The use of sentinel 2A imageries to improve mangrove
inventarization at coremap CTI monitoring areas

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Abstract. In 2014, the project preparation for Coral Reef Management (Coremap) CTI claim that mangrove at Selayar was approximately 676.7 hectares distributed at 15 villages. Tambolongan at Bontosikuyu district was the largest area of about 132 hectares. These values extracted using Landsat imageries based on visual and composite image classification. Since Sentinel 2A launched in 2015, the use of this satellite imagery has spread widely in ecosystem monitoring due to its higher spatial, spectral and temporal resolution and mostly because it is free to access. Nevertheless, field sampling is still needed to crosscheck the final result. Since 2015 three mangrove locations at Selayar island monitored annually. By 2018, two new locations at Pasi island added. In 2019 three sites added at two different islands, so now a total nine mangrove station covering the whole Selayar islands. Nine species of mangroves were found by the end of 2019 monitoring, which are Avicennia alba, A. officinalis, A. marina, Bruguiera gymnorrhiza, Rhizophora apiculata, R. mucronata, R. stylosa, Cerios tagal, and Sonneratia alba. Spectral image characterization by using 12 bands of Sentinel 2A shows that most of these mangroves had peak reflectances at 783 and 865 nanometer, and the highest reflectance are lower than 0.45. These findings may contribute to better spatial identifications for mangrove monitoring and also the consequences to the revision of previous information extracted from Landsat imageries.

1. Introduction

Mangroves in Selayar Regency, South Sulawesi Province can be found on several islands, namely in Selayar Island, Pasi Island, Tambolongan Island, Jampea Island, and Bonerate Island. Apart from Selayar and Pasi Island, the mangrove locations are very remote where transportation access is very rare, and the accommodation facilities are very limited. These cause field surveys for mangrove monitoring are relatively more expensive and need extra time to do. Satellite remote sensing technology then becomes the best solution to solve problems like these [1]. Land satellite imagery has been freely available in cyberspace for almost the last two decades before Sentinel 2 launched in 2015 and add more options for remote sensing applications. At least there are two advantages by using Sentinel 2 compared to Landsat. The first is its spatial resolution, which about 10 meters (3 times more detail) and, secondly, its temporal resolution. Sentinel 2 has 5 days temporal resolution compared to Landsat that has 16 days. These advantages may support monitoring activities that often require a lot of image data series in a long time of observation [2,3].

The use of Landsat imagery for mangrove monitoring in Malaysia has been practicing for more than 25 years [3]. Visual interpretation is usually involved in mangrove identification by using satellite imagery. The interpretation is performed on a pseudo-color image composing of three
primary colors from Landsat bands that can optimize the spectral reflection of mangroves. Landsat imagery had succeeded in distinguishing Rhizophora and Avicennia-Sonneratia mangrove forests in Malaysia [4]. The higher spectral resolution of the satellite image may result in better mangrove identification [5].

Selayar district has total area 10,503.7 square kilometers (km) consists of land area about 1,357 square km and sea waters 9,146.7 square km [6]. A study conducted by Hasanuddin University in 2014 in preparation for the Coral Reef Management Project reported that Selayar has mangroves area around 676.7 hectares and located in 15 villages [7].

Since started in 2015, mangrove monitoring by Coremap-CTI has only been carried out on Selayar island at three locations: Patumbukang, Tongke-tongke, and Matalalang. In 2018 three more stations had added, which was one station at Selayar island and two stations at Pasi island. In 2019 three more stations were added, that was one in Tambolongan island and two in Jampea island. Therefore among six islands that have mangrove ecosystems, four of them have been validated.

This study aims to revise the location and extent of mangroves previously mentioned in PPG (Project Preparation Grant) Coremap CTI report, based on 2019 field monitoring and Sentinel 2A satellite imagery mapping. This study may contribute to the future as a baseline for mangrove change detection in the Selayar islands.

