The selection of aquaculture site based on chlorophyll-a concentration at Sidoasri Bay, Sendang Biru, Malang regency, East Java

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Abstract. Currently, offshore fish farms are using floating net cages or offshore aquaculture is one alternative to support the fisheries sector in Indonesia. Several requirement parameters must be met before the installation of floating cages for the sustainability of the fish culture. One of which is the distribution of chlorophyll-a in the waters. In this paper, Landsat 8 satellite imagery was collected to evaluate the chlorophyll-a concentration in the waters of Sidoasri Bay, Sendang Biru, Malang regency, East Java. The concentration of chlorophyll-a will be used as indicators to select a suitable location for offshore aquaculture. Based on the satellite image observations indicated that at Sidoasri Bay, there are two locations appropriate for floating cages. The location is generally suitable for floating cages installation with an average score of 2.26 on a scale of 3.

1. Introduction

Aquaculture or fish farming with floating cages could provide an alternative to reduce the negative effects of overfishing. The aquaculture activities using floating cages can be developed at sea, river, or lake. A sufficient and good water quality such as Sidoasri Bay in Sendang Biru, Malang Regency, East Java provides a great option for floating cages aquacultures. The aquaculture activities are influenced by environmental conditions such as current speed, water depths, wave height, wind speed, distance from the shoreline, and water qualities such as sea brightness, water temperature, salinity, acidity, suspended sediment, dissolved oxygen (Diposaptono, etc), For East Java, another six parameters have been added, namely social-economic, disaster risk, source of seed, water quality, other activities in the vicinity of aquaculture, zoning plan [1].

In the current technology developments of remote sensing, the distribution of sea surface temperature, current speed, salinity, dissolved oxygen, wave height, acidity, sea brightness, wind speed, suspended sediment, and distance from the shoreline can be detected based on satellite imagery and quantifiable. However, the new six qualitative parameters are unquantified, since they consist of descriptive explanations obtained based on questionnaire results.

Due to limited space, this paper will only discuss the processing of satellite image data containing the distribution of chlorophyll-a concentration. By utilizing remote sensing technology, and overlaying the processed images containing those parameters, information about the spatial information for the best option of Aquaculture will be presented. Sidoasri Bay, at Malang Regency, East Java as shown in Figure
1 was selected as the area of study since the location was planned as the location for ITS Ocean Farm installation.[2].

![Map of Sidoasri Bay, Malang Regency](image)

**Figure 1.** Sidoasri Bay, Malang Regency.

### 2. Materials and methods

#### 2.1. Remote Sensing and GIS

Remote Sensing is a science or art to obtain data or information from an object at the surface of the earth using equipment remotely from the object[3]. Remote sensing is also considered a variation technique developed to obtained and analyze information about the earth [4]. In the remote sensing system, natural or artificial energy is needed. The energy can be in the form of an electromagnetic spectrum. Such as cosmic spectra, gamma-ray, ultraviolet, sunray, infra-red, radio wave, and microwave. The natural energy used
for remote sensing was the sun, as the sun transmitted energy to the earth. Energy transmitted from the object on the earth’s surface can be recorded by the sensor remotely installed in the satellite from the object, using the infrared thermal spectrum. The information in the form of electromagnetic energy is reflected, emitted, and transmitted from the objects on the earth’s surface to the sensors attached in the satellite. Some of the energy transmitted to the earth dissipated by the atmosphere and some portions reach the earth’s surface and hit the object. The object will absorb some of the energy and transmitted it to the sensor attached to the satellite. The electromagnetics from the satellite captured by the earth station and send the data to Data Processing Centre for further analysis.

![Figure 2. Remote Sensing System](image)

One of the objects in the earth covered by remote sensing is the sea surface. The energy transmitted from the sea surface may contain the concentration of chlorophyll-a. The chlorophyll-a concentration is a significant parameter for determining areas with potential fishery resources. The temperature contours that show a dense temperature gradient over the surrounding area and high chlorophyll-a concentrations indicate the areas with high fish potential [6]. 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 into 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 [7]. The technology is growing rapidly due to the development of information technology or computer technology 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 the 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 coordinates system (x, y). In the vector data, one can make 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 a suitable floating cage location.

As two factors determine the suitability of the location of fishery cultivation, namely environmental factors and water quality [8]. 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 can be used to predict the location of the floating cage using overlay analysis of parameters that have been classified into a raster map [9].

2.2. Digital Image Processing

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

2.2.1. 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 staging process in adjusting the image data with the appropriate coordinate system. The reference coordinates 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 Sidoasri Bay performed using available Ground Control Point (GCP).

