

Mangrove Biodiversity, GIS Weighted Overlay Analysis, and Mapping of Suitable Areas in Alabel, Sarangani Province, Philippines

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ABSTRACT

The utility of Geographic Information System (GIS) has been adopted in mapping and predicting sites for mangrove suitability in Alabel, Sarangani Province, Province. Biodiversity assessment of coastal mangroves in Alabel, Sarangani Province, Philippines was performed in purposive manner using sampling quadrats. There were 13 observed mangrove species in sand-dominated (51.48%) soil. The sampled field data points are scattered irregularly, showing slight curvature on the east-west trendline but a flatter surface on the north-south trendline. The abundance and soil data were converted into shapefiles and subjected to inverse distance weighted (IDW) interpolation. The rasterized and reclassified thematic map layers were assigned with factor influence consisting of mangrove abundance (40%), land cover (30%), sand composition (20%), and slope (10%) for suitability analysis. The suitable mangrove areas were computed using weighted overlay suitability analysis, and the final score for the suitability index was converted into suitability classes. Prediction of mangrove suitable areas was performed under the ModelBuilder workflow tool in ArcMap. The mangrove suitability classes were extracted using a zonal geometry tool depicting three suitability classes. The predicted mangrove high suitability areas covered 463.37 km², the low suitability areas covered 573.02 km², and the unsuitable areas covered 9,403.77 km². The study utilized a combination of field gathering and available online data for GIS analysis which local government units could perform. The results could be used to plan and manage mangrove resources in the area effectively.

Keywords: *Digital elevation model, landcover, suitability index, mangrove soil.*

1 Introduction

Mangroves are in the confluence along the river mouths, tidal flats, and boundaries along the coastal areas adapted to saline conditions (Ellison et al., 2022). Mangroves grow at or above mean sea level (MSL), tidally inundated not more than 30% of the time (Balke et al., 2015). The importance of mangrove ecosystems can be summarized ecologically and economically (Kathiresan and Bingham, 2001). The mangrove systems contribute significantly to the well-being of coastal communities through a wide array of ecosystem services generally classified into regulating, provisioning,

and supporting. Despite the ecological and economic importance of mangroves in the Philippines, they suffered considerable degradation after decades of conversion to aquaculture ponds (Primavera, 1998). Consequently, the Philippine mangrove cover from almost 500,000 hectares in 1918 was reduced to about 130,000 hectares in 2000 (Long and Giri, 2011). Rehabilitation of mangrove resources has been initiated to manage this degraded critical natural resource in the country (Primavera and Esteban, 2008).

The utility of GIS has been adopted in mapping

and predicting sites for mangrove rehabilitation. Geographical Information Systems (GIS) is a computer-derived technology for handling digital forms of geographical data that could store, manipulate, analyze, display, and capture georeferenced data (Burrough and McDonnell, 1998). Few Philippine studies took advantage of this tool to advance mangrove research. The high acquisition cost of equipment, software, and expertise was the major constraint limiting GIS technology to well-financed institutions (Altamirano et al., 2010). It was suggested that a GIS-based tool leading to implications for mangrove conditions should be developed, given that data inconsistencies were commonly encountered in Southeast Asia (Adeel and Pomeroy, 2002).

Management plan development for mangrove rehabilitation using GIS techniques requires site-specific spatial analysis. It involves ecological data of biotic communities collected in situ, which is crucial for effective implementation. Previous studies conducted in mangroves of the Sarangani Bay area include mangrove and soil substrate relations (Mullet et al., 2014; Natividad et al., 2014); vegetation structure (Natividad et al., 2015); and carbon stock assessment (Barcelete Jr. et al., 2016). These studies could serve as baseline data for management actions. The other tool that needs to be utilized is GIS techniques to map suitable mangrove areas. The GIS spatial analysis extension is often done through interpolation methods to characterize the spatial variability and generate the weighted suitability prediction maps (Jumawan and

Macandog, 2021). This procedure is not commonly implemented by local government units but could effectively manage mangrove resources. The GIS analysis can enhance governance and regulations by acquiring knowledge to identify, map, and determine the extent of forest distributions for effective mangrove management (Omar et al., 2019).

