Mangrove condition at Selayar Island based on field data and NDVI

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Abstract. Mangrove monitoring in Selayar is part of Reef Health Monitoring which starts from 2015 to 2019 as a result of collaboration between Coremap CTI and Hasanuddin University. The results of satellite image analysis show that the estimated mangrove area in Selayar is 695 hectares, spatially distributed over 9 islands and 24 villages. This study aims to map the condition of mangroves in Selayar and Pasi Island based on canopy cover and NDVI. There were six mangrove locations visited on the field, four locations at Selayar Island, and two locations at Pasi Island. Each station was divided into three observation plots where positions are determined as detail as possible using GNSS, laser distance meter, and compass. There were 18 observed plots. The canopy cover was measure using the hemispherical photo method. Sentinel 2A satellite image was use to mapping NDVI and mangrove condition based on its canopy cover. The correlation between canopy cover and NDVI was 0.96. The coefficient of determination of the regression was 91.3%, and the RMSE value was 5.3%. Referring to KLH standards, mangroves in Selayar and Pasi Island classified as dense, moderate and sparse was 34%, 39%, and 27% respectively of the total 274 hectares. Mangroves in damaged condition are about 75 hectares scattered on Selayar Island. These results are expected to become a benchmark to monitor mangrove conditions in the Selayar Islands and its vicinity.

1. Introduction
Mangrove usually develop in certain coastal areas where the slope of the coast is quite gentle and the tide is quite high [1,2]. Optimal mangrove development can only occur in sheltered habitats, and on open beaches, mangroves are generally found in areas that are protected from the coming wind. Mangroves usually grow in fine-grained sediment, but can also grow on other types of substrates such as sand and rock. The sediment that has accumulated in the mangrove swamp can be categorized into two types, namely sediment collected from outside the swamp both from land and sea and sediment collected insitu, namely from the mangroves themselves.

Mangroves have a fairly extensive capacity for environmental services, such as land formation [3], reduce chromium metal pollution [4] and play a role in determining bird species composition [5]. The low level of predation and the high availability of food sources have made mangrove swamps an ideal nursery for juvenile fish and decapods [6,7]. Although mangrove forests only occupy a small part of the coastal area, they contribute greatly to storing carbon into sediments, thereby helping to reduce greenhouse gas emissions [8].

Selayar Island is classified into the karst hills and structural hills of Sulawesi [9]. The Sulawesi karst hill ecoregion is characterized by porous limestone and easily absorbs water which is then channeled into underground rivers. The karst ecoregion is physically characterized by relatively hot air, the soil
surface appears dry and arid, and the terrarosa soil type which is relatively poor in nutrients. Commonly visible land uses are rainfed fields, scrub, and some forest. The ecoregion of Sulawesi’s structural hills is formed by tectonic processes and is composed of sedimentary and igneous rocks. Soils on structural hills usually have low to medium fertility with land cover in the form of forests, shrubs, grasslands, fields and settlements.

Mangroves on Selayar Island are scattered in several places on the west and east coasts of Bontosikuyu District, namely in the villages of Lowa, Latimbongan and Binanga Sombaya. In Bontoharu District, mangroves can be found on the west coast of Bontosunggu and Bontobangun Villages. Meanwhile, on Pasi Island, a large mangrove area can be found in the east of Bontolebang Village. Based on Sentinel 2A image analysis, total area of mangrove at Selayar Island is about 215 hectares and on Pasi Island is estimated about 60 hectares [10]. Apart from Pasi Island, the mangrove area is currently vulnerable to land conversion, such as expansion of fishpond areas. This situation emerges the need for time-series monitoring for Selayar mangroves. The multispectral satellite remote sensing technology is the best choice for it.