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

2.2.3. Chlorophyll-a Estimation. The implementation of algorithms to match the desired output performed using the band math feature on the satellite imagery after the cloud masking process. The extraction of chlorophyll-a concentration values based on the following algorithm:

\[
Chl = a = 0.067 \frac{\lambda_{\text{green}}}{\lambda_{\text{blue}}} + 0.126
\]  

where:
- Chl-a = chlorophyll-a concentration in satellite imagery (mg/m)
- \(\lambda_{\text{green}}\) = reflectance value on green wavelengths
- \(\lambda_{\text{blue}}\) = reflectance value on blue wavelengths.

The validation of chlorophyll-a estimation using Landsat 8 imagery refers to a research of Hamuna and Dimara [10]. In their study, the RMSE (Root Mean Square Error) was 0.283761. In addition, the correlation between satellite imagery and in situ data is relatively high with a significant value of 0.957.

2.2.4. 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 rectangular shapes in the vicinity of Sidoasri Bay.

3. Results and discussion

3.1. Distribution of Chlorophyll-a concentration

Chlorophyll –is a pigment that able to photosynthesis and is found in all phytoplankton and plant organisms. Nutrient concentrations greatly affect the distribution of chlorophyll-a concentrations in the water. In general, the concentration of nutrients at sea surface level is less than the thermocline and the deep layer. A light that can be absorbed by chlorophyll-a is found at the intensity of light with wavelengths of 430 nm and 663 nm. Marine plants generally have other pigments to support the function of chlorophyll-a to absorb sunlight and transfer the energy accumulated to chlorophyll-a [11]. This pigment can absorb light with different wavelengths of chlorophyll-a. Some of these pigments include:
• Chlorophyll-\textit{b}, capable of absorbing light at a wavelength of 450-645 nm and is commonly found in some types of algae.

• Carotene, capable of absorbing light at wavelengths of 450-470 nm, is mostly found in algae.

• Xanthophyll, capable of absorbing light at a wavelength range of 480-540 nm.

• Phycoerythrin has maximal light absorption at wavelengths of 540-560 nm.

• Phycocyanin, capable of absorbing light at a wavelength in the range of 610-630 nm.

The concentration of chlorophyll-\textit{a} in the seawater can be estimated by the number of phytoplankton since phytoplankton is organisms that have chlorophyll-\textit{a} in their metabolic system. Phytoplankton is marine organisms that drift in the water and able to photosynthesis. The concentration of phytoplankton can reach thousands to millions of cells per liter of seawater. Phytoplankton can be found in all water depths, from the surface to the deep-sea area where the sunlight can be captured [12]. Phytoplankton is among the primary producers in the aquatic food chain due to their ability to form organic substances from inorganic substances. In the food chain, phytoplankton will be consumed by herbivorous animals found in waters such as zooplankton. Zooplankton that is in the food chain referred to as secondary producers will be re-consumed by larger carnivorous animals as shown in Figure 3 below.

Figure 3. Food Chain in the Ocean.

In coastal waters where upwelling occurs are the locations where phytoplankton are found and thrive. The fertility process occurs in those areas due to a large amount of nutrients from run-off events in coastal areas. The upwelling caused nutrients to be lifted to the surface. A large number of food sources for fish in those areas can be indicative of the fertility rate of the waters and support for aquaculture activities. The fertility of water is influenced by the chlorophyll-\textit{a} levels and is considered as one of the influenced factors in the development of aquaculture activities in those areas. Chlorophyll concentrations can be classified as follows [13]:

| Class | Concentration (mg/m$^3$) | Notes |
|-------|--------------------------|-------|
| I     | <0.3                     | low concentration /clear water |
| II    | 0.3–0.5                  | medium concentration /medium rich phytoplankton |
| III   | 0.5–1.0                  | high concentration /rich phytoplankton |
| IV    | 1.0–2                    | chlorophyll-\textit{a} and suspended load |
| V     | >2                       | high/slightly turbid water |

The analysis of chlorophyll-\textit{a} from satellite imagery was performed based on the consideration of the weather change in Indonesia. March represents the rainy season, April represents the transition
season from rain to dry, May represents the dry season, and October represents the transition season from dry to rainy season. In this study, the satellite images used for analysis were on October 2019, March 2020, April 2020, and May 2020.

The average chlorophyll-a concentration at ten sampling points for each season above is presented in Table 2. It can be seen the changes of chlorophyll-a concentration due to the difference in seasons. From October 2019 to March 2020, chlorophyll-a concentration increased as Indonesia experienced a transitional season from dry to rainy season. However, the increase in chlorophyll-a is not very significant—only 0.2 mg/m$^3$—compared to the increment in April to May, when Indonesia enters the dry season with a difference in chlorophyll concentration-a of 1 mg/m$^3$. Figure 4 shows the observation points at Sidoasri Bay.

