Suitability analysis of mangrove conservation areas in Mundu District, Cirebon Regency using Geographic Information Systems (GIS)

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Abstract. This study aims to analyze the suitability of mangrove conservation areas in the Mundu District, Cirebon Regency. In this study, we used Sentinel-2A satellite data obtained from ESA Copernicus’s web to analyze the normalized difference vegetation index (NDVI) of mangrove that will be used as a mangrove health indicator and several oceanographic characteristics to assess the suitability of mangrove conservation areas based on weighing-scores systems. All data were then analyzed using image processing combined with geographic information systems (GIS) tools available in the open-access QGIS software. Results show that the health of the mangrove based on vegetation index was in the range of 0.3–0.6. Mangroves in Mundu Region have consisted of two species, Avicennia marina, and Rhizophora apiculata. The substrate in this area is dominated by muddy sand with a pH value of 8 and an average salinity of 32 PSU. The tidal type in Mundu region has mixed semi-diurnal characteristics with an average tidal height of 1.22 m. Based on those parameters and NDVI analysis, the suitability rank for mangrove conservation areas can be classified as suitable with a total score in the ranges of 101-200.

Keywords: mangrove, NDVI, suitability score, conservation, mundu district

1. Introduction
In recent decades, marine spatial planning, from the coast to the high seas, is being developed and applied worldwide [1]. This is done as a response to the demand and utilization of marine resources, which are expected to continue increasing, significantly impacting marine ecosystems [2]. Spatial planning is one of the regional government affairs related and takes part in realizing the community’s welfare to utilize natural resources in a sustainable manner, especially in the maritime sector. This marine spatial planning has several approaches, such as holistic and integrated approaches, reactive
strategy, bioregionalism, integrated coastal management, and interdisciplinary approaches involving the fields of ecology, economics, engineering, sociology, law, and other fields of science [3, 4].

The existence of the Zoning Plan for Coastal Zone and Small Islands, also known as Rencana Zonasi Wilayah Pesisir dan Pulau-Pulau Kecil (RZWP3K) in Indonesia, is a follow-up by Act No. 27 of 2007 concerning the Management of Coastal Zone and Small Islands. This RZWP3K can be the most decisive planning document in spatial planning [5]. The objective of RZWP3K in West Java Province is "to realize the sustainability of coastal resources and small islands in an integrated and sustainable manner," as stated in Regulation No. 5 of 2019, Article 8. The RZWP3K arrangement can help us identify and determine the focus of WP3K development, such as the field of protection, integrated industry, maritime tourism, sea transportation, and the field of defense and security [6].

The estuary of Mundu District that covered by mangrove of 1,383 ha acts as a barrier to Cirebon City. The coast of Mundu District consisted of reddish-black sand and muddy substrate [7] with a coastline length of 1.345 km, while the length of the mangrove strip is 1.195 km with the beach border width of 100 m, and an average mangrove green belt of 22.5 m [8].

Mangrove ecosystems have a significant role in various aspects of social, economic, and coastal development. This ecosystem is located in tidal areas and is influenced by the geographical location and topography of the coastal zone. In the Cirebon area, the mangrove area is relatively wide because it is close to the Java Sea, characterized by calm waves, sloping soil, and mud substrates that support the growth and development of mangroves [10].

In the coastal area of Mundu District, Cirebon Regency, there are two species of mangroves, Avicennia marina, and Rhizophora apiculata [11]. The condition of mangroves in this area has been damaged due to mangrove conversion for developing settlements, fish/shrimp ponds, exploiting living resources associated with mangroves, and high water pollution [10]. The lack of community participation in maintaining the mangrove ecosystem is still considered very low [10].

In general, the government and various environmental policymakers have difficulty studying and monitoring the mangrove condition due to the lack of information and inadequate funds for conducting direct field observation [12, 13]. Therefore, an effective and efficient technology such as remote sensing is needed to monitor and identify mangrove conditions. Remote sensing is the science and art of extracting information about an object, area, or phenomenon by analyzing data collected by a device that does not directly contact the object, area, or phenomenon being studied. [14]. Some advantages of remote sensing, such as data retrieval, are more comprehensive, detailed, efficient, and specific, thus facilitating the analysis process. It can be used for a large area and save time, energy, and data retrieval costs [14, 15].

