability. The final output was displayed as a predicted mangrove suitability map.

The derived data sets

The derived data sets were created from the data input to generate new information. In the analysis, the following conditions were considered in data processing:

(a) Slope location of mangroves. The ground truth surveys in Kenyan mangroves varied in zonation and species distribution from the regular slope of seaward or creek ward areas to multiple topographic ridges and depressions in landward zones (Dahdouh-Guebas et al. 2004). In the study area, most of the mangroves were located along 1-3% slope in seaward to creekward areas. Patches of mangroves were also located to slope <6% as evaluated in the DEM and mangrove data layers.

(b) Mangrove areas. The mangrove map was utilized using the PhilGIS data. The resulting map was generated from Landsat imagery data of mangrove forests focusing in Oriental Mindoro, Philippines (Long and Giri 2011).

(c) Land cover map. The land cover map was based on NAMRIA, which utilized cadastral data for GIS applications. The mangrove areas and inland fishponds were significant in the analysis. The DAO 15 (1990) indicated abandoned fishponds to be reverted to mangrove forests (Primavera 1993; Pulhin et al. 2017). Introduction of aquasilviculture integrated mangroves in present fishponds (Aypa and Baconguis 2000; Dieta and Dieta 2015) influence fishpond areas in the data analysis.

(d) Soil Types. Soil types in mangrove areas consist of a combination of sand, silt, and clay (Natividad et al. 2014 and Hossain and Nuruddin 2016). It was reported that sand particle was dominant in studied mangrove sites (Clough 1992; Ferreira et al. 2010).

(e) River Map. Strategic rivers located within the vicinity of mangrove areas were only considered in the analysis. The Ministry of Natural Resources (MNR) A.O. 42 (1986) required a mangrove belt of

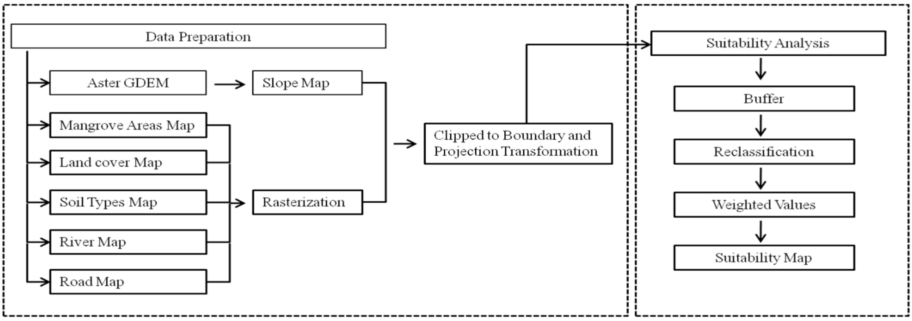

Figure 2. The process flow on the weighted suitability of identifying mangrove rehabilitation sites in Oriental Mindoro, Philippines.

up to 50m for riverbanks (Primavera et al. 2013). However, areas beyond 50m can be planted further for effective rehabilitation. Proximity to streams and rivers contributes to vegetation dispersion (Valente and Vettorazzi 2008).

(f) Road Map. Only strategic roads along the mangrove vicinity were considered in the analysis. Access to roads was considered a significant factor in mangrove rehabilitation. Ease of seedling's movement, monitoring, and evaluation could be effective with access to transportation.

The enumerated factors were data inputs considered in predicting suitable mangrove areas. These are considered as the main influential factors during ocular observations and suggestions from environmental managers in the area. However, other factors can be used other than those considered in the study hence considered as data limitations.

Buffer distances in rivers, roads, and mangrove areas

Thematic maps on rivers, roads, and existing mangrove areas were strategic components to consider in mangrove rehabilitation initiatives. Proximity to these components was seen as a positive influence for effective rehabilitation. Distances from rivers, roads, and mangrove areas were generated using the Euclidean Distance function in the spatial analyst of Arcmap. The resulting raster data generated buffer in metric distances classified into class 1 (0-50m), class 2 (50-500m), and class 3 (500-1,000m).