The study explores this gap by conducting field assessments using diversity, soil data, and GIS analytical applications. Available online and downloadable land cover data and digital elevation models can be used to generate thematic maps. Under the GIS environment, these data can be used to create a straightforward mangrove suitability prediction model. Assessment, monitoring, and evaluation are significant activities for the environment and natural resource managers to determine the relevance, effectiveness, and impact of achieving a program's targets or outcomes. This study is essential as it could potentially identify and provide quantitative data on suitable areas for mangrove growth.

2 Materials and Methods

The Study Area

Sarangani Province is located in southeastern Mindanao; the selected mangrove areas were geographically located in the coastal areas in the municipality of Alabel $06^{\circ}03'04''$ $-125^{\circ}16'31''$ (Figure 1). Mapping of sampling plots in each sampling area was obtained through Global Positioning System (GPS).



Figure 1. The location of the study area in Brgy. Kawas, Alabel, Sarangani Province, Philippines

Mangrove vegetation, soil sampling, and trend analysis

A purposive quadrat sampling was performed by establishing 21 plots (10 m X 10 m) along the coastal mangrove stretch in the area (Natividad et al., 2015). Mangroves in the sampling area were identified *in situ* and included only the shrub to tree individuals. Corresponding mangrove soil samples were collected inside the quadrats at a depth of 30 cm. At least 100 g of soil were collected and air-dried for up to 1 week at room temperature. Dried soil samples were weighed at 100 g for granulometric soil analysis using USA Standard Test Sieve (WS Tyler brand). Soil characterization was classified based on pore size as gravel (850 mm - 1.4 mm), very coarse sand (600 μ m - 849 μ m), coarse sand (425 μ m - 599 μ m), medium sand (300 μ m - 424 μ m), fine sand (212 μ m - 299 μ m), and silt/clay (150 μ m - 211 μ m) (Jumawan et al., 2015). Trend analysis is a tool in Arcmap that provides a three-dimensional plot of the abundance values sampled in the study area. The trend analysis tool raised the sampled points relative to the height of the attribute values in the area of interest projected in two directions perpendicular to the map plane (Esri, 2016). The trend was evaluated based on the projected curve such that no trend exists on a flat projection.

Preparation of data as input in GIS analysis

The landcover cover map utilized cadastral data for GIS applications based on NAMRIA (PhilGIS, 2017). The land cover data for Alabel, Sarangani province, was selected and downloaded from an online source. The digital elevation model was sourced from Aster GDEM by choosing the file sheet covering the sampling area and downloaded from the United States Geological Survey (USGS) Earth Explorer website (Aster GDEM, 2017). A separate data matrix for geographical locations, mangrove abundance, and soil data of the sampling sites were encoded in Microsoft Excel and saved as comma-separated values (csv) format. The sand composition was selected among soil variables since it is the prominent particle in the area located in the seaward zone. The prominence of sand content in the seaward zone is attributed to the sea's wave action, which permits sand sediments to settle (Sukardjo, 1994). The Google Earth was used to determine the area with extracted the keyhole markup language (kml) format and loaded

into Arcmap using a conversion tool from kml to shapefile. This procedure was performed on both mangrove abundance and soil data generating shapefiles and subjected to Inverse distance weighted (IDW) interpolation. IDW interpolation is a process in GIS that uses measured values as a closer approximation to prediction locations than those farther values (Esri, 2022). It assumes that measured variables close to one another have similar attributes to those far away. The IDW procedure used the standard neighborhood type parameter with a mean error value of 0.0035 and a Root Mean Squared Error (RMSE) value of 0.1512. The low error values implied IDW as appropriate for generated shapefiles displaying a more smooth and gradually fluctuating surface (Figure 2).

Factor influence of the reclassified data

The data input consists of mangrove abundance, the sand composition of the soil, slope, and land cover were rasterized and reclassified. The reclassified thematic layers were assigned with factor influence relative to the importance of each raster layer in the analysis (Table 1).