### Table 2. Average Chlorophyll Concentration at Observation Points.

| Station | X       | Y       | Zone | Oct 2019 | Mar 2020 | Apr 2020 | May 2020 |
|---------|---------|---------|------|----------|----------|----------|----------|
| 1       | 695990.00 | 9071257.47 | 49L  | 2.03     | 2.03     | 1.02     | 2.46     |
| 2       | 695443.80 | 9072255.41 | 49L  | 2.04     | 2.50     | 1.03     | 2.34     |
| 3       | 695002.73 | 927853.21 | 49P  | 1.90     | 2.01     | 1.30     | 2.29     |
| 4       | 694670.31 | 928294.14 | 49L  | 1.94     | 2.01     | 1.01     | 2.30     |
| 5       | 695219.51 | 928628.44 | 49P  | 1.80     | 2.15     | 1.09     | 2.30     |
| 6       | 694885.60 | 929401.18 | 49P  | 1.74     | 1.20     | 1.04     | 1.80     |
| 7       | 694638.82 | 929732.00 | 49P  | 1.86     | 1.30     | 2.50     | 2.47     |
| 8       | 695546.43 | 929404.17 | 49L  | 1.42     | 2.04     | 2.10     | 2.47     |
| 9       | 696429.05 | 9070923.65 | 49L  | 1.01     | 2.20     | 1.20     | 2.45     |
| 10      | 695993.51 | 9072031.70 | 49L  | 1.29     | 2.01     | 1.02     | 2.20     |
|         | 1        | 1.70     | 1.95 | 1.33     | 2.31     |

**Figure 4. Observation Points and depth of Sidoasri Bay.**

In October 2019, the Indonesian archipelago experienced a transitional season from the dry season to the rainy season. The spread of chlorophyll-a in October 2019 can be seen in Figure 5. The shade of colors shows the range of chlorophyll-a concentration. Red for concentration less than 0.3 mg/m$^3$, orange for the concentration in the range of 0.31 – 0.71 mg/m$^3$ and yellow for concentration in the range of 0.71 – 1.00 mg/m$^3$. The light green shows the range of concentration of 1.01 – 2.00 mg/m$^3$ and the dark green shows concentration between 2.01 – 2.50 mg/m$^3$. The minimum concentration of chlorophyll-a in this season is 1.01 mg/m$^3$ at station 9 and the maximum concentration is 2.04 mg/m$^3$ at station 2 with an average value of 1.7 mg/m$^3$. 
Figure 5. Chlorophyll-a Distribution (October 2019).

Figure 6 shows a map of chlorophyll distribution in Sidoasri Bay in March 2020. This is at the end of the rainy season. The minimum concentration in Teluk Sidoasri on March 2020 is 1.2 mg/m$^3$ at station 6 and the maximum concentration value is 2.5 mg/m$^3$ at station 2 with an average concentration of 1.9 mg/m$^3$. Compared to the previous season, during the rainy season, low concentration is more found in the area of study as some red spots are seen in the area.

Figure 6. Chlorophyll-a Distribution (March 2020).

In April 2020, Indonesia began to enter the transition period from the rainy season to the dry season. The distribution of chlorophyll-a in Sidoasri Bay in this season is shown in Figure 7. The minimum concentration value is 1.01 mg/m$^3$ at station 4 and the maximum concentration value is 2.5 mg/m$^3$ at station 7 with an average concentration of 1.3 mg/m$^3$. 
While on May, Indonesia entered the dry season and the distribution of chlorophyll concentrations in Sidoasri Bay is shown in Figure 8. The minimum value of chlorophyll-a concentration in May 2020 is 1.8 mg/m$^3$ at station 6 and the maximum value is 2.47 mg/m$^3$ at stations 7 and 8 with an average concentration of 2.30 mg/m$^3$.

3.2. Suitability Location for Offshore Aquaculture based on spatial analysis

The parameters used for the classification of ITS Ocean Farm suitability were based on environmental factors such as turbidity, depth, current speed, and wave as presented in Table 3. Water quality such as temperature, salinity, pH, and dissolved oxygen as presented in Table 4. The weight values for environmental and water quality factors were presented in Table 5.

The pairwise comparison matrix was used to determine the influenced parameter in the decision-making process. Each parameter is weighted based on previous studies [9] and parameters that have a large influence will have a large weight. Some parameters used in the pairwise comparison analysis are presented in Table 3, Table 4, and Table 5 as follows:
Table 3. The Weight based on Environmental Factors [9].

| 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 4. The Weight based on Water Quality [9].

| 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 5. The Weight based on Environmental Factors and Water Quality [9].