Factor influence in the reclassified map layers

The thematic map layers were reclassified and assigned to their respective score class (Figure 3). Each map layer was allocated with a particular weight influence. The designation of weight influence and score class was shown in Table 2. The designation of the weight of a factor was its relative percentage score being added has a sum of 100% factor influence. A straightforward score class criteria of 1, 2, and 3 were implemented.

The ModelBuilder employed in generating suitability map.

Esri’s model builder is a workflow tool in ArcMap that can be manipulated as a standalone or drag-and-drop feature to a ModelBuilder window (Best et al. 2007). The ModelBuilder was applied to mangrove suitability analysis and mapping in the sampling area (Figure 4). This tool allowed suitable mangrove sites to be computed in a wizard tool consisted of data inputs into executable outputs.

Extracting the mangrove suitability classes using zonal geometry tool.

The resulting suitability map consisted of three suitability classes, namely: low suitability, mid suitability, and high suitability. The weighted overlay analysis predicted suitable mangrove sites in the study area. The raster layer derived from the analysis consisted of the mangrove suitability map. The area (in km²) of mangrove suitability classes was extracted using a zonal geometry tool. Zonal geometry tool is another feature in ArcMap spatial analysis extension which could extract raster information and quantify the value of the raster cells. The predicted mangrove suitable areas were presented in tables and figures.

Table 2. The factor influences and weight index used in weighted overlay analysis

No.	Thematic Maps	Weight Influence (%)	Score Class	Description
1	Mangrove Areas	30	3 2 1	0 - 50m 51 - 500m 501m - 1,000m
2	Land Cover	20	3 2	Mangrove Fishpond
3	Rivers	15	3 2 1	0 - 50m 51 - 500m 501m - 1,000m
4	Roads	15	3 2 1	0 - 50m 51 - 500m 501m - 1,000m
5	Soil types	10	3 2 1	Sandy loam, beach sand Clay loam, silt loam Clay, loam
6	Slope	10	3 2 1	0° - 3° 4° - 6° > 6°