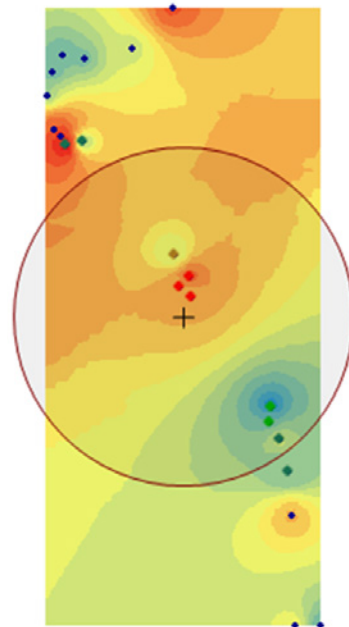


Figure 2. The IDW interpolated data on sampling points for mangrove abundance and soil (shown in blue dots). It was selected interpolation procedure with low error values generating smooth surface of prediction locations

The designation of the weight of a factor was its relative percentage score being added with a sum of 100% factor influence. A straightforward score class criteria of 1, 2, and 3 was implemented. The individual thematic map was reclassified into units of suitability and multiplied by a corresponding weight. The relative importance of each thematic map was designated with influence as follows: (a) mangrove abundance (40%), (b) land cover (30%), (c) sand composition (20%), and (c) slope (10%).

Weighted Overlay Suitability Analysis

The suitable mangrove areas were predicted using the weighted overlay suitability model. The weighted overlay is a feature in Arcmap as a GIS technique for determining suitable areas for mangroves. The raster data inputs were integrated as thematic layers for predicting 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):

$$(1) \quad S = \sum w_i x_i \text{ where:}$$

- S = suitability index for each pixel in map
- w_i = the weight of criterion i
- 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 derived weight of the combined layers could be expressed as follows:

$$(2) \quad S = (MA * 0.40) + (LC * 0.30) + (SC * 0.20) + (SL * 0.10) \text{ where:}$$

- MA = mangrove abundance;
- LC = land cover;
- SC = soil composition; SL = slope

The final score for the suitability index was converted into suitability classes: Not suitable, low suitability, and high suitability. The suitability classes were based on the straightforward score class criteria of 1, 2, and 3, respectively. The final output was displayed as a predicted mangrove suitability map in Brgy. Kawas, Alabel, Sarangani Province, Philippines.

Generating a suitability map using ModelBuilder

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 of the sampling area (Figure 3). This tool allowed suitable mangrove sites to be computed in a wizard tool consisting of data inputs into executable outputs. Extracting the mangrove suitability classes was conducted using a zonal geometry tool. The zonal geometry tool is another feature of ArcMap spatial analysis extension, which could extract raster information and quantify the value of the raster cells. The resulting suitability map consisted of three suitability classes: not suitable, low suitability, and high suitability. The predicted mangrove suitable areas were presented in tables and figures.

Table 1. The factor influence and weight index used in weighted overlay analysis

No	Raster Data	Weight Influence (%)	Score class	Description
1	Reclassified Land cover	30	1	Inland Water
			2	Fishpond
			3	Mangrove
2	Slope	10	1	>6°
			2	3°-6°
			3	0°-3°
3	Reclassified Abundance	40	1	0-15
			2	16-20
			3	21-37
4	Reclassified Sand	20	1	61%-98%
			2	31%-60%
			3	0%-30%

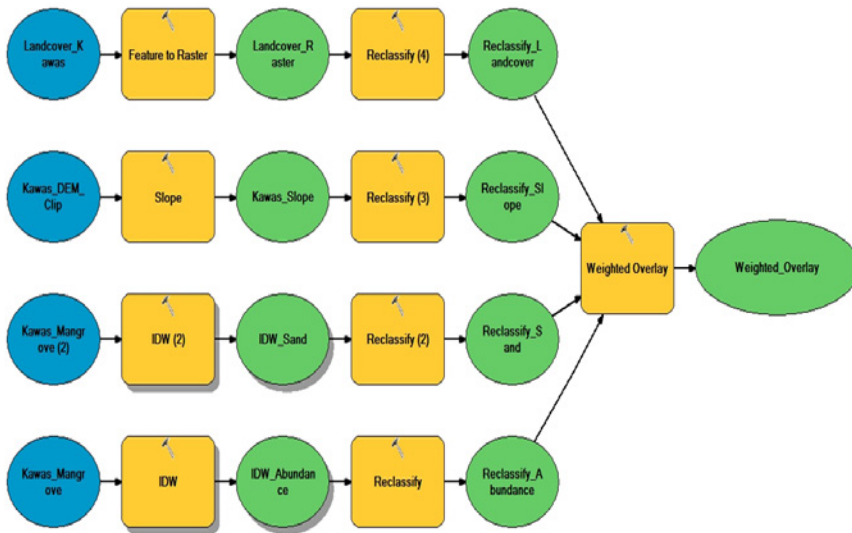


Figure 3. The workflow on mangrove suitability analysis in the ArcMapModelBuilder environment