Remote sensing multispectral images usually uses a number of combinations of visible or infrared light bands to create a composite image as a basis for object analysis [11]. Jordan was the first who compare the radiance of near infrared and red wave lengths to estimate biomass from forest canopy before the satellite era [12]. This method was then developed [13] during the Landsat-1 satellite using the radiance of band 5 and 7 from the MSS (Multi Spectral Scanner) sensor. The radiance differences of those two bands are normalized by the sum so that a vegetation index obtained and used to measure vegetation conditions. According to [14] a linear combination of red and infrared radiance can be used to monitor photosynthetically active biomass from a plant canopy. Nowadays, NDVI (Normalized Difference Vegetation Index) has become an effective index for assessing vegetation. NDVI has been used for many applications including estimating plant canopy cover [15], canopy cover and plant fraction [16], changes in area of vegetation affected by hurricanes [17,18], biomass estimation of agricultural commodity yields [19], biomass estimation of mangroves [20], plant health studies [21] and many other studies.

These study aims are to map the condition of mangroves in Selayar Island and Pasi Island by utilizing multispectral satellite imagery using vegetation index and canopy cover. The results of this study may contribute to sustainable spatial monitoring of mangrove condition at Selayar and its vicinity.

2. Materials and Methods

This study uses field data from the 2019 Coremap-CTI RHM (Reef Health Monitoring) survey. Observations of mangrove canopy cover were carried out at Pasi and Selayar Island on 26 to 30 June 2019. There have been four observation stations at Selayar island which are at Bontobangun namely, Lowa, Latimbongan and Bontosunggu villages. Two more stations have been observed at Pasi island which are at Bontolebang and Gusunglengu villages. Each station divided into three plots hence there have been 18 plots in total. The location of the station and the observation plot of mangrove canopy cover are shown in Figure 1.
The equipment used during the sampling were a map and a list of the coordinates of the sampling station, handheld GNSS (Global Navigation Satellite System) receiver type 64s with the ability to receive GPS and Glonass data, measuring tape, rope, roll meter, spray paint, camera, mangrove observation form, identification book, plastic sample, compass, laser distance meter (80 m range), stationery and personal protective equipment. Four-wheeled vehicles have been used for mobilization on land and boats for mobilization on the coast. The number of personnel involved in the survey was 4-5 people with tasks that have been detailed before going to the field. The software used were Idrisi Terrset 18.3, QGIS 3.4, DNRGPS 6.1, Mapsource, ImageJ and others.

2.1. Plot positioning and insitu canopy cover

The sampling plot positioning has been set by observing handheld GNSS, combined with distance and angle measurements. Initial station coordinates that have been input into GNSS were backtracked on-field by utilizing the navigation function. The tracking function was activated continuously during survey so that all personnel movements from and at the sampling location can be continuously recorded.

The process of determining the position was as follows: first the surveyor tracked the station coordinate using GNSS receiver. When he reached the sampling location, the first corner of each plot may mark as long as the GNSS signal was good (minimal error). otherwise, the marking position was set out at a specific point closest to the first plot. The next first corner of the plot may determine using the open polygon method using a compass and laser distance meter. This positioning method was described graphically in Figure 2. The coordinates of first corner of plots 1, 2 and 3 can be calculated using the following formula:

Point A, \( X_A = X_{\text{GNSS}}, Y_A = Y_{\text{GNSS}} \)
Point B, \( X_B = X_A + d_1 \sin \alpha, Y_B = Y_A + d_1 \cos \alpha \)
Point C, \( X_C = X_B + d_2 \sin \alpha, Y_C = Y_B + d_2 \cos \alpha \)
Point D, \( X_D = X_C + d_3 \sin \alpha, Y_D = Y_C + d_3 \cos \alpha \)
Figure 2. Determining first corner of plot by using GNSS marking as a basis of triangulation.

The plots have a size of 10 m x 10 m square and at each starting tree of the plot was marked using color paint. The surveyed plot areas are then fenced with raffia ropes. All individual mangroves in the plot were identified and classified as trees and saplings. Identification of mangrove species in the plot was carried out by observing the types of leaves, roots, fruits, and flowers [22]. Canopy cover has been measured indirectly by utilizing photographic techniques. For this purpose, each plot was hypothetically divided into four quadrants where in each quadrant a canopy cover photo was taken. When shooting, the camera was placed at chest level and the lens was pointed towards the zenith. The photos should be taken between the trees and taking photos next to the trees should be avoided [23].