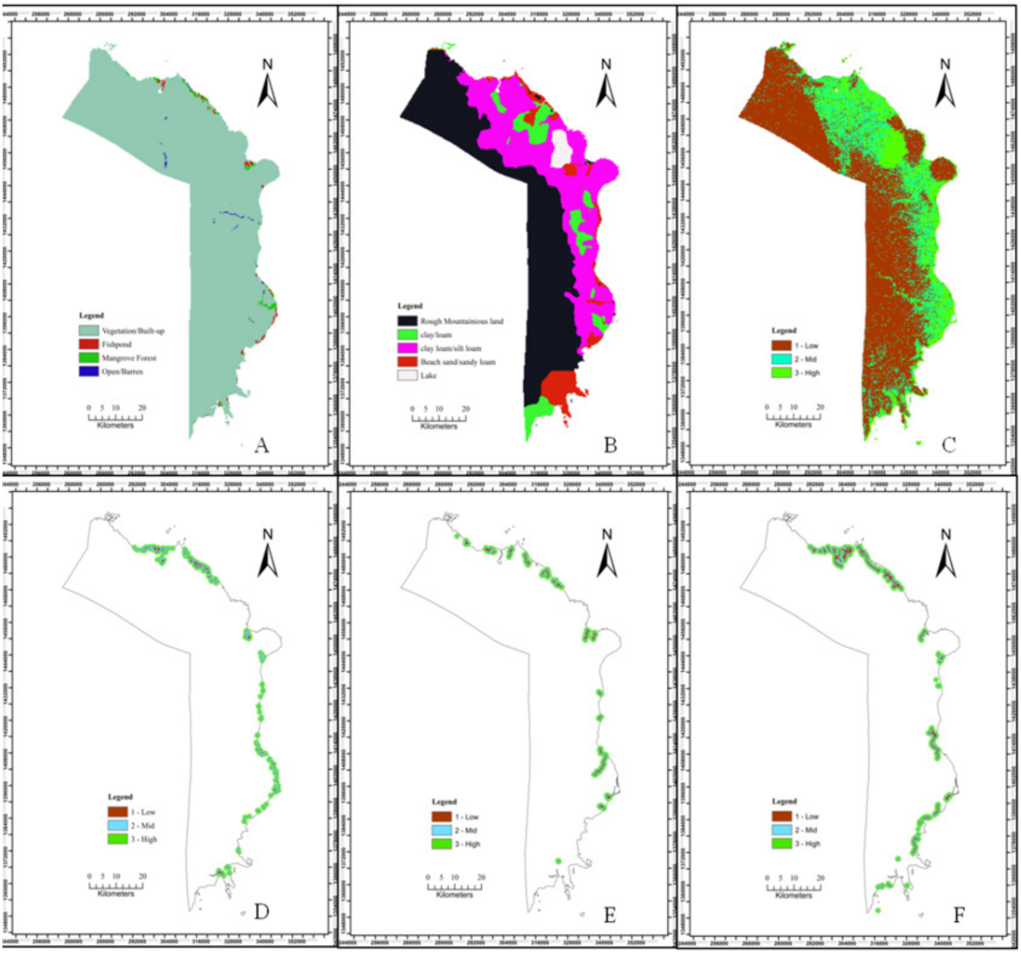

Figure 3. The reclassified data inputs used in predicting mangrove suitability in Oriental Mindoro, Philippines. These include a land cover (A), soil types (B), slope (C), mangrove cover (D), rivers (E), and roads (F).

3 Results and Discussion

The mangrove suitability was generated using the weighted suitability analysis (Figure 5). There were six thematic maps utilized and made to run in the ModelBuilder feature of Arcmap. The suitability map was classified into three categories: low suitability, mid suitability, and high suitability. The gray-colored areas in the suitability map were detected as unsuitable for mangroves.

The predicted land area suitable for mangroves is about 75,433.20 km² in Oriental Mindoro, Philippines (Figure 7). Among the three suitability categories, the mid suitability areas gave the highest predicted area for mangroves with 41,326.22 km². This was followed by the low suitability areas with 32,018.93 km² and high suitability areas with 2,088.05 km². Suitable areas were detected in 10 out of 15 municipalities of Oriental Mindoro, Philippines (Figure 6).

The zonal geometry tool was utilized to extract the predicted mangrove suitable areas in the 10 municipalities of Oriental Mindoro, Philippines (Table 3 and Figure 8). The municipality of Mansalay gave the highest in low suitability areas with 13,549.26 km². In the mid suitability areas, Calapan City had the highest value with 15,321.13 km². There were only three municipalities with high suitability areas. These were Naujan (891.11 km²),

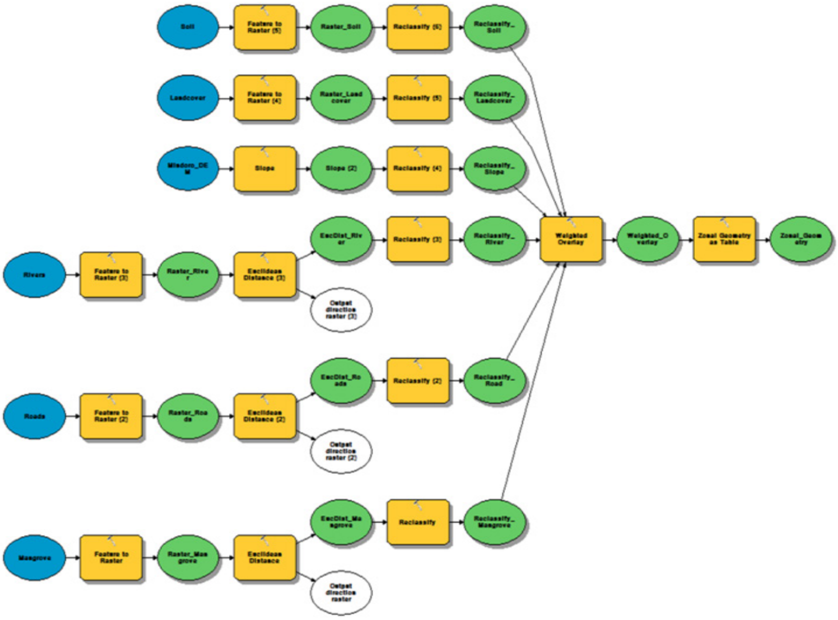

Figure 4. The workflow on mangrove suitability analysis in the ArcMapModelBuilder environment.