3 Results and Discussion

Inventory of mangrove species and soil particle characteristics. There were 13 species of true mangroves accounted for in the coastal areas in Alabel, Sarangani Province (Table 2). Three species were identified outside the sampling plots: *Pemphis acidula*, *Lumnitzera racemosa*, and *Xylocarpus granatum*. These species belong to six mangrove families, and the family Rhizophoraceae has the highest number with six species. This mangrove observation is similar in other areas in Sarangani Province, with 16 species in Malapatan municipality (Mullet et al. 2014) and 12 species in Maasim municipality (Natividad et al., 2014). The sampling covered 21 plots along the coastal areas in the sampling area with mean values for species richness of 3.19, abundance value of 16.05 individuals, and Shannon diversity value of 0.8805 (Table 3). It can be described as low diversity and high abundance per 100 m² sampling area.

Among the six soil particle types, the highest was gravel, with 29.19% of the sampled soil in the area (Figure 4). Medium sand followed with 22.63%, and the lowest soil particle composition was fine sand with an 8.61% composition. However, the combined sand particle is attributed to the composition of 51.48%, and sand particles dominate the area. The sand particle was also observed in high percent composition in upper sediment in cleared mangrove zone in Xuan Thuy

National Park, Vietnam (Grellier et al., 2017). An increase in sand content in coastal zones is due to the turbulent action of the sea, allowing the coarser sand sediments to settle (Sukardjo, 1994). The information on the sand as the dominant soil particle size was utilized as data input for the GIS procedure.

Trend analysis evaluation

The mangrove data in abundance was evaluated using trend analysis (Figure 5). The figure showed no significant global trend in abundance data in the sampling area. The sampled points are scattered irregularly on the projected green and blue arcs. The east-west trendline (in the green arc) depicted a slight curvature, but the north-south trendline depicted a more flat surface (in the blue arc). This figure illustrated that the mangrove abundance has no significant pattern in the sampled area. It can be attributed to the sampling area's location or might indicate that the mangroves were disturbed in the area. The geographic features could also influence the resulting reduced curvature in the north-south trendline in the sampled sites.

Weighted Overlay Analysis for Predicting Mangrove Suitable Sites

Rasterization and Reclassification of Land Cover Map

The land cover map was rasterized and projected to PCS Zone 51N. The raster layer of

Table 2. List of mangrove species observed in sampling sites of Alabel, Sarangani Province, Philippines

Family	Species
Avicenniaceae	<i>Avicenna marina</i> (Forssk.) Vierh.
Lythraceae	<i>Sonneratia alba</i> J.Smith
	<i>Pemphis acidula</i> * J.R.Forst. & G.Forst.
Combretaceae	<i>Lumnitzera racemosa</i> * Willd.
Meliaceae	<i>Xylocarpus moluccensis</i> (Lam.) M.Roem.
	<i>Xylocarpus granatum</i> * J.Koenig
Myrsinaceae	<i>Aegiceras floridum</i> Roem. & Schult.
Rhizophoraceae	<i>Rhizophora mucronata</i> Poir.
	<i>Rhizophora apiculate</i> Blume
	<i>Bruguiera cylindrica</i> (L.) Blume
	<i>Bruguiera gymnorhiza</i> (L.) Lam.
	<i>Ceriops decandra</i> (Griff.) W.Theob.
	<i>Ceriops tagal</i> (Perr.) C.B.Rob.