The mangrove canopy cover photo was then converted from full color to black and white at an 8-bit level. In this case the sky pixel will be very different from the mangrove canopy pixel so that the pixel percentage can be calculated. The canopy cover for each plot can be estimated as an average of four photos. This value has been used as a reference to categorise the condition of mangrove forest. There are three categories, namely dense, medium and sparse, good and damaged (Table 1), referring to the Minister of Environment Decree No. 201 of 2014 [24].

| Condition / Criteria | Canopy cover (%) |
|-----------------------|------------------|
| good                  | dense            | ≥ 75             |
|                       | moderate         | 50 - 75          |
| damage                | sparse           | < 50             |

2.2. Image processing

This study was use Sentinel 2A imagery date recorded on July 6, 2019. The difference of days between field sampling and satellite recording was about 14 days and it was assumed that there are no significant changes at area of study. Satellite image was obtained from the site https://earthexplorer.usgs.gov/ at level 1C. At this level, the image still has pixel values in units of brightness values. The range of digital values corresponds to the radiometric capacity of the sensor, which was 12 bits, so that for each band there are variations in brightness values ranging from 0 to 4,095. Therefore, it is necessary to convert the digital pixel value to the reflectance value on the TOA using the ATMOSC module [25] and continue with the application of the DOS method [26] to obtain variations in the spectral response of objects that are closer to the conditions when recorded.

This study uses shapefile data in the form of mangrove polygons from the previous study [10] as a masking image to limit the mangrove area. The spectral and spatial specifications of the Multispectral Instrument (MSI) sensor from the Sentinel 2A satellite can be detailed as follows [27]:

- four bands with a spatial resolution of 10 meters are band 2 (490 nm), band 3 (560 nm), band 4 (665 nm) and band 8 (842 nm)
- six bands with a spatial resolution of 20 meters are band 5 (705 nm), band 6 (740 nm), band 7 (783 nm), band 8B (865 nm), band 11 (1610 nm) and band 12 (2190 nm)
- three bands with a spatial resolution of 60 meters, namely band 1 (443 nm), band 9 (945 nm) and band 10 (1375 nm)

2.3. NDVI and mangrove canopy cover estimation
Prior to estimate canopy cover we use normalized difference vegetation index (NDVI) that has been use widely to mapping vegetation using satellite imagery. The NDVI formula is [13,16,28,29]:

$$NDVI = \frac{N - R}{N + R}$$

Where R is Sentinel 2A image from red band (band 4=665 nm) and N is image from near infrared band (band 8=842 nm).

An estimate canopy cover function then determined by a regression between insitu canopy cover and NDVI extracted from satellite pixel correspondence sampling plot. We use a linear regression formula:

$$\hat{cc} = a + b \cdot (NDVI)$$

Where $\hat{cc}$ is an estimated canopy cover as an independent variable and NDVI as a dependent. The a and b are intercept and slope coefficient that calculated using least square methods. Actual cc (canopy cover) has been measured on the field hence for that reason the Root Mean Square Error (RMSE) may use to measure the quality of canopy cover estimation. The RMSE formula is write as:

$$RMSE = \sqrt{\frac{1}{n} \sum_{i=1}^{n} (\hat{cc} - cc)^2}$$

Where n is number of observation (in this case plot number), $\hat{cc}$ is estimated canopy cover and cc is insitu canopy cover measurement.

3. Results

3.1. Mangrove plot positioning uncertainty
The position differences between GNSS marking and insitu triangulation range between 0.5 m to up 6 meters on the ground. On average the differences position of both methods are about 3 meters for all of sampling stations. Station 4 was the lowest uncertainty of position among five other stations and station 1 was the highest (Figure 3).
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Figure 3. Average differences between GNSS and trilateration positioning of all stations.

