The Usage of Geographical Information System in the Selection of Floating Cages Location for Aquaculture at Prigi Bay, Trenggalek Regency, East Java

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Abstract. Floating cages is one of the methods of fish farming (aquaculture) that can be developed at rivers, lakes or seas. To determine a proper location for floating cages, there are some requirements that need to be fulfilled to maintain sustainability of floating cages. Those requirements are the quality of the environment. This paper will discuss the selection of best location for aquaculture activities using Weighted Overlay method in the Geographical Information System, based on the concentration of chlorophyll-a, sea surface temperature presented by Aqua MODIS Level 1b satellite images. The satellite data will be associated with the measured field data on March and October 2016. The study take place on Prigi Bay, at Trenggalek Regency, East Java. Based on spatial analysis in the Geographical Information System, the Prigi bay generally suitable for aquaculture activities using floating net cages. The result of Weighted Overlay combinations in both periods showed a mean score of 2.18 of 3 where 8.33 km\textsuperscript{2} (23.13% of the water area) considered as "very suitable" and 27.67 km\textsuperscript{2} (76.87% of water area) considered "suitable".

1. Introduction

Aquaculture or fish farming with floating cages could provide an alternative to reduce negative effects of overfishing. The aquaculture activities using floating cages can be developed at sea, river or lake. A sufficient and good water quality provides a great option for floating cages aquacultures. The aquaculture activities also influenced by the conditions or oceanographic and meteorological parameters such as wind, ocean depths, sea brightness, current speed, salinity, acidity and dissolved oxygen.

In the current technology developments of remote sensing, the distribution of chlorophyll-a and sea surface temperature can be detected using satellite imagery. The image data can be processed to determine the area of fish farming. Such data must be processed first, and the available parameters must be evaluated to choose a location that has the potential for fish farming. This paper will discuss the processing of satellite image data containing the distribution of chlorophyll-a concentration and sea surface temperature. By utilizing remote sensing technology, and overlaying the processed images containing those parameters, an information about the spatial and temporal information for the best option of Aquaculture will be presented in form of thematic map. Prigi Bay, at Trenggalek Regency, East Java was selected as the area of study since the location was considered clean and calm.

2. Remote Sensing and Geographical Information System

Remote Sensing is a science or art to obtain data or information from an object at the surface the earth using equipments remotely from the object [1]. Remote sensing is also consider as variation technique developed to obtained and analyse information about earth [2]. In the remore sensing system, a natural
or artificial energy is needed. The energy can be in the form of electromagnetic spectrum. Such as cosmic spectra, gamma ray, ultraviolet, sunray, infra red, radio wave, and micro wave. The natural energy used for remote sensing was sun, as the sun transmitted energy to the earth. Energy transmitted from the object in the earth surface can be recorded by the sensor remotely installed in the satellite from the object, using infrared thermal spectrum. The information in the form of electromagnetics energy reflected, emitted, and transmitted from the objects in the earth surface to the sensors attached in the satellite. Some of energy transmitted to earth dissipated by atmosphere and some portion reach the earth surface and hit the object. The object will absorb some of the energy and transmitted to the sensor attached in the satellite. The electromagnetics from satellite captured by earth station and send the data to Data Processing Centre for further analysis.

![Figure 1. Remote Sensing System [3]](image)

One of the object in the earth covered by remote sensing is the sea surface. The energy transmitted form the sea surface, may contain the concentration of chlorphyll-a. The chlorophyll-a concentration is a significant parameter for determining areas with potential fishery resources. The temperature contours that shows a dense temperature gradient over the surrounding area and high chlorophyll-a concentrations indicate the areas with high fish potential [4]. Therefore, by examining the distribution profile of chlorophyll-a concentration obtained from satellites and other related parameters for aquaculture, one can select the suitability of the area for floating cages placement for fish aquaculture. The selection process is integrated in the geographic information system.