Legend= *Found outside the sampling plots

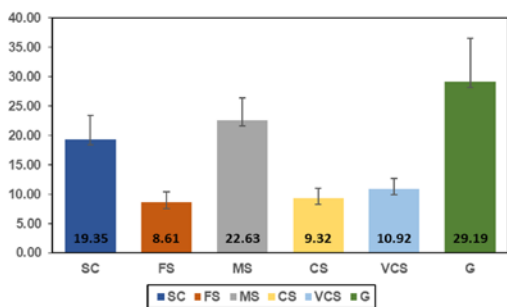


Figure 4. The percent composition of soil particle size in coastal mangrove of Alabel, Sarangani Province, Philippines. Legend: SC= silt/clay; FS= fine sand; MS= medium sand; CS= coarse sand; VCS= very coarse sand; and G= gravel

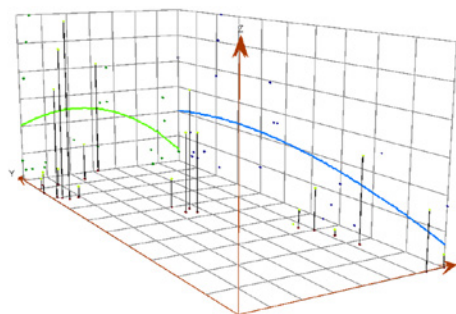


Figure 5. Trend analysis of mangrove abundance. The East-West Trendline was shown in green arc while the North-South Trendline was shown in blue arc

land cover was reclassified in field values as follows: (1) inland water; (2) fishponds; and (3) mangrove areas. The highest value influence was assigned to mangrove areas depicted in the land cover map. The next field value was set to fishponds since DENR Administrative Order (DAO) 15 of 1990 indicated that abandoned fishponds reverted to mangrove forests (Pulhin et al., 2017; Primavera, 1993). The most negligible field value was assigned to inland water (river) as mangroves thrived along the riparian zones contiguous to the sea. The Ministry of Natural Resources (MNR), through Administrative Order (AO) 42 (1986), required a mangrove belt of up to 50m for riverbanks (Primavera et al., 2013).

The DENR AO 76 (1987) also required the lessee of the fishpond lease agreement (FLA) to plant a 50 m strip of mangrove, which include

riparian zones (Primavera et al., 2013). The rasterized and reclassified land cover raster data is shown in Figure 6.

The generated and reclassified slope map

The spatial analyst tool in ArcMap was used to create the study area's slope map through Aster GDEM. This map was clipped and fitted into the boundary shapefile of Brgy. Kawas. The generated slope map was in degrees format, and it was observed that the slope varied significantly across the study area. The natural mangrove stand was observed to be aggregated in 0-3 degrees of slope. The fishpond areas with some scattered mangroves were confounded primarily within 3-6 degrees of slope. Some isolated mangroves towards the landward portion were observed above 6 degrees of slope. The study area was naturally characterized

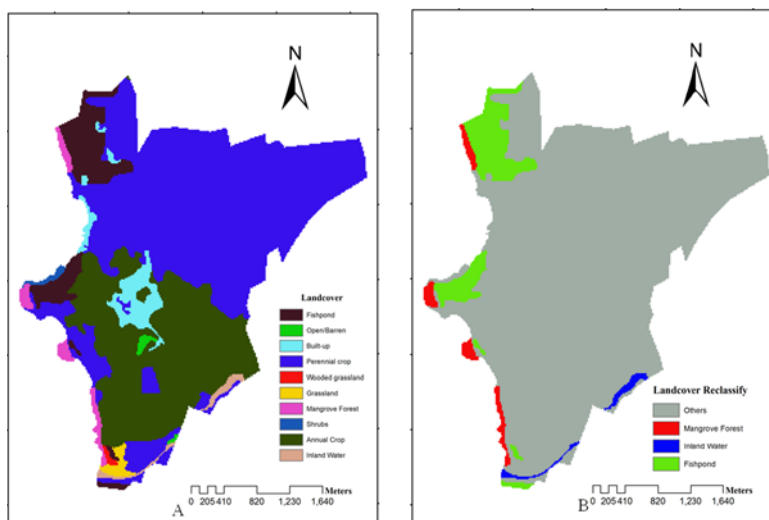


Figure 6. The processed land cover map for predicting mangrove suitable sites. The rasterized land cover map (A) and the reclassified landcover map (B)

as an undulating land surface. Hence, there were mangroves on the slope greater than 6 degrees in natural stands. This observation was the basis for reclassifying the slope raster layer such that the highest score class of 3 was assigned to 0-3 degrees of slope. This was followed by 3-6 degrees of slope for a score class of 2. The score class of 1 was assigned to a greater than 6 degrees slope. The generated and reclassified slope map is shown in Figure 7.