Calapan City (861.00 km²), and Baco (335.93 km²). The total area for low suitability was 32,018.93 km². The mid suitability has a total area of 41,326.22 km². For the high suitability, a predicted land area of 2,088.05 km² was computed. The total predicted suitable area in the province was 75,433.20 km². Regardless of the categories, Calapan City has the highest computed suitability areas with 19,847.28 km². This was followed by Mansalay (18,214.67 km²), Naujan (11,289.01 km²), Gloria (9,652.63 km²), and Bongabong (7,438.49 km²).

The study predicted suitable mangrove sites in the province of Oriental Mindoro, Philippines. It was illustrated in a mangrove suitability map indicated by three categories: low, mid, high suitability areas. This straightforward classification approach in GIS having three categories is regularly implemented in other weighted suitability analyses (Parry et al. 2018; Mansouri Daneshvar et al. 2017). The thematic map layers utilized as data inputs were accessible to any person or institution as these were sourced online. This was deliberately done for potential replication in other mangrove areas for effective planning and management of natural resources. The thematic maps on land cover, mangrove vegetation, soil types, roads, rivers, and administrative boundaries were sourced from the PhilGIS website. The slope

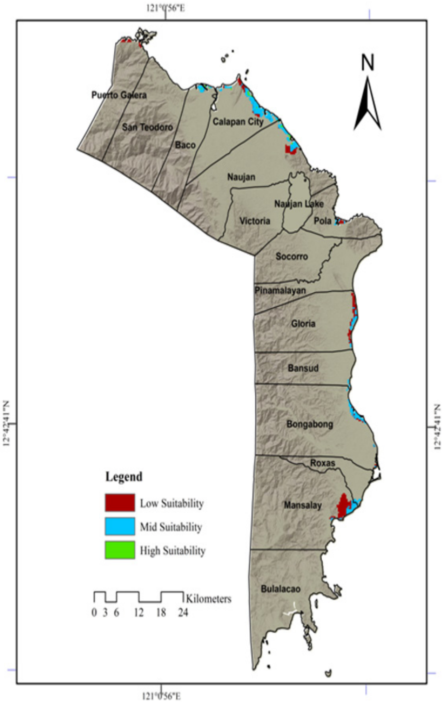

Figure 5. Mangrove suitability map of Oriental Mindoro, Philippines was classified into low, mid and high suitability.