Geographic Information System (GIS) is a set of tools used for collecting, storing, transforming, and presenting the spatial data of a real surface phenomenon of the earth for specific purposes [5]. The technology is growing rapidly due to the development of information technology or computer technology [6] which capable of handling databases, displaying an image (graph) and consider as the alternatives in presenting a map. GIS graphic data can be presented in two data models, namely raster data model and vector data model (spatial). The raster data model represents data expressed by grid or cell, whereas the vector data model presents graphical data (dots, lines, polygons) in vector format structures or in coordinates system (x, y). In the vector data, one can made a comparison between the line and area information in the form of data that have magnitudes, directions, and relations.

In the field of fisheries and marine science, GIS can be a valuable input for fishermen or fisheries entrepreneurs to predict the best locations for fishing. The interaction of attribute data with spatial data is very useful at fishing sites, where regular reports can be made to inform the potential fisheries around the ship landing site. Such information can be utilized in the selection process to find suitable floating cage location.
There are two factors that determine the suitability of the location of fishery cultivation, namely environmental factors and water quality [6]. Environmental factors are determined by the depth, brightness, current and wave while water quality is determined from temperature, salinity, acidity and oxygen. The rate of water fertility is also influential by considering the distribution of a-chlorophyll concentration in the waters. The use of satellite image data of chlorophyll-a concentration and sea surface temperature can be used to predict the location of floating cage using overlay analysis of parameters that have been classified into a raster map [7].

3. Analysis and Discussion

3.1 Area of Study

Prigi Bay in Trenggalek Regency, about 190km from Surabaya in the southern part of East Java Province, located at coordinates 8°19’39”S and 111°43’43” E as shown in Figure 2. The Ministry of Fisheries and Ocean have a fishing port in this place and equipped with a fish auction facility.

![Figure 2. Area of Study](image)

3.2 Data Collection

The data in this study is collected from various sources:

1. Distribution of chlorophyll-a concentration data in Prigi Bay obtained from the LADSWEB (ladsweb.modaps.eosdis.nasa.gov/search/) on March 2016 and October 2016. Data selected position limit to 8°19’39” S - 111°43’43” E.
2. Wind data obtained from the Agency of Meteorology, Climate and Geophysics (BMKG).
3. Oceanographic data such as depth of the sea, the sea brightness, current speed, salinity, dissolved oxygen and acidity obtained from Prigi Fishing Port and the Oceanographical Research Center – Indonesian Institute of Science (LIPI).
4. The map obtained from The National Agency of Survey and Mapping (ww.bakosurtanal.go.id/).

3.3 Digital Image Processing

The satellite images were processed to obtain distribution of chlorophyll-a concentration in the Prigi Bay waters. The processing stages include:

1. **Geometric correction.** Prior to image data processing, projection or map coordinate system must be adjusted to the area of interest or with previous spatial data. Geometric correction or rectification is the stage process in adjusting the image data with the appropriate coordinate
system. The references coordinate used in geometric correction were either a base map or previous image data that has been corrected. The geometric correction on a digitized topographical map of Prigi Bay performed using available Ground Control Point (GCP).

2. **Radiometric correction.** To clearly read and interpreted the information contained in the image data, the radiometric correction is performed. In this stage, the earth surface images are separated with clouds images using cloud masking processes. Satellite imagery that has been corrected geometrically were defined on the mask feature definition. Next, the images were overlaid with the desired canals, such as sea surface temperature or the concentration of chlorophyll-a.

3. The application of the algorithm associated with the preferred output using Band Math features on the cloud masked satellite images. After applying a predetermined algorithm, the processed files are stored and cropped by GIS software, subsequently.

4. The final stage is image cropping. This stage is performed to restrain the observed areas into the area of interest and reduce the size of the images. This stage will ensure that more focused, detailed and optimized data processing was achieved. The cropping image processes can be carried out following the desired polygon shapes such as following on the district, sub-district or village shape.

### 3.4 Processing of chlorophyll-a concentration and SST in MODIS Satellite Imagery

The image data processed in this study was the MODIS level 1b freely obtained from NASA Ocean Color Web. The file has the format of Hierarchical Data Format (*.hdf) which describe the captured time and spatial resolution of 1 km. The radiometric and geometric correction, as well as cloud masking will performed on MODIS data using satellite image processing software.