The interpolated and reclassified mangrove abundance

The IDW interpolation method was initially validated as the best interpolator for mangrove abundance data in the study area. The resulting raster layer showed the distribution of IDW interpolated mangrove abundance in the study area (Figure 8). The highest mangrove abundance consisted of 38 individuals in plot 13 (Table 3). The raster layer was reclassified into three classes, assigned with respective score classes. This layer was classified into score class of 1 to abundance ranging from 6 to 10 individuals. A score class of 2 was assigned to abundance values ranging from 10–20 individuals. Score class of 3 was assigned to abundance values ranging from 20-37.

The interpolated and reclassified sand composition

Sand composition data was generated in the same sampling sites with mangrove abundance.

The IDW could be a suitable interpolator also for sand composition data because it was sampled from the same sites with mangrove abundance. Based on the produced raster layer of the sand composition map, there was little variation observed in the sand composition in the study area (Figure 9). However, it was reported that sand particle was dominant in mangrove sites (Ferreira et al., 2010). In mangrove areas, the sand soil is usually combined with a relative proportion of silt and clay (Hossain and Nuruddin, 2016).

Mangrove suitability map generated using weighted overlay analysis

The resulting raster layer consisted of the predicted mangrove suitability map of Brgy. Kawas, Alabel, Sarangani Province (Figure 10). The high suitability sites were located near the coastal areas and clustered into four distinct locations. This information could be helpful in the planning and management of mangroves in the study area. Rehabilitation activities could be streamlined when priority sites could be assigned immediately. Depending on the order of priority for rehabilitation, the environmental manager could prefer low suitability or high suitability areas. By so doing, funds allocated for similar activities could be maximized. It is essential to determine sites with natural suitability as the initial step in mangrove planting and rehabilitation activities (ADB 2018).

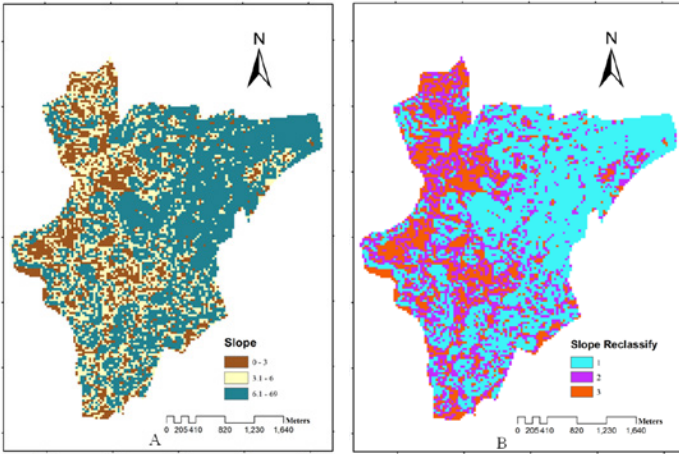


Figure 7. The processed raster data to generate slope map. The slope in degrees format was generated from Aster GDEM (A) and the reclassified slope map (B)

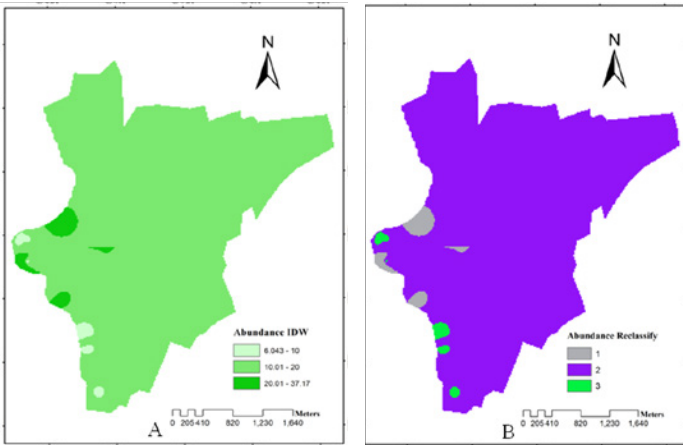


Figure 8. The processed mangrove abundance map used in the study. The IDW interpolated mangrove abundance map (A) and the reclassified mangrove abundance map (B)