2. Materials and Methods

Mangrove ecosystem monitoring in 2019 has been carried out from 22 to 30 June for locations on Selayar, Pasi, and Tambolongan Island. The Jampea Island was visited on 10-12 October 2019. The location of mangrove monitoring stations is presented in detail in Table 1 and Figure 3.

| Islands      | Villages       | Sta.ID    | Longitude | Latitude |
|--------------|----------------|-----------|-----------|----------|
| Selayar      | Bontobangun    | SLYM01    | 120.450   | -6.143   |
|              | Lowa           | SLYM02    | 120.471   | -6.393   |
|              | Latimbongan    | SLYM03    | 120.493   | -6.399   |
|              | Bontosunggu    | SLYM04    | 120.437   | -6.167   |
| Pasi         | Gusung Lengu   | SLYM05    | 120.422   | -6.120   |
|              | Bonto Lebang    | SLYM06    | 120.424   | -6.114   |
| Tambolongan  | Batupalangka   | SLYM07    | 120.432   | -6.634   |
| Jampea       | Bontosaile     | SLYM08    | 120.643   | -7.010   |
|              | Tanamalala     | SLYM09    | 120.569   | -7.078   |

2.1. Mangrove data collecting and processing

There were nine observation stations, where each station had three plots so that mangrove data collection plots in total are 27. At each observation station, the transect lines are made perpendicular to the coastline from the sea to land along the mangrove zone. Each plot measured 10 m x 10 m area and was made permanent by installing markings in the form of spray paint and rope. The Global Positioning System (GPS) was used to determine the starting and ending position of the transect line. The detail of the plot location was determined by using a compass and a laser distance meter. Each mangrove with a stem circumference of at least 16 cm was measured at the height of the observer's chest (about 1.3 meters) using a measuring tape. Mangrove species were identified based on the type of roots, leaves, flowers, and fruit [8]. The number of trees in each plot was counting to get a density value. The calculation of canopy cover was using the hemispherical photography method [9].

2.2. Collecting and processing sentinel 2A images

Sentinel 2A satellite imagery downloaded from the site https://earthexplorer.usgs.gov/ according to the closest date of the sampling activity, July to August 2019. Six Sentinel 2A imagery tiles had
downloaded, and for the Jampea Island area, several tiles were adding to avoid cloud cover at the mangrove site. The list of Sentinel images, tile numbers, and band specifications [10] use in this study are presented in Table 2 and Table 3.

| Tiles Code | Date of Image | Islands Covered |
|------------|---------------|-----------------|
| 50MRU      | 2019.07.06    | Pasi, Selayar    |
| 50MRT      | 2019.07.26    | Tambolongan     |
| 50MRT      | 2019.08.20    | Jampea          |
| 51MTN      | 2019.08.20    | Jampea          |
| 51MRT      | 2019.08.20    | Jampea          |
| 51MTM      | 2019.06.01    | Karalo, Bonerate, |
| 51MUM      | 2019.08.20    | Karumpa, Kalaotoa, Pulomadu |

Table 3. The specification of Sentinel 2A bands.

| Sentinel 2A Bands                  | Central Wavelength (nm) | Spatial Resolution (m) |
|------------------------------------|-------------------------|------------------------|
| Band 1 – Coastal aerosol           | 443                     | 60                     |
| Band 2 – Blue                      | 490                     | 10                     |
| Band 3 – Green                     | 560                     | 10                     |
| Band 4 – Red                       | 665                     | 10                     |
| Band 5 – Vegetation Red Edge (VRE) | 705                     | 20                     |
| Band 6 – Vegetation Red            | 740                     | 20                     |
| Band 7 – Vegetation Red Edge       | 783                     | 20                     |
| Band 8 – Near Infra Red (NIR)      | 842                     | 10                     |
| Band 8A – Vegetation Red Edge      | 865                     | 20                     |
| Band 11 – SWIR                     | 1,610                   | 20                     |

The sentinel's bundle file saved in the SAFE folder consists of the raw band file and its metadata. This bundle file then imported using the IDRISI Terrset software, which able to convert raw image values into surface reflectance values through the choice of dark object subtraction (DOS) method [11,12]. Processing multi-temporal satellite imagery requires atmospheric correction procedures that are reliable and incomparable units such as surface reflectance [13]. The Red, Green and Blue (RGB) band composite then composed based on three bands, the band that works on NIR (near-infrared) or VRE (vegetation red-edge), SWIR (short-wave infrared), and Red band. Furthermore, the OIF (Optimum Index Factor) Calculation performed to determine the three best composite image composing bands, according to the following formula [14]:

$$OIF = \frac{\sum_{i=1}^{3} SD_i}{\sum_{j=1}^{3} ABS(CC_j)}$$ (1)

SDi = standard deviation of band i.
ABS (CCj) = absolute value of 3 band correlation coefficient.

