IMPROVING RIVER NAVIGATION SYSTEMS WHILE PRESERVING OYSTER FARMS: A SITE SUITABILITY ANALYSIS FOR AQUACULTURE FEATURES ALONG HINIGARAN RIVER

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ABSTRACT: Rivers may be used for both navigation and aquaculture. With this twin yet conflicting services provided by the river, a science-based management approach is necessary in order to protect and regulate the river's use. The Hinigaran River of Negros Occidental Western Philippines is home to various aquaculture facilities, ranging from very large fish pens to small structures such as oyster culture-stakes. The main objective of this study was to delineate the suitable area for aquaculture along the river and identify the optimal navigation route without jeopardizing culture operations. Through weighted overlay, the following were used in the suitability analysis: vulnerability to flooding, land suitability, vulnerability to erosion, land cover, slope classification, type of soil, rain induced landslide, strategic agricultural and fisheries development zone, and tsunami vulnerability. The section of the river that has been identified as suitable based on the weighted overlay, was then added with an inward buffer that was classified as candidate sites for oyster culture. These candidate sites were then further classified as to whether it was not suitable or suitable for oyster culture. With the use of Light Detection and Ranging (LiDAR) data, a slope derivative was generated from the Digital Surface Model (DSM). Sections with greater elevations and unsuitable depth were then removed from the candidate sites for oyster culture. The resulting polygons have successfully shown suitable sites for oyster culture along the Hinigaran River. For future studies, additional criterions may be included such as the effects of the adjacent floodplain and the contribution of the culture method i.e. floating or stick method being used in the area and its effect on the river bed. This will require further investigation for future suitability analysis.

1. INTRODUCTION

Oysters are mollusks—shelled invertebrates (or animals without backbones) in the same zoological phylum, Mollusca, as the mussel, clam, abalone, snail, octopus and squid (Toba, 2002). Oysters are also classified as bivalves. Their shells are in two parts, or "valves," held together by an elastic ligament hinge (Toba, 2002).

The Philippines, as an archipelagic country has numerous sites that are suitable for oyster farming. Oyster culture in the country has originally started in Bacoor Bay in Bacoor and Kawit towns in the province of Cavite wherein operations were generally small-farm and family business (Lovatello & Bueno, 1988). The Philippines is also home for various species of oyster that are particularly abundant in bays and estuaries that have some runoff from the land (Lovatello, 1988). According to Lovatello (1988), there are four species of oysters that are cultured in the Philippines, the slipper-shaped oyster Crassostrea iredalei, the subtrigonal oyster C. malabonensis and the curly or palm rooted oysters C. palmipes and Saccostrea cucullata, likewise, the species receiving particular attention in terms of culture are C. iredalei, which are usually 6–9 cm long when marketed and the moderately sized C. malabonensis, which are usually 4–5 cm long. As early as the 1950's, the Western Visayas region, situated in central Philippines and is also home to the municipality of Hinigaran is one of the first and major sources of oysters and mussels in the country (Samonte, 1992). Due to the regions abundance of oyster culture, the natural population of oysters and mussels along rivers and bays and the need to augment income from fishing have led to the propagation of oyster and mussel farms (Samonte, 1992).

Silva et al. (2011) suggests that in order to create better site selections for these types of aquaculture, a dynamic farm-scale carrying capacity model must be accompanied with geographical information systems. This study aims to address the GIS methods in site selection with the aid of LiDAR technology through its extremely high accuracy (Csanyi, Toth, Grejner-Brzezsinska, Ray, 2005) as compared with remotely sensed data.

2. MATERIALS AND METHODS

2.1 Workflow

The figure below shows the workflow used for coming up with a suitability site for Oyster Culture along Hinigaran River.