After image correction, the algorithm to determine the content of chlorophyll and sea surface temperature were applied. For chlorophyll concentration estimation, the algorithms OC4 [8] as shown below is applied:

\[
X = \log_{10}\left(\frac{Rrs(\lambda_1)}{Rrs(\lambda_2)}\right) \quad (1)
\]

\[
Chl-a = 10^{\left[a_0 + a_1 + (a_2, X_2) + (a_3, X_3) + (a_4, X_4)\right]} \quad (2)
\]

where:

\[
Rrs(\lambda_1) = RRS \text{ channel a blue (488 nm)}
\]

\[
Rrs(\lambda_2) = RRS \text{ in the green channel (531 nm)}
\]

\[
a_0 = 0.3272
\]

\[
a_1 = -2.9940
\]

\[
a_2 = 2.7218
\]

\[
a_3 = -1.2259
\]

\[
a_4 = -0.5683
\]

The algorithm for sea surface temperature (SST) is expressed as follows [9].

\[
SST \text{ Modis} = C1+ C2 \times T31 + C3 \times T31-32 \times Tb + C4 \times (sec(\Theta) - 1) \times T31-2 \\ (3)
\]

where:

- \(Tb = \text{Channel 20}\)
- \(C1 = \text{constant radiation that is worth 1.1911x108 W m}^{-2} \text{ sr}^{-1} \mu\text{m}^{-4}\)
- \(C2 = \text{constants of radiation that is worth 1.4388x104 K \mu\text{m}}\)
- \(\Theta = \text{sSatellite zenith angle}\)

The constants C1, C2, C3 and C4 available in Table 1

| Coefficient | \(\Delta T \leq 0.7\) | \(\Delta T > 0.7\) |
|-------------|----------------|------------------|
| C1          | 1.228552       | 1.69521          |
| C2          | 0.9576555      | 0.9558419        |
| C3          | 1.1182196      | 0.0873754        |
| C4          | 1.774631       | 1.199584         |

The constants C1, C2, C3 and C4 available in Table 1

### Table 1. The coefficient of C in B31 and 32 [9]
3.5. Classification for Aquaculture Suitability

The evaluated parameters used for classification of aquaculture suitability in this study were based on environmental factors turbidity, depth, current speed, and wave as presented in Table 2, and water quality such as temperature, salinity, pH, and dissolved oxygen as presented in Table 3. The weight values for environmental and water quality factors were presented in Table 4.

Table 2. The Weight values based on Environmental Factors [7]

| Environment   | Turbidity | Depth | Current | Wave | Weight |
|---------------|-----------|-------|---------|------|--------|
| Turbidity     | 1         | 2     | 4       | 7    | 0.53   |
| Depth         | ½         | 1     | 2       | 3    | 0.26   |
| Current       | ¼         | 1/2   | 1       | 2    | 0.14   |
| Wave          | 1/7       | 1/3   | 1/2     | 1    | 0.07   |
| Consistency ratio | 0.0029   |       |         |      |        |

Table 3. The Weight values based on Water Quality. [7]

| Water quality | Temperature | Salinity | PH | Oxygen | Weight |
|---------------|-------------|----------|----|--------|--------|
| Temperature   | 1           | 2        | 7  | 4      | 0.52   |
| Salinity      | ½           | 1        | 4  | 2      | 0.27   |
| pH            | 1/7         | 1/4      | 1  | ½      | 0.07   |
| Oxygen        | ¼           | 1/2      | 2  | 1      | 0.14   |
| Consistency ratio | 0.0008   |       |     |        |

Table 4. The Weight values based on Environmental Factors and Water Quality [7]

| Land Eligibility Criteria | Environment | Water quality | Weight |
|---------------------------|--------------|---------------|--------|
| Environment               | 1            | 3/2           | 0.6    |
| Water quality             | 2/3          | 1             | 0.4    |
| Consistency ratio         | 0.0000       |               |