GNSS signal reacts differently on each sampling plot (Figure 4). GNSS trackline records show that on dense mangrove the GNSS signals was more chaotic (i.e stasion 1, 2, 3, and 6) compare to low density at stasion 4. This GNSS signal disturbance impacts to positioning marking as well and hence contribute to higher position differences or uncertainty at dense mangrove. On the other hand, in mangrove areas where trees are sparse, the GPS signal can be received better, increasing the certainty of plot marking. Therefore, in this study, the plot positioning was combined using angles and distance observations starting at every first corner of the plot. It was hoped that this improvement can increase the certainty of the location of plot on the satellite image pixel so that it can increase the correlation between in situ canopy cover and NDVI derived by satellite image.

Figure 4. The plot of every first plot corner positions of GNSS marking and triangulation overlaid to image’s pixel (notes: \(
\bigcirc\) = position by trilateration, \(\blacklozenge\) = position by GNSS marking, — = GNSS tracks).

3.2. Mangrove Canopy Cover and NDVI

Insitu canopy cover has correlation 0.9554 to NDVI, and the regression of them results a determination coefficient 0.9128 (Figure 5). This regression equation then uses to estimated canopy cover by NDVI
image and produce RMSE = 5.3 %. Futhermore, the NDVI value on satellite image has been ranged to set the estimated canopy cover distribution and then categories into three classes: dense, moderate and sparse (Figure 6). The NDVI values of sparse canopy cover are range from 0.36 to 0.61, for moderate canopy cover are 0.61 to 0.74 dan dense canopy will take value higher than 0.74. These NDVI classification directly result on mangrove condition image and finally the distribution of mangrove condition map.

![Figure 5. Insitu canopy cover and NVDI regression (left). Comparison of insitu and estimated canopy cover based on regression equation (right)](image)

![Figure 6. Histogram of NDVI image, coloring is representing different canopy cover classes.](image)

3.3. **Spectral signatures and mangrove condition at Selayar Island**

Spectral respons of dense, moderate and sparse canopy cover of mangrove have been extracted from MSI multispectral band and shown at Figure 7. The spectral respons of mangrove canopy cover are low at visible spectrum and slowly increase between 665 to 705 nm. The response steeply increase at 740 until have a peak at 865 nm and then decrease at 1610 nm. The dense and moderate canopy cover significantly different from sparse canopy cover, more over moderate canopy cover have two significant peak which are at 783 nm and 865 nm.
Figure 7. The spectral signatures of mangrove at dense, moderate and rare canopy cover at Selayar and Pasi Island from Sentinel 2A MSI.

The spatial distribution of mangrove canopy cover and condition at Selayar and Pasi island from classified canopy cover image is shown in Figure 8. This figure indicate that Pasi island has better mangrove conditions compare to Selayar showed by more dense class pixel proportion on a single area. Mangroves at the middle West of Selayar island (stations 1 and 4) are commonly classified as sparse canopy cover or in damaged condition. The damage condition of mangrove at Selayar island is higher than Pasi island which is 33% compared to 8% (Table 2), while a good mangrove condition only 67% compared to 92% at Pasi island. Mangroves in good condition at Pasi and Selayar Islands were 55.7 and 143.6 hectares, respectively. The total area of mangroves for both islands estimated was 274 hectares.

Figure 8. The distribution map of dense, moderate and sparse canopy cover at Selayar and Pasi Island from Sentinel 2A MSI.
Table 2. The area of mangrove conditions in Selayar Island and Pasi Island is based on the NDVI value from Sentinel 2A imagery.

| Island | Estimated mangrove area (Hectares) | Condition | Canopy Cover Categories | Area (Hectares) | Percentage (per Island) |
|--------|-----------------------------------|-----------|-------------------------|-----------------|-------------------------|
| Pasi   | 60.4                              | good      | dense                   | 41.5            | 69%                     |
|        |                                   | damage    | moderate                | 14.2            | 24%                     |
|        |                                   | damage    | sparse                  | 4.7             | 8%                      |
|        |                                   | good      | dense                   | 51.5            | 24%                     |
|        |                                   | damage    | sparse                  | 4.7             | 8%                      |
| Selayar| 213.7                             | good      | moderate                | 92.1            | 43%                     |
|        |                                   | damage    | sparse                  | 70.2            | 33%                     |