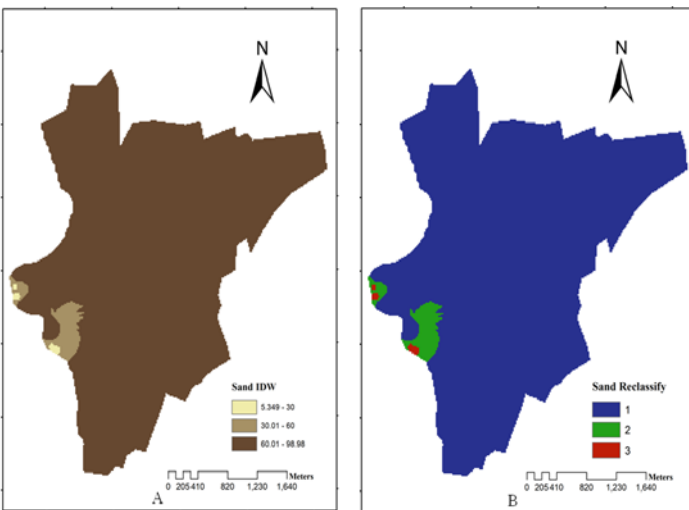


Figure 9. The processed sand composition map used in the study. The IDW interpolated sand composition map (A) and the reclassified sand composition map (B)

Table 3. The sampling plot locations and diversity indices of mangroves in Brgy. Kawas, Alabel, Sarangani Province

Plot	Lat	Long	Species Richness	Abundance	Shannon Diversity
P1	6.0494	125.2762	4	20	1.2210
P2	6.0497	125.2757	4	20	0.8261
P3	6.0501	125.2761	4	27	1.2090
P4	6.0509	125.2756	3	11	0.7595
P5	6.0455	125.2790	2	6	0.6931
P6	6.0450	125.2789	2	9	0.6870
P7	6.0443	125.2793	2	13	0.6663
P8	6.0433	125.2796	2	7	0.6829
P9	6.0417	125.2797	2	20	0.6730
P10	6.0378	125.2798	2	15	0.6909
P11	6.0378	125.2807	2	8	0.5623
P12	6.0549	125.2724	1	8	0.0000
P13	6.0547	125.2718	6	38	1.5620
P14	6.0551	125.2716	5	33	1.1650
P15	6.0553	125.2713	5	26	1.3580
P16	6.0565	125.2711	4	10	1.2210
P17	6.0573	125.2713	4	8	1.3860
P18	6.0580	125.2716	4	8	1.3210
P19	6.0578	125.2724	3	9	0.8487
P20	6.0582	125.2741	1	13	0.0000
P21	6.0596	125.2755	5	28	0.9570
Mean Values			3.19	16.05	0.8805

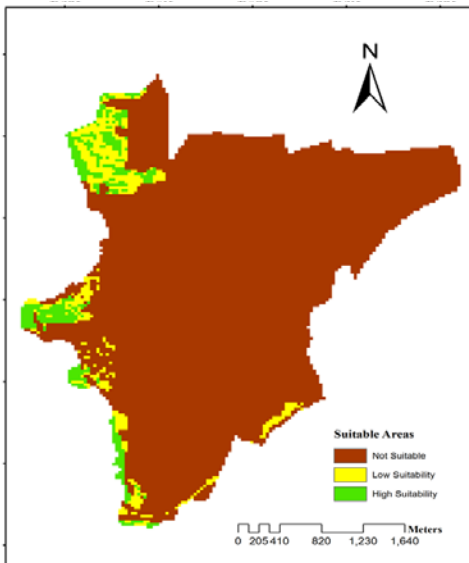


Figure 10. Mangrove suitability map showing the suitable classes in the study area

Computed areas covered by mangrove suitable sites

The zonal geometry tool was used in computing the areas (in km²) covered by the assigned mangrove suitability classes. The area categorized as high suitability has an area of 463.37 km². This is a portion of 4.44% of the total area in the study location. The low suitability area has 573.02 km². This consisted of 5.49% of the total area in the study location. The site categorized as unsuitable has 9,403.77 km² and is 90.07% of the study location. The data indicated that mangrove resources in Brgy. Kawas, Alabel, Sarangani Province comprised only a small component of the total land area. Mangrove areas were also utilized for fishponds. The extracted data from the raster layer of the mangrove suitability map is shown in Table 4 and Figure 11.