Furthermore, scoring method is used in determination of the criteria and the division suitability class (3 for very suitable, 2 for suitable, and 1 for not suitable) for floating cage aquaculture activities using physical and chemical parameters by reducing some parameters such as sheltering location, substrate condition and distance from pollution. The weighting is performed by Pair Wise Comparison analysis as presented in matrix form as presented in Table 5 [7] [10] [11]. Parameters that have strong influence to the aquaculture activities have higher weighting factors than those with less influence. However, due to limited space, from various suitability parameter for Aquaculture presented in Table 5 below, only distribution of chrolophyll-a and sea surface temperature on Prigi Bay is discussed in this paper.

Table 5. Matrix of Parameter Suitability for Floating Cage Aquaculture

| No | Parameters     | Weight (%) | Unit | Very Suitable Score 3 | Suitable Score 2 | Not Suitable Score 1 |
|----|----------------|------------|------|------------------------|------------------|----------------------|
| 1  | Turbidity      | 31.8       | NTU  | <11                    | 11–40             | 40+                  |
| 2  | Temperature    | 20.8       | °C   | 27–29                  | 26–27 and 29–32   | <26 and >32          |
| 3  | Depth          | 15.6       | m    | 15–25                  | 5–15 and 25–40    | <5 and >40           |
| 4  | Salinity       | 10.8       | %   | 30–35                  | 20–30             | <20 and >35          |
| 5  | Current Speed  | 8.4        | cm/s | 15–35                  | 10–15 and 35–100  | <10 and >100         |
| 6  | Dissolved Oxygen| 5.6      | mg/l | >6                     | 4–6               | <4                   |
| 7  | Wave           | 4.2        | cm   | <20                    | 20–40             | >40                  |
| 8  | pH             | 2.8        |      | 7.0–8.5                | 4–7 and 8.5–9     | <4 and >9            |
3.6. Determination of Class Classification

The total score of each class is defined by multiplying the suitability level score with the parameter weight as presented in Table 5 using the following expression. [12].

\[
Y = \sum (a_i \times X_n) \quad \text{.................................................................(4)}
\]

where:

\[
Y = \text{Total Score}
\]
\[
a_i = \text{Weighting factors}
\]
\[
X_n = \text{Suitability level score}
\]

Furthermore, the interval classes for suitability levels were estimated using Equal Interval method [12] to divide the range of attribute values into sub-range with the same size. Mathematically it can be expressed as follows:

\[
I = \frac{(\sum (a_i \times X_n)_{\max} - \sum(a_i \times X_n)_{\min})}{k} \quad \text{.................................................................(5)}
\]

Where:

\[
I = \text{Interval of suitability classes}
\]
\[
k = \text{Number of the desired suitability classes}
\]

As presented in Table 5 above, there are three suitability classes: “very suitable”, “suitable” and “not suitable”. Based on equation 5, if the value of Nmax is 3 and the Nmin is 1, and the desired suitability classes is 3, it is found that the class interval was 0.667, and the score of suitability were:

- 2.333 to 3 = Very Suitable (S1)
- 1.668 to 2.332 = Suitable (S2)
- 1 to 1.667 = Not Suitable (S3)

The level of suitability is defined as [13]:

- Very Suitable (S1)
  This grade indicates that the reviewed location is potentially suitable for aquaculture activities. At this location there are minor to no limiting factor and will not affect the productivity of aquaculture significantly.

- Suitable (S2)
  This grade indicates that the aquaculture activities can be implemented in this location, but less suitable because it has a considerable limiting factor that affecting the productivity. Therefore, it required additional treatment and modification for aquaculture activities.

- Not Suitable (S3)
  This grade indicates that the location is unsuitable for aquaculture due to limiting factors that affect the productivity of aquaculture activities.