Several research shows that the prerequisite for establishing land-use planning is island suitability assessment [16]. Thus, selecting the processes and criteria for land suitability assessment is essential [17]. Several studies on land suitability analysis show that Geographic Information Systems (GIS) is one of the most suitable tools, for example, land suitability analysis in Yusufeli District, Turkey [16] and land suitability analysis for city layouts in Lisbon, Portugal [18]. Studies to fulfill these prerequisites lead to optimal land use accompanied by information about opportunities and constraints in using certain land areas [19].

The method for conducting land suitability studies can be done by using a combination of GIS with other analytical techniques, for example, the combination of GIS with Analytical Hierarchy Process (AHP) [16] and a combination of GIS with multi-criteria evaluation (MCE) [20]. Remote sensing indices, in the form of normalized difference vegetation index (NDVI) and normalized difference water index (NDWI), can be used to increase the accuracy of land suitability analysis of a specific area [21, 22]. The advantages of combining GIS with other methods have been widely evaluated [18, 23]. However, such kind of information on the study site is limited. Therefore, this study aims to determine the vegetation health index, substrate type, and other oceanographic parameters, such as pH, salinity,
and tidal types, to assess the suitability of the mangrove conservation areas in the coastal zone of Mundu District, Cirebon Regency.

2. Materials and methods
This study was carried out in the Cirebon Regency, Mundu District, the north coast of West Java as shown in the red box of Figure 1 below.

![Figure 1. Map of the study area in Mundu district’s coastline.](image)

This study used Sentinel 2 satellite data to assess the mangrove health index (NDVI) and several oceanography parameters data to assess the suitability scores. The Sentinel 2 data was obtained in June 2020 from the ESA Copernicus (https://scihub.copernicus.eu) with a spatial resolution of 10 m. The remote Sensing method is used in this study to identify the vegetation index using the NDVI algorithm. QGIS software was then used to process the NDVI and other parameters data to calculate the suitability score of mangrove conservation areas and visualize it in the map form.

The mangrove health index was analyzed using the Normalized Difference Vegetation Index (NDVI) that derived by applying the red (B4) and near-infrared (NIR/B8) bands of Sentinel-2 satellite data by applying the equation of NDVI, expressed as bellow:

\[ \text{NDVI} = \frac{[\text{NIR(B8)} - \text{Red(B4)}]}{[\text{NIR(B8)} + \text{Red(B4)}]} \], NDVI is in the ranges of -1 to +1 [24].

The calculation of the band-math algorithm will result in an index value of -1–1. These results will show the vegetation index and then be continued to the layouting process. In classifying the suitability
rank of mangrove conservation areas, we apply a scoring method using several parameters, particularly mangrove health (NDVI), mangrove diversity, in addition to oceanographic parameters, and then assign a weight to each parameter as shown in Table 1.

Table 1. Land suitability assessment for mangrove forest conservation areas (modified from: [25]).

| No | Parameter                  | Weight (100) | S1 (3) | S2 (2) | S3 (1) | N (0) |
|----|----------------------------|--------------|--------|--------|--------|-------|
| 1  | Mangrove health index      | 30           | >0.60; | 0.30 to 0.60 | 0.10 to 0.30 | < -1  |
|    |                            |              | Score: | Score= 60 | Score= 30 | Score= 0 |
|    |                            |              | 30 x 3 = 90 |        |        |       |
| 2  | Mangrove species           | 20           | > 4; Score: | 3-4    | 1-2    | 0     |
|    |                            |              | 20 x 3 = 60 | Score= 40 | Score= 20 | Score= 0 |
| 3  | Tides (m)                  | 10           | 0-1; Score: | > 1-2  | > 2-5  | > 5   |
|    |                            |              | 10 x 3 = 30 | Score= 20 | Score= 10 | Score= 0 |
| 4  | Main substrate             | 10           | Mud+Sand | Sandy | Sand+rubble | Rock  |
|    |                            |              | Score= 30 | Score= 20 | Score= 10 | Score= 0 |
| 5  | pH                         | 10           | 6-7     | 5-<7 and >7-8 | 4-<5, > 8-9 | <4 and >9 |
|    |                            |              | Score= 30 | Score= 20 | Score= 10 | Score= 0 |
| 6  | Current velocity (m/s)     | 10           | < 0.3   | 0.3-0.4 | 0.41–0.5 | > 0.5 |
|    |                            |              | Score= 30 | Score= 20 | Score= 10 | Score= 10 |
| 7  | Salinity (‰)               | 10           | 25-<29  | 29-33  | 0--1   | 0     |
|    |                            |              | Score= 30 | Score= 20 | Score= 10 | Score= 0 |

The score of suitability ranges, 201-300 very suitable, 101-200 suitable, ≤ 100 fair suitable, not suitable at all.