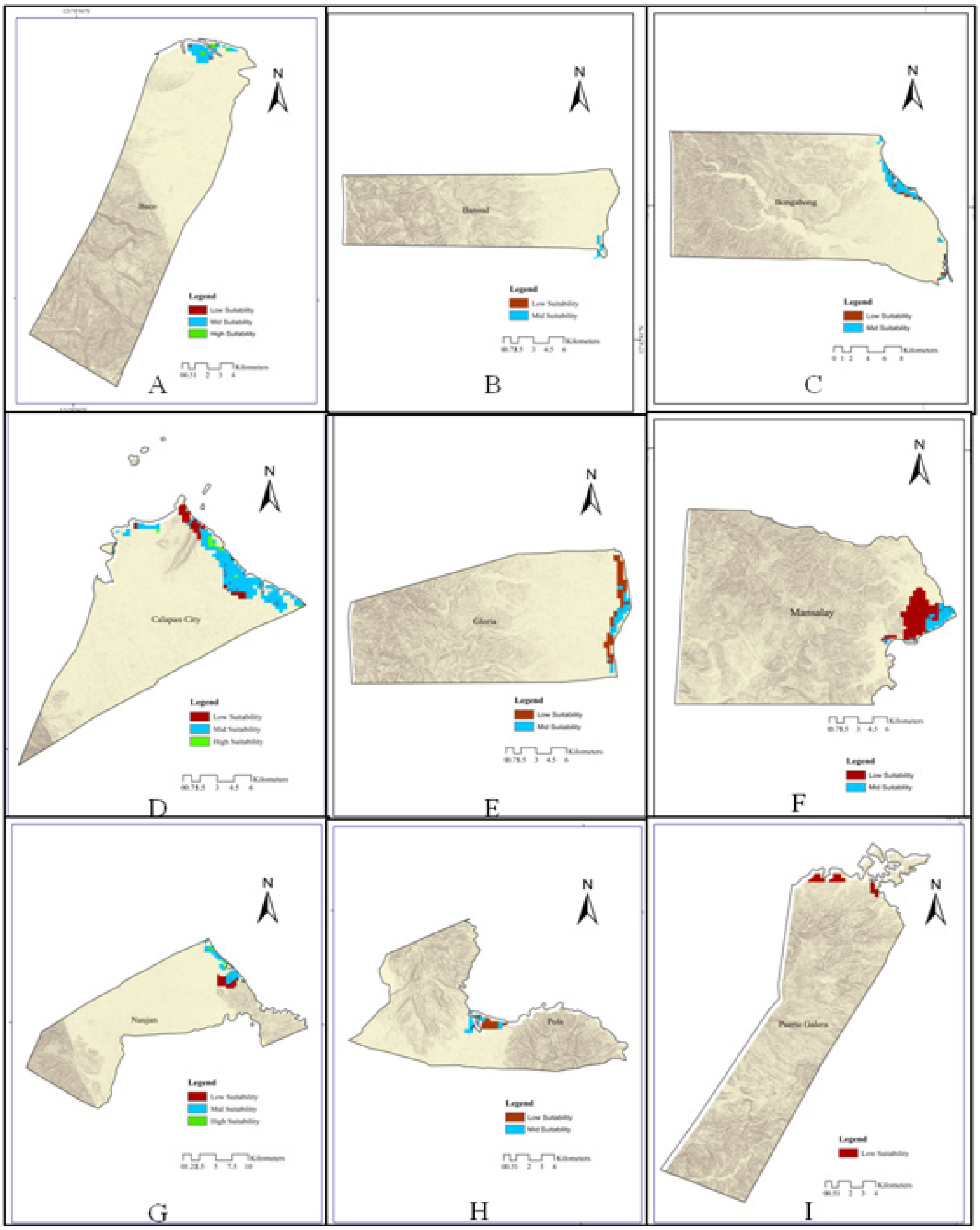

Figure 6. Predicted mangrove suitability map showing the low, mid and high suitability areas in the municipalities of Baco (A), Bansud (B), Bongabong (C), Calapan City (D), Gloria (E), Mansalay (F), Naujan (G), Pola (H), and Puerto Galera (I).

map was derived from Aster GDEM downloaded through earthexplorer.usgs.gov. The data inputs are limited only to the six factors considered in the study. However, other factors can be used upon validation to its significance in the suitability analysis. In other studies, it utilizes the multi-criteria method in assessing suitability studies based on GIS applications due to the inclusion of multiple factors

(Maddahi et al. 2016). The suitability procedure validates the weight distribution of score classes using the analytical hierarchy process (AHP) and resolves multi-criteria decision-making (MCDM) problems (Chang et al. 2007).

Data availability, quality, and reliability limit the setup of GIS as a tool (Kahinda et al. 2008). In this study, the inclusion of factors for suitability analysis came from field observations and suggestions of environmental managers in the area. Different sources of data were sourced in a straightforward classification of data inputs. The significance of using several data variables is needed in producing more accurate predictions. However, it can also make the task highly complicated and augment data quantity (Store and Jokimaki 2003). The GIS as the spatial tool can manage, integrate and analyze several spatially related information (Collins et al. 2001). This presents GIS as a reliable and effective technique in suitability assessment. Weighted suitability analysis in GIS had been effectively utilized in various suitability studies (Malczewski 2004; Valente and Vettorazzi 2008; Pourebrahima et al. 2011).

Approaches to mangrove rehabilitation should consider comprehensive and integrated methods to regain mangrove loss in the past (Buitre et al. 2019). It is important that research must consider other parameters which are influential to mangrove establishment. Previous studies explored the importance of mangrove and soil relationships in rehabilitation (Mullet et al. 2014; Jumawan et al. 2015b), reversion of abandoned fishponds (Duncan et al. 2016), and seedling regeneration capacity (Raganas et al. 2020). These studies considered other parameters which are perceived to be essential in mangrove rehabilitation. However, appropriate sites which are ideal for mangrove growth and development must be determined as well for effective management (Primavera and Esteban 2008). Inappropriate strategies and implementations on mangrove planting have been a major criticism in the past decades. Planting mangroves in unsuitable seagrass bed areas and favorable conditions resulted in the mortality of replanted species (Samson and Rollon 2008). The availability of GIS techniques provided opportunities to limit if not eradicate mistakes in the past due to failure of identifying suitable sites for mangroves.