3.7. Sampling Data Interpolation

The interpolation method called Inverse Distance Weighted (IDW) was employed to consider the spatial distance as “weights”. The distance meant in this study here is the distance of the sample points to a block of data to be estimated. So, the closer the distance between sample points and a block to be estimated, the greater the “weight”, and vice versa. The IDW method assumes that the estimated value at the point which is not recorded is a function of the distance and the average value point located nearby. The interpolation depends on how strong a data point affects the area around it. It is also the number of points in the vicinity which are used to calculate the average value, and the pixel size / raster desired. IDW interpolation method provides more accurate results than Kriging method [14]. This is because the value of data generated in IDW, are close to the minimum and maximum value of the sample data. While the method of interpolation Kriging sometimes results in a low range and have less influence on the sampling variation.
4. RESULTS

4.1. Distribution of Chlorophyll-a concentration on Prigi Bay

The minimum value of concentration in March 2016 was 0.4 mg/m$^3$ while the maximum value was 2 mg / m$^3$, with the average concentration was 0.8 mg/m$^3$. Meanwhile, the concentration on October 2016 had a minimum value of 0.5 mg/m$^3$ and a maximum value of 2.1 mg / m$^3$, with the average of 0.9 mg /m$^3$.

Figure 3 shows the map of chlorophyll-a distribution on March and October 2016.

Figure 3. Distribution Map concentration of chlorophyll-a in Prigi Bay (5 ranges)

The concentration of chlorophyll-a in March 2016 did not have a significant difference compared to the distribution of chlorophyll-a concentration in October 2016 as the average differences is only 0.1
Figure 3 were re analysed to classify the water quality based on chlorophyll-a concentration and sediment suspension [17] resulting map as shown in Figure 4 below. Again, there are no significant difference of concentration between March and October 2016.

4.2 Distribution of Sea Surface Temperature Prigi Bay

The sea-surface temperatures in March and October 2016 also did not have a significant differences, although in the month of October, the sea surface temperatures tend to be lower compared to March. Sea surface temperature in March has the lowest temperature and the highest temperature of 30,25°C and 30,96°C, while the average temperature was 30,54°C. Meanwhile on October the sea surface temperature has 29,47°C as lowest temperature and 30,43°C as highest temperature with average value of 30,1°C. The temperature distribution are shown in Figure 5 below.
The sea surface temperatures are very feasible for aquaculture in the range of temperature 28-32°C [7]. Therefore, based on field data and spatial analysis shown in Figure 5 above, the sea surface temperatures in the Prigi bay are very suitable for aquaculture activities. Although the processed satellite images had average temperatures slightly lower than the data sample points, the temperature was still feasible for aquaculture activities.

4.3 Suitability Location using Weighted Overlay Method
The spatial analysis using various parameters presented in Table 5 above can be reclassified based on three interval suitability classes as discussed previously; i. Very Suitable (S1), ii. Suitable (S2) and iii. Not Suitable (S3). A suitability score can be evaluated using equation 4, and the result of aquaculture suitability location is shown in Figure 6.
Figure 6. Map of Suitability Location in Prigi bay based on March and October 2016

The green color in Figure 6 represents the very suitable location and yellow colors indicate suitable location for floating cages aquaculture. In general, the waters of the Prigi Bay quite suitable for floating cage aquaculture activities.

By weighted overlay methods and combining March and October 2016 analysis results, the average suitablity score was 2.18 of 3 and categorized as "suitable". Further analysis shows that “very suitable” area in Prigi Bay was 8.33 km$^2$ (23.13% of the water area) while "suitable" area was 27.67 km$^2$ (76.87% of the total water). The most suitable location for Aquaculture activities are stations 5, 6 and 10 in Figure 6.

5. Conclusion

From the results of the analysis conducted in this study could be concluded as follows:

1. The waters of the Prigi Bay in March and October 2016 has high chlorophyll-a concentration or considers rich phytoplankton. The average distribution of chlorophyll-a concentration reaches from 0.8 to 0.9 mg / m$^3$.

2. The spatial analysis performed at Prigi Bay shows that the area generally suitable for Aquaculture activities. A "very suitable" area was found of 8.33 km$^2$ (23.13% of the water area) while "suitable" was 27.67 km$^2$ (76.87% of the total water).

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