The best OIF value can display the color of the best mangrove vegetation so that it becomes easier to recognize from the surrounding land cover. The separation of land and water areas did by a reclassification of the infrared band reflectance.

The next step in image processing is the classification of land cover described schematically in Figure 1. Pixel samples from several types of land cover were extracted from composite images to obtain spectral statistics. Types of land cover extracted in this study are mangroves, non-mangrove
vegetation, bare land, shallow water, and deep water. The name of the land cover determined to its color in the composite image and its spectral signatures [15]. Object spectral statistics used as input for the classification process using the Maximum Likelihood method.

![Figure 1](image-url)

Figure 1. The image classification steps to extract mangrove areas: (a) object pixel training polygons, (b) object spectral signatures, (c) image classified by maximum likelihood, (d) converting mangrove to vector polygons.

The Maximum Likelihood classification is based on the probability density function associated with a particular training site signature. Pixels are assigned to the most likely class based on a comparison of the posterior probability that it belongs to each of the signatures being considered. Maximum Likelihood classification works very well when the training sites are well defined [16]. The result from the image classification process was a raster data that need to convert into vector. This vector then collected to the spatial administration database using QGIS 3.4 Madeira. The spatial analysis then performed to get the area and administration of mangrove on the whole of the study area.

3. Results
3.1. Mangrove species distribution
There were ten species of mangroves found at Coremap CTI monitoring stations in 2019. Every station has a different mangrove species composition, and no single species found for all locations (see Table 4). Matalalang station had the highest number of species though the frequency of species presence was relatively low. The total number of mangrove species on every single location was high, but many of them were found outside of the observed plot. Mangrove diversity influenced by anthropogenic and natural factors. Indeed, the bottom sediment substrate may also affect mangrove diversities. Rhizophora spp are the most common species found at monitoring stations while Avicennia spp were the rarest to found. The species diversity was lower in the insular area (stations 05 to 09) than in the mainland (stations 01 to 04).

| No | Mangrove species      | Abbre     | Stations Name: SLYM- |
|----|-----------------------|-----------|----------------------|
|    |                       | viation   | 01 02 03 04 05 06 07 08 09 |
| 1  | *Rhizophora mucronata* | Rm        | p  p  p  p  p  p  p |
| 2  | *R. apiculata*        | Ra        | p  p  p  p  p  p  p |
| 3  | *R. stylosa*          | Rs        | o  o  o  p  o  o  p  |
| 4  | *Avicennia alba*      | Aa        | p  p  p  p  p  p  p  |
| 5  | *A. marina*           | Am        | p  p  p  p  p  p  p  |
| 6  | *A. officinalis*      | Ao        | p  p  p  p  p  p  p  |
| 7  | *Bruguiera gymnorrhiza* | Bg     | p  p  p  p  p  o  o  o  |
| 8  | *Ceriops tagal*       | Ct        | p  p  p  o  o  o  o  |
| 9  | *Sonneratia alba*    | Sa        | o  o  o  o  o  o  o  |
| 10 | *S. ovata*            | So        | o  o  o  o  o  o  o  |
|    | **Σ species**         |           | 7  5  4  4  3  5  3  4  4 |

Table 4. Mangrove species found at monitoring sites (p=inside plots, o=outside plots).
3.2. Canopy Coverage

The lowest mangrove canopy cover was found at SLYM 04 (Bontosunggu), with an average 35.2 ± 7.2%. The highest canopy cover was found at Bonto Lebang (SLYM 06), with an average 82.4 ± 0.3% (Figure 2), proving that this conservation area is still maintained. Referring to the Decree of the Minister of Environment No. 201/2004, the mangrove condition at all monitoring stations in Selayar Islands are relatively in good condition with dense canopy cover more than 75%. Rarest canopy cover was only found at station SLYM04 in Bontosunggu. This plot located at the north end of the Aeropala airport runway and according to the local community, the mangrove grows naturally on the land that was previously a salt pond.