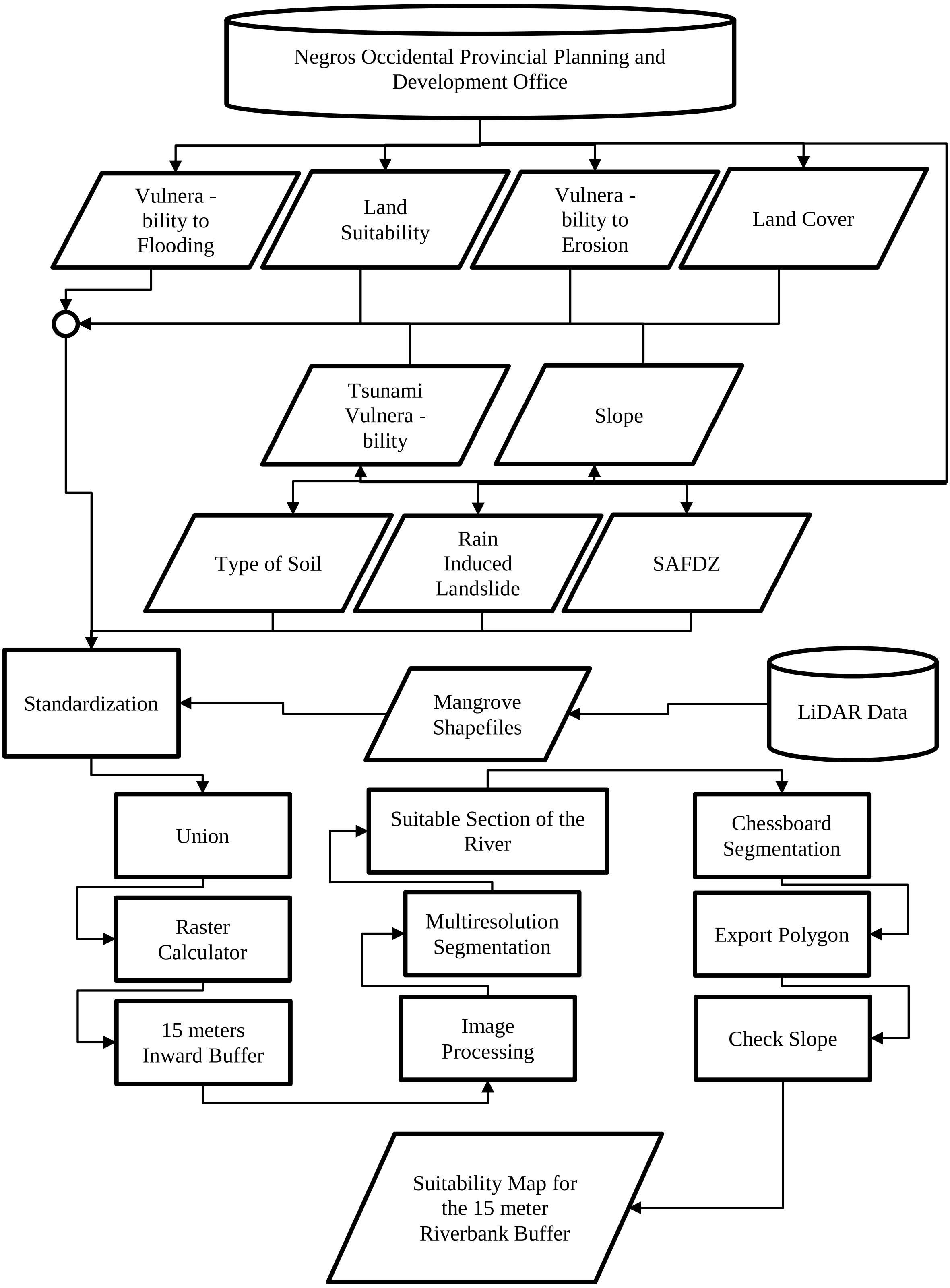


Figure 1. Workflow for Oyster Culture Analysis

Starting from the shapefiles gathered from the Negros Occidental Provincial Planning and Development Office and the mangrove shapefiles from the Phil-LiDAR 2 Project, we performed standardization of weights per suitability criterion. After analyzing all the shapefiles, a union was performed. Given the union of all the layers, the suitability factor was calculated and was used to determine which sections of the Hinigaran River have the most suitable location for river-based aquaculture. Through image processing the LiDAR data was segmented according to the resulting union of the suitability layers, the river shapefile and the 15 meter buffer along the sides of the river. After segmentation the thematic layer from the suitability layer was used to classify suitable areas of the river. These area was then divided using chessboard segmentation. Each of the objects generated from the chessboard segmentation was then exported together with mean LiDAR values for analysis in ArcMap. The output shapefile was then loaded in ArcMap and was then classified based on slope.

2.2 Sources of Data

The following shapefiles were retrieved from the Negros Occidental Provincial Planning and Development Office:

- Vulnerability to Flooding
- Land Suitability
- Vulnerability to Erosion
- Land Cover
- Tsunami Vulnerability
- Slope Classification
- Type of Soil
- Rain Induced Landslide
- SAFDZ

The mangrove shapefile that was used in the study was an output of the Phil-LiDAR 2 Project. Pada et. al. (2016) have extracted the mangroves from LiDAR data using Object Based Image Analysis.