Suitability rank and color legends

The results of the interpolation data were processed with QGIS 3.10 Qoruna. Previously, the pH, salinity, and other parameters data were compiled and put to QGIS in an excel (csv.) format. The Coordinate System that we use is the EPSG:4326-WGS 84. The interpolation method we used was the IDW Interpolation that can be found in the Processing Toolbox. We chose the vector layer according to our parameters, then chose the interpolation with 200000 distance coefficient and saved it. We also changed the interpolation color as needed in the symbology section.

3. Results and discussion

3.1. Mangrove condition in Mundu District

Cirebon Regency has a mangrove forest area of 1,780 ha. Mangroves in reasonable, moderate, and damaged condition are 1,100 ha, 200 ha, and 480 ha, respectively. The planting mangrove area in Mundu District is 11,383 ha. Here mangroves grow in muddy substrates, so they are susceptible to change [7]. For example, in 2013, this area experienced a decrease of 240 ha. Mangrove species in Mundu District are dominated by mostly one species of *Avicennia marina* [26], which has a characteristic by leaf with a width of around 3 cm, a light green color at the base of the leaf, and dark green at the tip of it. The characteristics of the flowers are no more than 5 cm wide, with a yellowish white color [11]. However, there are still other species of mangroves found on the coast of Cirebon.
Regency, namely *Avicennia* sp., *Bruguiera* sp., and *Rhizophora* sp. [11]. These three mangrove species also have great potential to grow in Mundu District.

Figure 2 shows the NDVI derived from Sentinel-2 satellite. The NDVI index in the study area was in the range of -0.4 to 0.6. The NDVI < 0 classified as non-vegetation such as water body, bared soil, the roof of the housing in a city, concrete (buildings), asphalt (streets) etc., while the distribution values of NDVI in mangrove areas of Mundu District was in the range of 0.3–0.6, which indicated that the mangrove in the study sites could be classified as dense vegetation. The NDVI values have a relationship with mangrove health. The higher the index value, the better the vegetation condition or the healthiest of the mangroves. Healthy vegetation absorbs the lightest spectrum in the blue band and red to near infrared bands [27].

The vegetation index value obtained from the NDVI equation is closely related to the fAPAR (Absorbed Photosynthetically Active Radiation fraction) or photosynthesis [28]. NDVI values were also highly correlated with LAI and sensitive to chlorophyll content [29, 30]. Therefore, when referring to the map of the mangrove health index in Figure 2, mangroves in the study area tend to have dense vegetation around the coast marked with a darker green color, which means that the vegetation cover is healthy [31, 32].

![Figure 2. Map of NDVI derived from Sentinel-2 satellite that is showing mangrove health index in Mundu District.](image)

### 3.2. Characteristic of oceanographic parameters

Based on the results of visualization of interpolated data from the ESA Copernicus (Figure 3), the acidity (pH) level of coastal waters in Mundu District was in the range of 7.96–8.03. The pH value in
this area is relatively standard and indicates that the biological activity and oxygen content are regular. A pH value that is too high or too low will affect the growth and development of mangroves. The mangrove vegetation health index results show that the mangroves in the study area are reasonably good. The pH value can affect the health of mangroves. If the pH were too high (pH > 8) or too low (pH < 7) (see Table 1), the Mangroves will have difficulty in tolerating it and potentially disturb the growth of the mangroves. However, *Avicenna* sp. has resistance at high pH values [7].

The interpolation of salinity data obtained from the ESA Copernicus (Figure 4) shows that the salinity level in the coastal waters of Mundu Regency ranges from 32.24 to 33.05 PSU. Salinity is a significant environmental parameter that significantly determines the growth of mangroves and affects the composition of mangroves. The environmental conditions that significantly affect the salinity of mangroves are river flows and silt deposits along the coast. The ideal salinity range for mangroves is from 10 to 34 PSU [33]. The right salinity level is essential for the growth of the mangrove so that they can reach their maximum height [34]. The increase in salinity in the environment makes mangroves have to adapt to their environment. Many mangrove species survive by filtering out 90 percent of the salt found in seawater as it enters their roots [34].