The study effectively computed the suitable mangrove areas in 10 municipalities. Information on mangrove biodiversity, vegetation structure, and species composition could be integrated to come up with a comprehensive approach in rehabilitation

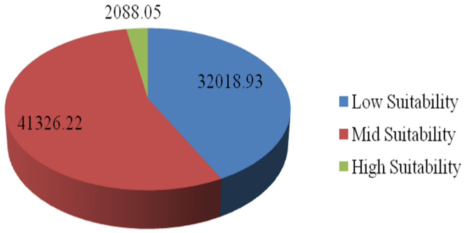

Figure 7. The proportion of area (km²) covered by mangrove suitability classes in Oriental Mindoro, Philippines.

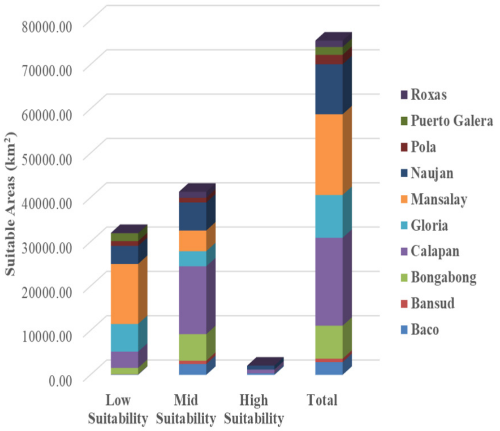

Figure 8. The histogram of predicted suitability areas (km²) in 10 municipalities of Oriental Mindoro, Philippines.

Table 3. Computed suitable areas (km²) showing the three classes in 10 municipalities of Oriental Mindoro, Philippines extracted using zonal geometry.

Suitability Classes	**Baco**	**Bansud**	**Bongabong**	**Calapan**	**Gloria**	**Mansalay**	**Naujan**	**Pola**	**Puerto Galera**	**Roxas**
Low Suitability	90.33	36.70	1,438.77	3,665.14	6,246.27	13,549.26	4,066.00	1,074.61	1,774.70	77.16
Mid Suitability	2,447.50	730.21	5,999.73	15,321.13	3,406.37	4,665.41	6,331.90	1,045.44	0.00	1,378.54
High Suitability	335.93	0.00	0.00	861.00	0.00	0.00	891.11	0.00	0.00	0.00
Total	2,873.77	766.90	7,438.49	19,847.28	9,652.63	18,214.67	11,289.01	2,120.04	1,774.70	1,455.71

actions. Mangrove assessments were conducted in the past years in Oriental Mindoro, which provided an inventory of species (Alcanices 2017; Gonzales et al. 2000). A more robust plan can be objectively drawn with various data sources. The information can be extensively used by implementing agencies.

The main advantage of the study was its functionality in the planning and management of mangrove resources in different municipalities. It may provide several options for environmental managers in planning across various levels. It can be integrated or utilized as a support tool for a better understanding of mangroves in the entire province. In this manner, managers can carry out accurate decisions and execute significant actions. This provides a framework as a support tool in finding alternatives in future developments.

4 Conclusion and Recommendations

The analysis generated a suitability map that predicted potential rehabilitation areas in Oriental Mindoro, Philippines. The suitable areas were categorized into low, mid, and high suitability areas. It utilized several thematic layers for accuracy in the prediction of mangrove suitable areas. The thematic maps were obtained from available sources, which can be replicated in other areas of the country. The generated data could be effectively utilized in the planning and management of mangrove resources. It can be integrated with relevant information generated from biodiversity assessments leading to a contextualized approach in rehabilitation actions. In this aspect, environmental managers can be provided with better options and draw strategic actions. The study imparted the applicability of GIS in predicting suitable mangrove areas as a decision support tool for rehabilitation initiatives.

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Statement of Conflict of Interest

The authors Jess H. Jumawan and Damasa M. Macandog declare that they have no conflict of interest.

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