![Figure 2. Canopy Coverages at monitoring sites.](image)

3.3. The best image composite by OIF

The results of VRE/NIR, SWIR, and Red band combination are shown in Table 5. The highest OIF (Optimum Index Factor) value is 0.246 obtained by combining bands 8a, 11, and 3. The lowest OIF value is 0.127 as a result of the combination of bands 7, 11, and 5. Considering the spatial resolution of band 8 higher than band 8a, we then chose composite bands 8, 11, and 4 with an OIF value of 0.220 to analyze.

| Band Combination | \( \Sigma \) Standard Deviation | \( \Sigma \) correlation coefficient | OIF rank |
|------------------|------------------------------|-----------------------------------|---------|
| 8a 11 3          | 0.252                        | 1.022                             | 0.246   |
| 8a 11 4          | 0.258                        | 1.066                             | 0.243   |
| 8 11 3           | 0.233                        | 1.050                             | 0.222   |
| **8 11 4**       | **0.240**                    | **1.091**                         | **0.220**|
| 7 11 4           | 0.238                        | 1.111                             | 0.214   |
| 7 11 3           | 0.231                        | 1.093                             | 0.211   |
| 8a 5 4           | 0.235                        | 1.409                             | 0.167   |
| 8 5 4            | 0.216                        | 1.476                             | 0.147   |
| 8a 11 5          | 0.264                        | 1.873                             | 0.141   |
| 7 5 4            | 0.214                        | 1.523                             | 0.140   |
| 8 11 5           | 0.245                        | 1.886                             | 0.130   |
| 7 11 5           | 0.243                        | 1.911                             | 0.127   |
3.4. Spectral signatures
The spectral response of mangrove species was digitally extracted from mangrove pixels at ten Sentinel bands and presented in Figure 3. The reflectance of mangroves starts to rise sharply at wavelengths of 705 nm to 740 nm (nanometers), then slightly sloped to reach 783 wavelengths nm and decreases to 842 nm. The mangrove reflectance then rises again until it reaches the highest value at a wavelength of 865 nm and decreases steeply at a wavelength of 1610 nm. There are two reflectance peaks, namely at wavelengths of 783 and 865 nm. The highest reflectance was 0.20 to 0.38 at a wavelength of 865 nm, and the lowest was 0.021 to 0.028 at 443 nm.

Rhizophora spp had a peak reflectance 0.21 to 0.38 at 865 nm while Avicennia spp, Bruguiera spp, and Sonneratia spp have 0.29 to 0.35. Rhizophora was indicating to have the highest reflectance than other mangrove species in this study.

![Figure 3. Spectral response of Rhizophora spp (left) and non-Rhizophora spp (right). Species names are abbreviated, while its estimated canopy cover shown as numeric after the initial.](image-url)

3.5. The mangrove area
The Mangrove distribution of Selayar Archipelago as a result of Sentinel images analysis is showing in Figure 4. Mangroves found at nine islands, namely Selayar, Pasi, Tambolongan, Jampea, Kalao, Bonerate, Karumpa, Kalaotoa, and Pulomadu islands. The total area of mangroves is estimated at 695 hectares and covers over 23 villages. The largest area of mangrove forest located in one village found at Tambolongan Island, with an area of 105.2 hectares.

Jampea Island has the largest area of mangrove forest, which is 230.6 hectares and located at eleven villages. Bontomalling is the village with the largest mangrove area on the island, which is 68.9 hectares, and Labuang Pamajang is the village with the smallest area of 2.4 hectares.

Mangroves on Selayar Island can be found at southern part, namely at Lowa, Latimbongan, Binanga Sombaya. At the central west coast side of the island, the mangrove grew at Bontosunggu and Bontobangun. The total area of mangroves at Selayar Island is about 197.5 hectares. Bontosunggu is a village with the largest area of mangrove in Selayar Island which around 78.6 hectares.

Mangrove on Pasi Island can be found at southern part, namely at Lowa, Latimbongan, Binanga Sombaya. At the central west coast side of the island, the mangrove grew at Bontosunggu and Bontobangun. The total area of mangroves at Selayar Island is about 197.5 hectares. Bontosunggu is a village with the largest area of mangrove in Selayar Island which around 78.6 hectares.