2.3 Data Pre-processing

The LiDAR data was pre-processed by the UP Training Center for Applied Geodesy and Photogrammetry (UP-TCAGP) which has been conducting a research entitled "Nationwide Disaster Risk and Exposure Assessment for Mitigation" (DREAM) supported by the Department of Science and Technology (DOST) Grants-in-Aid Program wherein the Data Processing Component (DPC) of the DREAM Program produces digital elevation models from the aerial LiDAR surveys conducted by the Data Acquisition Component (DAC) over the assigned areas (UP-TCAGP, 2013).

2.4 Study Site

The study was conducted in the Municipality of Hinigaran, Negros Occidental, Philippines. The municipality of Hinigaran has an area of 149.83 km.². The municipality is rich in various aquacultures such as fishponds, fish pens, oyster culture and more.

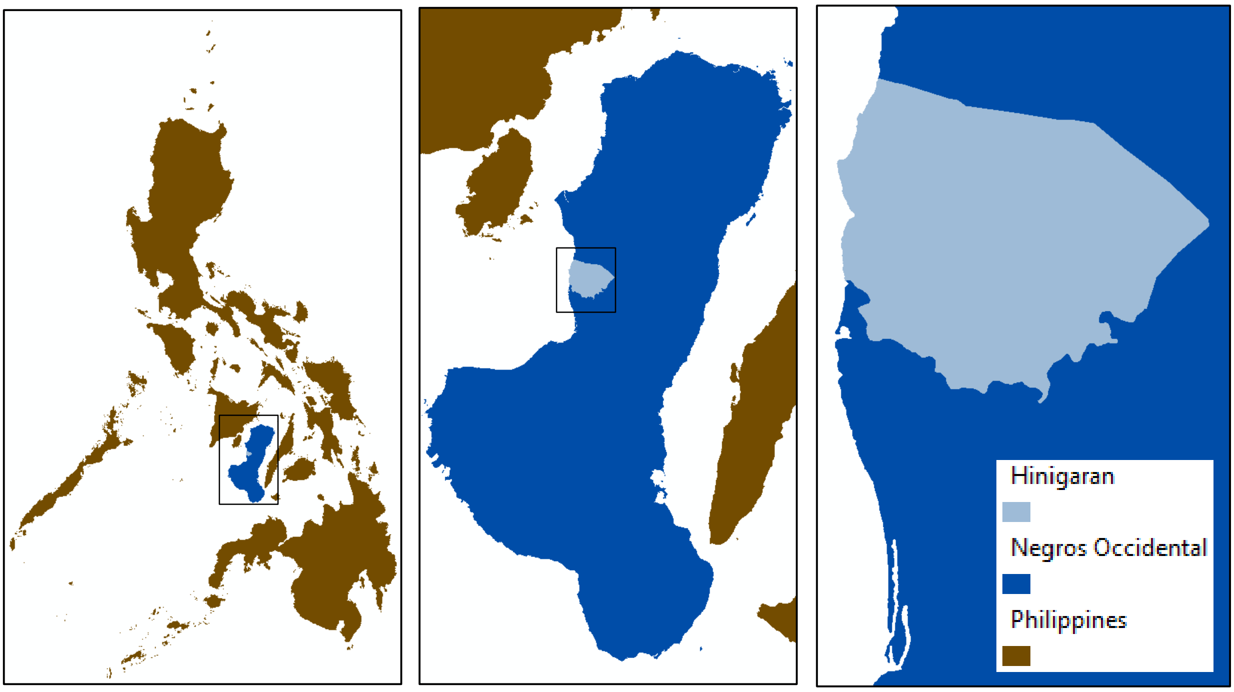


Figure 2. Municipality of Hinigaran in Negros Occidental

2.5 Layers

There are 10 layers involved in the selection of suitable areas along Hinigaran River for river-based aquaculture. Each layer was reclassified to produce a shapefile with 1 to 5 ratings were 5 is the most suitable and 1 is the least suitable.

2.5.1 Vulnerability to Flooding: The flood vulnerability shapefile contains polygons for areas with (1) high susceptibility to flooding, (2) moderate susceptibility to flooding and (3) not susceptible to flooding.

2.5.2 Land Suitability: The land suitability shapefile contains polygons that are (1) suitable for cultivated annual crops, (2) suitable for forestry plantations, (3) suitable for production forest, (4) suitable for rice paddies and (5) suitable for perennial tree and vine crops. Since all of the river-based aquaculture in Hinigaran River falls under the area that is suitable rice paddies, a high suitability value was given to it.

2.5.3 Vulnerability to Erosion: The erosion shapefile contains polygons for areas that contains: (1) moderate erosion, (2) no apparent erosion, (3) severe erosion, (4) slight erosion, and (5) unclassified erosion,

2.5.4 Land Cover: The land cover shapefile contains polygons that classifies areas of Negros Occidental into: (1) mangrove vegetation, (2) fishponds derived from mangroves, (3) arable land, (4) built up area and (5) other crops and plantations. Higher weights were given to areas that are classified as mangrove vegetation and fishpond areas that are derived from mangroves.