The current velocity (Figure 5) in the coastal waters of Mundu District ranges from 0.015 m/s to 0.017 m/s. The high current velocity in this area is influenced by river currents that cause the variability in salinity and pH in the mangrove area. Figure 6 shows that the average tidal height in Mundu Regency in June 2020 is 1.22 m calculated from the Mean Sea Level (MSL). While the highest tide was 1.93 m and the lowest during the ebb was 0.72 m. These parameters also significantly affect the growth and development of mangroves due to the variation of salinity levels in mangrove living areas.

**Figure 3.** Monthly pH interpolation of Mundu District.
Figure 4. Monthly salinity interpolation of Mundu District.

Figure 5. Monthly currents interpolation of Mundu District.
3.3. Land suitability for mangrove conservation areas

The Mangrove Ecosystem Area in the Mundu Region, Cirebon Regency, actually has two species, including natural and artificial mangroves, namely *Rhizophora mucronata* and *Avicennia marina* [7]. The Mundu Mangrove area has an area of 1,383 Ha with an NDVI value in the ranges of 0.3–0.6, categorized as dense mangrove (Figure 2) or mangrove in healthy condition [21]. Based on Table 1,

![Figure 6. Monthly tides interpolation of Mundu District (June 2020).](image)

![Figure 7. Map of suitability mangrove conservation area in Mundu District.](image)
there are 2 species mangroves, then the suitability score for Mundu District is 20, while NDVI is in the range of 0.3 to 0.6, thus the suitability score is 60. However, it is ideal in mangrove conservation if the number of mangrove species reaches 3-4 species or even > 4 species.

Based on the results of land suitability classification derived from interpolated physical oceanographic parameter data such as the tidal type and current speed in the Mundu District that categorized as mixed semi-diurnal with an average tidal height of 1.22 m and current speed tend to be 0.11–0.21 m/s, and reaching 0.03–0.09 m/s during the east monsoon period in August, make the suitability scores for these two physical parameters of 20 and 30, respectively (Table 1). The chemical parameters also have a considerable influence in determining the mangrove conservation area in Mundu District. The salinity and pH influence the growth of each species of mangrove and the zoning system. The pH in the study site was around 8, while the salinity was in the range of 29-33 PSU. Thus, according to Table 1, the suitability scores for each pH and salinity chemical parameter were 20 and 20, respectively. The substrate type of mangrove in the Mundu District is classified as muddy. So, the suitable score for this substrate type was 30. Thus, the total suitability values for overall 7 parameter items listed in Table 1 were 200 (20+60+20+30+20+20+30). This indicated that the suitability rank for mangrove conservation areas could be classified as suitable (nearly very suitable) with a total score in the ranges of 101-200.

Figure 7 shows the suitability map of the mangrove conservation area in Mundu District developed by analyzing the 7 parameter items of Table 1. Thus, the coastal of Mundu District is suitable areas for establishing mangrove conservation, although this area is poor in species diversity. In addition, these areas also support the planted mangrove along the coast of the study sites.

4. Conclusion
This study was conducted in Mundu District to determine the suitability of mangrove conservation areas using GIS and Remote Sensing methods. The results showed that the mangroves found in the Mundu only consist of 2 species with a vegetation index ranging from 0.3 to 0.6, which means the mangroves are healthy. The substrate in this area tends to have a muddy sand substrate with a pH value of 8 and an average salinity value of 32 PSU. The tidal type in the Mundu region has mixed semi-diurnal characteristics with an average tidal height of 1.22 m. The level of suitability for mangrove conservation tends to be at a score of S2 (2), with the level of land suitability in this area tending to match the total score of 101-200. Based on NDVI, several oceanographic parameters, and environmental conditions such as the substrate used to assess the suitability of the Mundu sub-district, shows that the area is suitable for mangrove conservation areas. Thus, the coastal area of Mundu can support the growth of well-planted mangroves, but a sound monitoring system for the mangroves is needed.

Acknowledgments
The author would like to thank Marine Science Major, Faculty of Fisheries and Marine Science, Padjadjaran University, all Departemen KOMITMEN Research Group members, and families who have facilitated and supported the authors during the making of this scientific paper. The authors also thank the reviewers and all ICMS ITK IPB committees. Also, they would like to thank the Europe Space Agency Copernicus and ERDDAP as secondary data providers in this research.

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