Mangrove on Pasi Island is part of a conservation area that was previously managed by the district government but has now been taken over by the provincial government. The area of mangrove in this area is around 60.6 hectares, and is a part of Bontolebang village.

Mangroves at Kalao island can be found at Lambego and Komba-komba. At Bonerate island was found at Bonerate, Majapahit, and Batubingkung. Mangroves can also find at the eastern end of the Selayar archipelago in the villages of Karumpa, Pulomadu, and Lembang matene.
Figure 4. The distribution of mangroves at Selayar based on its village administration. The values in parentheses indicate the area of mangrove in hectares.
4. Discussion

Mangrove ecosystem monitoring is a sub-activity of coral reefs and related ecosystems monitoring as a focus of Coremap CTI (Coral Reef Rehabilitation and Management Program–Coral Triangle Initiative) program. During 2015 to 2019 Coremap CTI program was projected to strengthen the institutional capacity for conservation and management of the coral reef and related ecosystems [7]. As an integral part of the coral reef and seagrass ecosystems, mangroves also contribute to environmental services and biodiversity providers. Mangroves known have a significant role in the life cycle of many marine biotas, such as shrimp, crabs, and fish, and also protect the coast from marine waves and tsunamis. However, along with the high level of human activity in coastal areas, pressure on mangrove ecosystems is also unavoidable.

PPG report stated that area mangrove in Selayar was approximately 676.7 Hectares [7], this study confirms that the actual total area of mangrove is about 677.1 Hectares. This study also confirms that the villages with mangroves are 23 (previously declared 15). The largest area of mangrove exist in one village is at Tambolongan, which is 105 hectares (previously declared 132 hectares). Currently, Jampea island is the largest mangrove area at this archipelago, and Selayar is the second. Selayar probably was the largest mangroves island in the past, but along with the growing population, there has been much pressure on this region, such as mangrove conversion into fishponds, settlements, urban development, and other needs.

Some limitations related to the values stated above are that the spatial resolution of the Sentinel 2A images is limit to 10 meters so that the uncertainty of the area value is still at least in the range of 100 square meters. A higher spatial resolution of satellite imagery is needed to improve accuracy [17,18]. Drone technology to mapping the mangrove is the most promising alternatives to get a more reliable mangrove area calculation. The advantage of using Sentinel 2A that its image available more frequently compare to Landsat, and it makes image substitution are possible to do whenever the clouds cover the area of a study. Also, Sentinel 2 has a more spectral band to pick than Landsat, and it has more band in the vegetation red edge spectrum for mapping vegetation. Nevertheless, Landsat 8 imagery combining with Google Earth Engine algorithm can be used to estimate area changes of mangrove with adequate accuracy [19].

The maximum likelihood method used in the Sentinel 2A image classification in this study works on pixels based. Currently, many object-based classification methods available, which can provide a higher level of thematic accuracy, but for a practical point of view, the maximum likelihood method is still an adequate choice. Alternatively, the object-based image analysis method may be used to compare to the traditional classification pixel-based method. Other methods such as sub-pixel, knowledge-based, contextual-based, object-based image analysis, hybrid, and support vector machines are common to implement in image classification [20,21].

The mangrove spectral signature can be used as a basis for species characterization so that it is useful in mapping mangroves to species level. The spectral signature can also contribute to higher thematic accuracy on image classification [22]. However, mangroves reflectances at various wavelengths are influenced by some factors such as atmospheric conditions at the time the satellite passes, solar elevation, leaf shape, and so on [15]. So, a more comprehensive study is still needed until the mapping of mangrove types using Sentinel imagery in Selayar can be carried out.

5. Conclusion

Satellite image analysis and field monitoring survey in 2019 proves that the Selayar archipelago currently has a mangrove area of about 677.1 Hectares. The mangrove existed at nine islands with Jampea island is the largest. The common mangrove found on the field was Rhizophora spp. The combination of band 8, 11, and 4 of Sentinel 2A are adequate to do multispectral analysis and pixel-based image classification in mangrove mapping. Even though the spectral response of mangrove species was recognized in this study but the advance method is still needed to do mangrove species mapping by using Sentinel 2A.
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