2.5.5 Tsunami Vulnerability: The tsunami vulnerability shapefile marks areas that are (1) prone or (2) not prone. Areas that are not at all prone to tsunamis were given the highest weight.

2.5.6 Slope Classification: The slope classification shapefiles give the percentage slope of a corresponding area and its description. There were only three slope classifications for Hinigaran since it is a coastal area as compare to the mountainous municipalities that has very steep hills and mountains. There are areas in Hinigaran that are (1) level to very gently sloping – 0%, (2) gently sloping to undulating – 3%, and (3) moderately sloping to rolling – 8%. The areas with zero percent slope were given the highest weights.

2.5.7 Type of Soil: The soil type shapefile gives the different types of soil present in that area. It is very much specific to the type of soil in the municipality. Soil classifications that are present in Hinigaran are the following: (1) Hydrosol, (2) San Manuel loam, (3) Silay clay, (4) Bago sandy clay loam, and (5) Silay loam. Higher weights were given to hydrosol, Bago sandy clay loam and Silay loam since all the existing river-based aquaculture are currently situated in the said soil types.

2.5.8 Rain Induced Landslide: The rain induced landslide shapefile contains the different levels of susceptibility, specifically: (1) high susceptibility to landslide, (2) low susceptibility to landslide, (3) moderate susceptibility to landslide and (4) possible landslide debris accumulation zone.

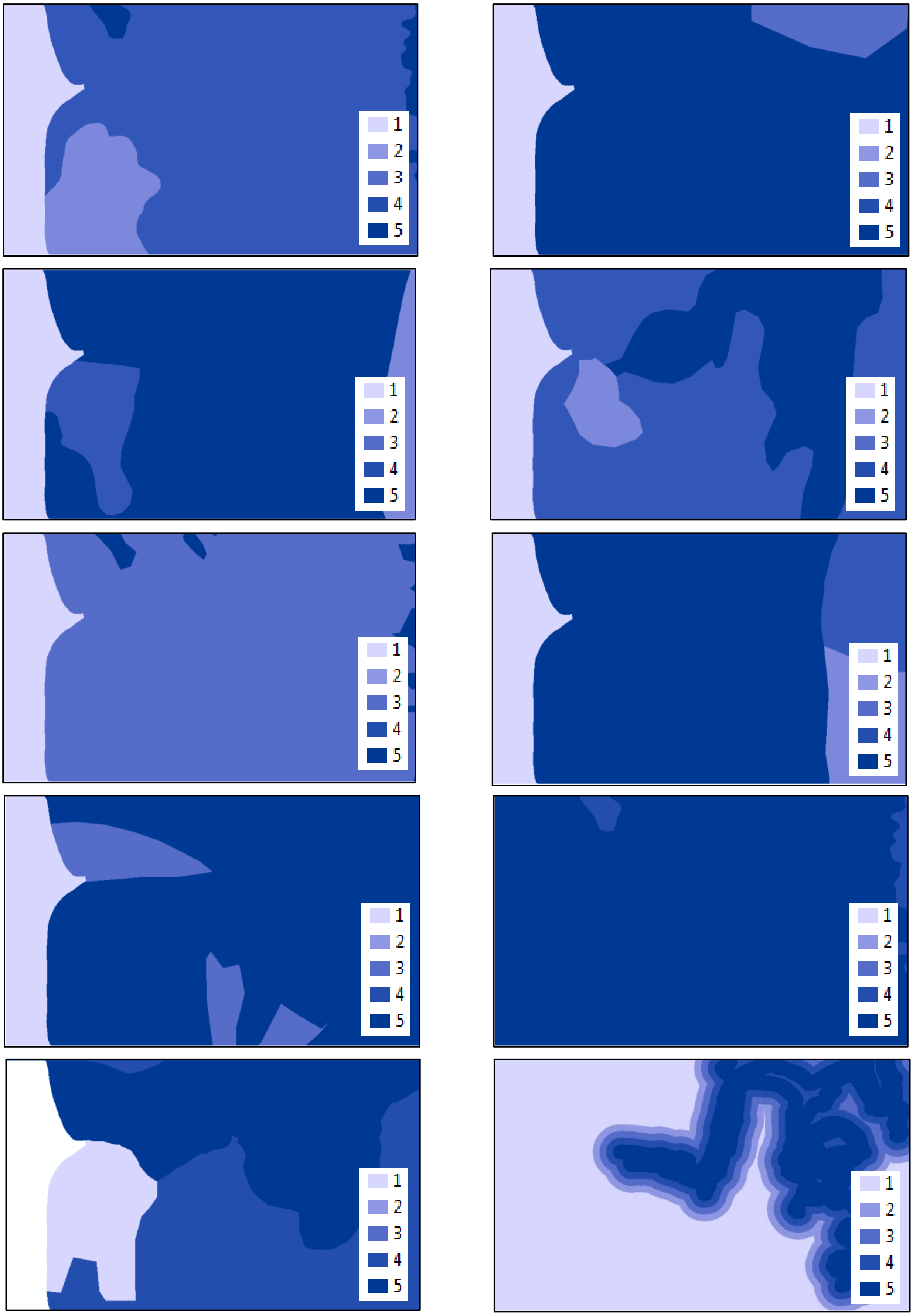
2.5.9 Strategic Agricultural and Fisheries Development Zones: The strategic agricultural and fisheries development zones shapefile contains: (1) strategic fishery sub-development zone, (2) strategic fishery sub-development zone, (3) agro-forestry zone, (4) network of protected areas for agricultural and agro-industrial development zones and (5) built-up zones.