4. Discussion

The coordinate determination of the sampling plot by using Global Navigation Satellite Systems (GNSS) is a crucial step in mangrove mapping, especially when the moderate or high image satellite resolution is chosen to analyze. In recent years, there is a lot of advanced technology embedded in a handheld global positioning device and the spatial accuracy performance is a lot better as well. Nowadays, with just using one handheld GNSS, it is common to receive not only GPS signal but also other GNSS such as Glonass or Beidou. Nevertheless, the spatial uncertainty for this handheld GNSS receiver is still limited to around 3 to 7 meters [30]. The horizontal absolute error may use as a good indicator to evaluate GNSS performance. Due to its high uncertainty, the handheld GNSS receiver is not recommended to georeferencing the field plot except where the accuracy assessment is not mandatory [31]. This study filling that limitation by combining GNSS with compass azimuth and distance measurement between plots. The results quite satisfied prove by higher determination coefficient between Insitu canopy cover and NDVI that being the focus of study. The results also show that horizontal positional uncertainty from these combined methods quite appropriate for the satellite image resolution used, in this case is ten meters.

The correlation coefficient between NDVI and canopy cover is 0.552, 0.698, and 0.718 for Landsat-TM, Landsat-MSS dan SPOT HRV XS respectively [15]. These sensors' spatial resolution is about 20, 30, and 80 meters. Another study [32] of NDVI based on Landsat 8 OLI has a significant correlation to canopy cover ($r = 0.7$) but low coefficient determination ($R^2 = 0.49$). NDVI based Sentinel 2A imagery has a correlation of 0.7739 to canopy cover coefficient determination 0.5989 [33]. This study achieves a good correlation coefficient between NDVI and canopy cover which is 0.9554. This value is also higher than some previous studies that using the same MSI sensor from Sentinel 2A or other satellite multispectral sensor. The coefficient of determination results was 0.9128 also significantly higher than some previous studies. An appropriate method of pixel georeferencing of Insitu canopy covers probably contributes a significant factor for those achievements.

Mangrove at Latimbongan was the oldest among the others, on average their heights were the highest as well (Figure 9c). Some of old trees reach up to 15 meters height. Three species have been identified on the plots which are *Rizophora mucronata*, *R. apiculata* and *Bruguiera gymnorrhiza* [10]. Four mangrove species have been identified at Bontosunggu which are *Rizophora mucronata*, *R. apiculata*, *Avicennia marina* and *Sonneratia alba*. This site is located at west side area of Aeropala runway, and dominated by young mangrove trees with their height on average are about 5 meters (Figure 9d). *Rizophora stylosa*, and *Sonneratia alba* were two species have been identified on plots at Gusung lengu stations, Pasi island. This is the location with the highest mangrove densities during sampling at 2019. Figure 9 presents the situation of all mangrove stations at Selayar dan Pasi islands during sampling in June 2019.
Declining mangrove on the mainland is a logical consequence of development activities at coastal area. The need for coastal space for various uses such as aquaculture areas, ports, and other economic activities will affect the existence of mangroves. The balance between various development activities and mangrove conservation needs to be maintained so that the mangrove resources in Selayar are sustainable. In this case, active participation from various parties and the community is needed. Mangrove resources need to be ecologically monitored regularly on a long term basis and accommodated in planning documents related to spatial and coastal areas at the Selayar archipelago.

5. Conclusion
Canopy cover can be used as a good predictor to estimate mangrove conditions through the use of NDVI imagery from sentinel 2A satellites. A high correlation of canopy cover and NDVI can be achieved by increasing the certainty of the sampling plot position using a combination of GNSS with angle and distance measurements. This study has proven that based on field surveys and satellite image analysis, in 2019 the mangrove conditions at Pasi Island were better than Selayar Island. However, in general, the condition of mangroves on both two islands is still in good condition. long-term active participation of the community and related parties is needed in an effort to preserve mangroves in the Selayar islands.

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