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

Each matrix in the table above has a consistency ratio (CR) with a limit less than 0.1 (CR < 0.1), if the ratio is greater than 0.1 it must be re-weighted. For the matrix in Table 3, the CR value is 0.0029, the matrix in Table 4 has a CR value of 0.0008, and the matrix in Table 5 has a CR value of 0.0. While the suitability matrix for environmental parameters and water quality for grouper fish is presented in Table 6:

Table 6. Matrix of Parameter Suitability for Aquaculture: Radiarta et al. (2006).

| 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            |

The total score of each parameter class is defined by multiplying the suitability level score with the parameter weight as presented in Table 3, Table 4, Table 5, and Table 6 using the following expression.

\[ Y = \sum (a_i \times X_n) \] (1)

where:
- \( Y \) = total score
- \( a_i \) = weighting factors
- \( X_n \) = suitability level score
Furthermore, the interval class for suitability level was estimated using the Equal Interval method [14] to divide the range of attribute values into sub-range of the same size. Mathematically it can be expressed as follows:

\[ I = \frac{Y_{\text{max}} - Y_{\text{min}}}{k} \]  

(2)

where:
- \( I \) = Interval of suitability classes
- \( k \) = Number of the desired suitability classes

As presented above, there are three suitability classes: “very suitable”, “suitable” and “not suitable”. Based on equation 2, if the value of \( Y_{\text{max}} \) is 3 and the \( Y_{\text{min}} \) is 1, and the desired suitability class is 3, it is found that the class interval was 0.667, and the score of suitability was listed as Table 7 below:

| Suitability Level | Score    |
|-------------------|----------|
| Very suitable     | 2.33 – 3.0 |
| Suitable          | 1.67 – 2.32 |
| Not Suitable      | 1.0 – 1.66 |

- **Very Suitable (S1)**. This level indicates that the reviewed location is potentially suitable for aquaculture activities. At this location, there are minor to no limiting factors and will not affect the productivity of aquaculture significantly.
- **Suitable (S2)**. This level indicates that the aquaculture activities can be implemented in this location, but less suitable because it has a considerable limiting factor that affecting productivity. Therefore, it required additional treatment and modification for aquaculture activities.
- **Not Suitable (S3)**. This level indicates that the location is unsuitable for aquaculture due to limiting factors that affect the productivity of aquaculture activities.

A thematic map for each water criterion for marine aquaculture must be compiled prior to spatial analysis. To convert data points into areas and grouped them by environmental and water quality factors, the *Inverse Distance Weighted Interpolation* (IDW) was used. The area of water suitable as an offshore aquaculture site is then arranged vertically and overlayed each other for the ease of analysis.

![Figure 9. Weighted Overlay Features on ArcGIS Software.](image-url)
The environmental parameters and water quality are reclassified based on their suitability and level of influence as presented in Table 7. The weighted overlaying method in the reclassification processes in ArcGIS is presented in Figure 9. The reclassification was performed based on the level of conformity divided into 3 (three) classes using Equation 2. A map of the suitability aquaculture location of 4 (four) seasons is shown in Figure 10.

The green color on the map above represents the “Very Suitable” location, the yellow color describes the “Suitable” location, and the red color represents the “Not suitable” location. It can be seen from the map that the location of Teluk Sidoasri is mostly suitable for aquaculture with an average score of 2.26 out of a scale of 3 for the whole season. The observation points that “Very Suitable” are point 6 and point 7, while other observation points consider as "suitable" as shown in Figure 10 above. The recommended area for OceanFarm ITS were located in the following coordinates: (-8.417°S, 112.761°E) to (-8.417°S, 112.787°E) and from (-8.393°S, 112.776°E) to (-8.393°S,112.781°E).

4. Concluding remarks
The initial analysis concluded that Sidoasri Bay in general has a high distribution of chlorophyll-a or rich phytoplankton with a high suspended load. The average concentration of chlorophyll-a are 1.7 mg/m³ in October 2019, 1.9 mg/m³ in March 2020, 1.3 mg/m³ in April 2020, and 2.3 mg/m³ in May 2020. Based on the distribution of chlorophyll-a on ten observation points, the potential locations for aquaculture are points 6 and 8.

The validity of the algorithm used to estimate the concentration of Chlorophyll-a in this study needs to be tested with field sample measurements. Due to the covid-19 pandemic, the field survey activities for sampling water quality have not been able to be carried out.

Further analysis is needed to include other factors that affect the fertility of Sidoasri Bay and environmental conditions to determine the location of ITS Ocean Farm aquaculture.
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