2.5.10 Mangroves: The mangrove layer consists of buffers that are: (1) 100 meters, (2) 200 meters, (3) 300 meters, (4) 400 meters and (5) greater than 400 meters. Objects that are nearest to the mangroves were given the highest weights.

2.5.11 Union: All layers were then used as input for the Union function in ArcMap. The Union function created a geometric union of the input features. Afterwards, a suitability field was then added to the attribute of the resulting shapefile. The suitability was calculated as follows:

$$Suitability_{x} = \frac{\frac{Factor\ 1_{x}}{Factor\ 1_{max}} + \frac{Factor\ 2_{x}}{Factor\ 2_{max}} \dots + \frac{Factor\ n_{x}}{Factor\ n_{max}} \dots + \frac{Factor\ 10_{x}}{Factor\ 10_{max}}}{10} \quad (1)$$

The resulting attribute yielded values ranging from 5 to 1. Values greater than 4.5 and less than 5 was considered acceptable.



Figures 3 - 12. From left to right, then from top to bottom: Layer Weights for (3) Vulnerability to Flooding, (4) Land Suitability, (5) Vulnerability to Erosion, (6) Land Cover, (7) Tsunami Vulnerability, (8) Slope Classification, (9) Type of Soil, (10) Rain Induced Landslide, (11) SAFDZ, (12) Mangroves.

Figure 13. Union of all Layers

2.6 Image Processing

The goal of the image processing section of the study was to create a chessboard segmentation of the suitable buffers of the river.

2.6.1 LiDAR Derivatives: The LiDAR derivatives that were used were the Digital Surface Model and the Slope derived from the Digital Surface Model using the Slope (3D Analyst) function in ArcMap.

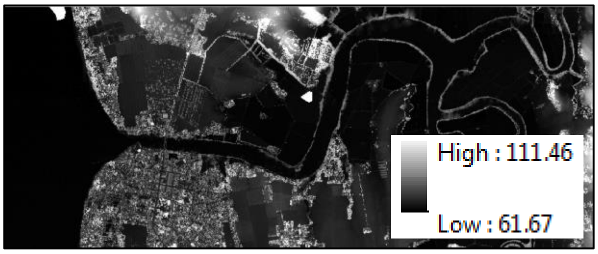


Figure 14. Digital Surface Model

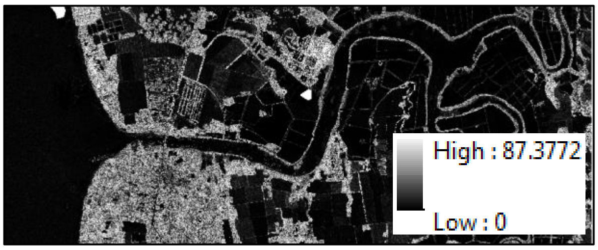


Figure 15. Slope

2.6.2 Segmentation: The image was segmented between data and no data first. Afterwards, all objects containing LiDAR data was then segmented using multi-resolution segmentation with 5 as layer weight for Digital Surface Model and 1 as layer weight for slope. Thematic layers for River, buffered zone, and output suitable area with suitability value greater than 4.5 was also included in the segmentation. The scale parameter for the multiresolution segmentation was set to 100 while the composition of homogeneity criterion for shape was set to 0.1 and compactness to 0.5

Figure 16. Data vs. No Data Classification

Figure 17. Image Segmentation

2.6.3 Suitable Area: The DSM was used to separate the land features from water. The thematic layers were then used on the segmented image. All objects that are within the river layer was assigned to the Class:River. The buffer shapefile is composed of polygons that are 15 meters away from the riverbank. The 15 meter value was given as a constant. The municipality of Hinigaran is currently passing a regulation allowing, only 10 meters from the side of the river for river-based aquaculture. Then 5 meters were added just as a buffer if in case there are inaccuracies with the river extent. From the river class, all objects that are within the buffer was assigned to Class: Buffer. From the buffer class, all objects that are within the suitability layer derived from the union was assigned to Class:Candidates.