Sarangani Bay is declared a protected seascape under Proclamation No. 756, s. 1996 to protect and maintain to maintain the coastal and marine resources. This mandate provided the legal basis to protect and manage the remaining coastal

Table 4. Mangrove suitability types and the corresponding covered area and percent area composition

Suitability Type	Area (km ²)	Percent Area
Not Suitable	9,403.77	90.07
Low Suitability	573.02	5.49
High Suitability	463.37	4.44

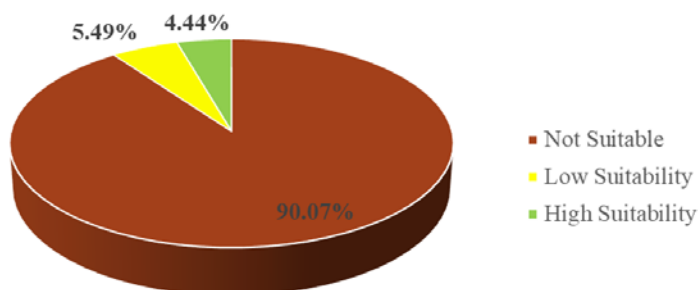


Figure 11. The percent composition of mangrove suitability classes in the study area

resources in the country. Effectively managing our coastal resources are huge natural and economic driver providing food, livelihood, revenues, and quality of life (White and Cruz-Trinidad, 1998). Natural resources can be effectively managed when environmental managers have available data. Regarding mangrove assessments in terms of biodiversity, vegetation analysis, carbon sequestration potential, and vegetation mapping are essential components in drawing strategic actions for effective management. These aspects need to be incorporated into the management plan of local government units, given the importance of Sarangani Bay as a protected seascape.

There is considerably limited mangrove research in the mangroves of Sarangani Bay, Philippines. Some of these were mangrove assessments correlated to soil properties to understand vegetation-soil relationships (Mullet et al., 2014; Natividad et al., 2014). Vegetation characteristics and carbon sequestration potential of mangroves were also evaluated to mitigate the impacts of climate change in the area (Barcelete et al., 2016; Bigsang et al., 2016). Mangrove vegetation in the Philippines was detected using remotely sensed data (Long and Giri, 2011). Light detection and ranging (LiDAR) and GIS have been effectively used in mapping mangrove resources (Novero, 2019). Every procedure must be evaluated as there are reported unaccounted

and missed mangrove detection using LiDAR in bays and gulf of Sarangani province (Neri et al., 2021). In the relatively smaller area under the local government unit's management, it is vital to account for all the input factors before subjecting to GIS analysis. Available data on mangrove vegetation, soil characteristics, and remotely sensed data could be integrated into GIS analysis for quantitative evaluation of mangrove sites. The generated output could provide information on areas suitable for mangrove growth. The study utilized a practical and straightforward procedure using available data to assess suitable mangrove sites in the area.

4 Conclusion and Recommendations

The study performed assessment on biodiversity of coastal mangroves and the information on the soil characteristics. Mangrove diversity consists of 13 identified species belonging to six different plant families.

The mean values for species richness of 3.19, abundance value of 16.05 individuals, and Shannon diversity value of 0.8805 suggest a low diversity and high abundance per 100 m² mangrove area. The data gathered in the field was utilized as input factors along with a landcover map and DEM from online sources. A straightforward weighted overlay suitability analysis was implemented to provide data in mangrove suitable areas. The GIS

analysis detected high suitability mangrove areas of 463.37 km² and low suitability areas of 573.02 km². This procedure is performed considering local government units' capability and available data sources. The results quantified suitable mangrove areas and translated output into map images that could be utilized to plan and manage mangrove resources. It is recommended that a similar study shall be conducted in other mangrove areas in Sarangani Bay, Philippines. A more robust detection and prediction of mangrove suitable sites to include further input factors are also highly recommended, including the application of Lidar data on detected mangrove sites, hydrology, mangrove dispersal, zonation pattern, and other soil parameters influential to mangrove growth. The study demonstrates the application of field assessments along with the GIS technique, which could effectively provide data on suitable mangrove sites in the area. It endeavored to assist environment officers with the necessary information for a better strategy in managing mangrove resources in the area.

5 Acknowledgement

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Statement of Conflict of Interest

The author declare that there is no conflict of interest regarding the publication of this paper.

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