2.6.4 Chessboard Segmentation: All suitable buffers were then segmented using Chessboard segmentation with 10 as the object size. The candidate class was then exported together with their slope values.

Figure 18. Subset of the Image Classification

3. RESULTS AND DISCUSSION

The green areas in the image below, shows the areas that has a value of 8 and below based on the slope layer derived from the Digital Surface Model. These areas signify the suitable portions of the river for oyster culture.

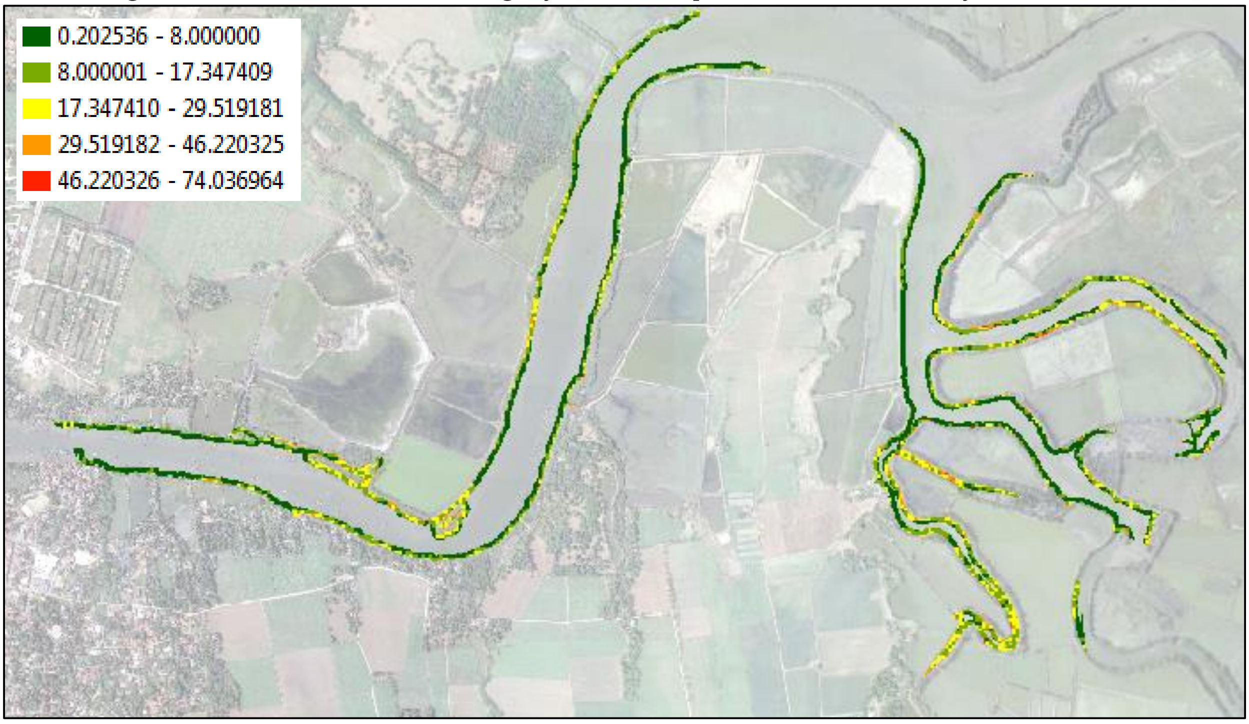


Figure 19. Slope Classification along the Suitable Buffer Zone in Hinigaran River

The following images are subsets of the areas that have a slope value of less than 8 paired orthophoto and the slope layer.

Figure 20. Orthographic Photo of a Subset of Hinigaran River

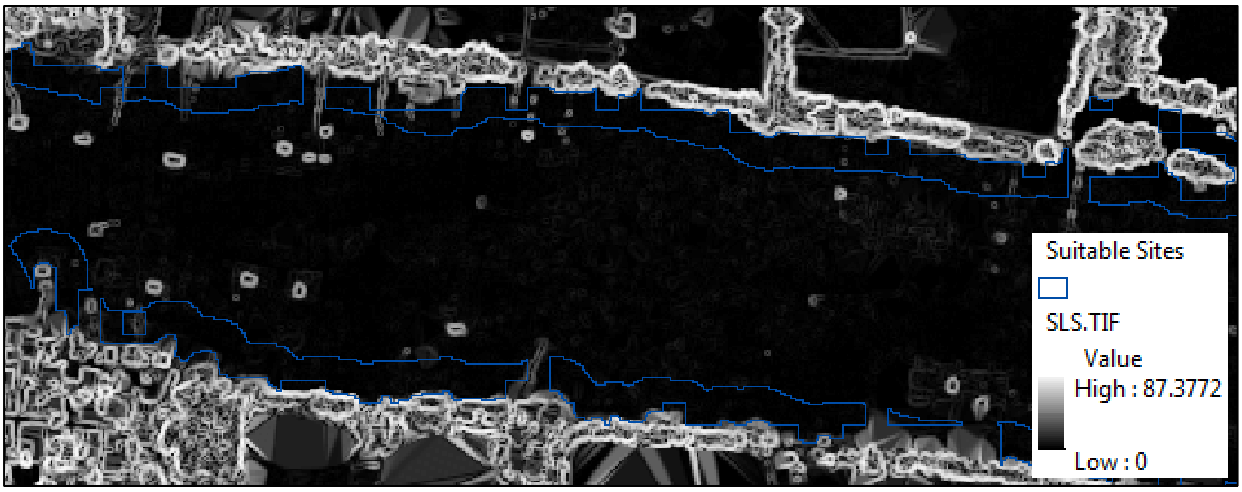


Figure 21. Slope Layer of a Subset of Hinigaran River

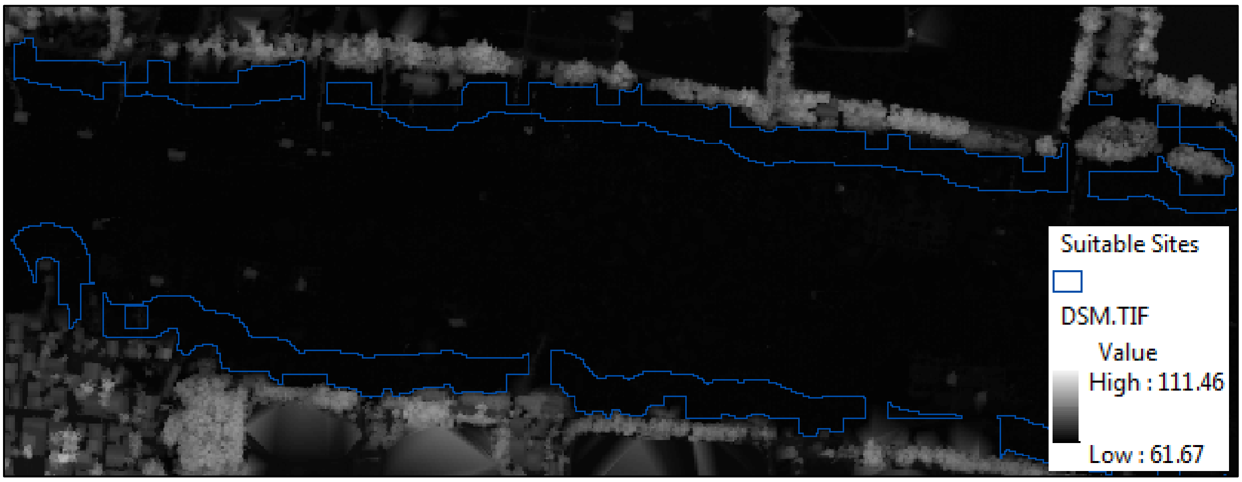


Figure 22. Digital Surface Model Layer of a Subset of Hinigaran River

As we can see in the images above, there are already existing oyster culture along the sides of the river. The suitability analysis produced suitable sites with already existing oyster culture. However as we can see the in the image, given the size of the river side buffer, the existing oyster culture features exceed by about approximately 7 to 13 meters.

Figure 23. Orthophoto Subset

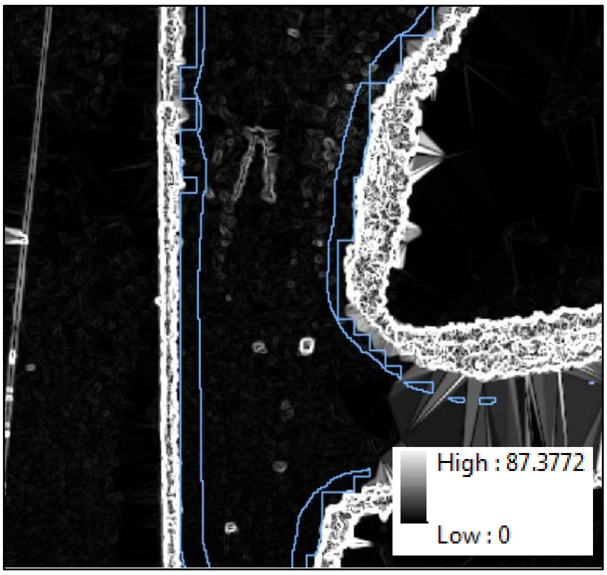


Figure 24. Slope Subset

The images shows sections of the river that still has existing oyster culture and some portions where the owner of the existing oyster culture might be able to expand his structure.

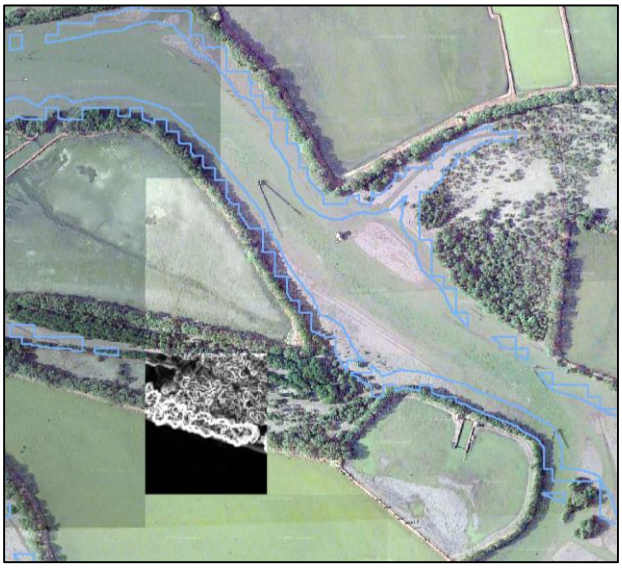


Figure 23. Orthophoto Subset

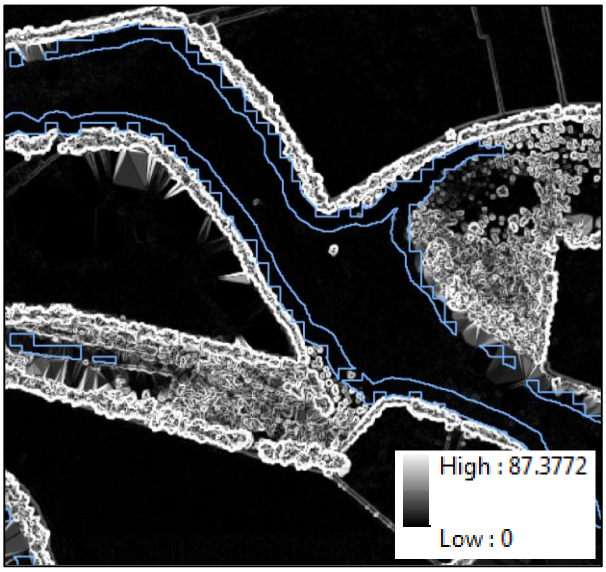


Figure 24. Slope Subset

The image shows section of the river that was classified as suitable but there are no existing oyster culture features. These areas may be utilized for oyster culture.

4. CONCLUSIONS

Through overlay analysis and image processing, a suitability map for oyster culture has been generated along Hinigaran River. By performing overlay analysis on these layers: vulnerability to flooding, land suitability, vulnerability to erosion, land cover, tsunami vulnerability, slope classification, type of soil, rain induced landslide, strategic aquaculture and fisheries development zone, and mangroves, a suitability layer was generated along Hinigaran River. The suitability map was then used in image processing to identify portions of the river that are suitable for oyster culture through the slope layer derived from the Digital Surface Model. It was then found out that some of the suitable areas generated has oyster culture, the remaining area can be utilized in expanding the oyster culture along Hinigaran River. This map can be turned over to the local government unit of Hinigaran in order to aid them in the decision making for the rehabilitation of Hinigaran River in terms of navigation and river-based aquaculture.

5. FURTHER STUDIES

A larger area with more oyster culture would be beneficial to the study. Since there is not that much research regarding oyster culture suitability using remote sensing, we can extract the oyster culture features and then learn from the characteristics of the extracted features much like machine learning. Both slope and depths should be checked since features might have lesser slope values but they might generally have lower depth values making them deeper. There are a lot more biological factors that are involved in oyster culture and it would be better if these would be considered. These factors were not included due to the time and financial constraints of the research. The result of this study cannot be treated as the absolute true situation. But it provides a mean to help the decision maker(s) to makes the right choice.

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