The Impact of Groundwater Variability on Mangrove Greenness in Karimunjawa National Park based on Remote Sensing Study

J Prihantono¹,², N S Adi¹, T Nakamura² and K Nadaoka²

¹Marine Research Centre, Ministry of Marine Affairs and Fisheries, Ancol, North Jakarta, Indonesia.
²Department of Transdisciplinary Science and Engineering, Tokyo Institute of Technology, Ookayama, Tokyo, Japan.

E-mail: prihantono@gmail.com

Abstract. This study aims to understand the impact of groundwater table on soil moisture and mangrove greenness in different seasons in Karimunjawa National Park (KNP). We used Sentinel-2 L2A satellite imagery, Global Precipitation Measurement (GPM) satellite rainfall data, and water table observations at KNP. This study estimates Normalized Difference Vegetation Index (NDVI) and Normalized Difference Water Index (NDWI) on time series Sentinel-2 imagery in 2019-2020 using Google Earth Engine. In addition, we compared the monthly average rainfall data, the monthly average water table data, and the monthly average NDVI, NDWI data extracted at the water table observation points. NDVI is a method to estimate mangrove greenness, and NDWI to estimate soil moisture. The obtained results indicate that NDVI and NDWI in the near shoreline area show a higher value than in the middle area of the KNP that is far from the shoreline. In addition, the value of the NDVI and NDWI correlation coefficients is 0.94, which indicates a positive and strong correlation. Moreover, The NDWI and water table correlation coefficients are 0.79, which indicates a relatively strong positive correlation. Furthermore, the correlation between rainfall and the water table is 0.61, which indicates a relatively strong positive correlation. Thus, these findings show that the water table influences soil moisture and then affects the mangrove greenness. Besides that, the water table change is governed by rainfall, and therefore, the mangrove greenness in KNP depends on seasons and is vulnerable to drought.

1. Introduction
Soil moisture and salinity are essential factors in mangrove growth. Therefore, mangroves are commonly found in intertidal areas where the soil is always moist and saline. Mangroves grow in saline soils because these plants have high adaptability to salinity compared to other land plants. This adaptation ability to salinity also affects the zoning of mangrove growth [1] [2]. Meanwhile, soil moisture in the mangrove area has a role in influencing organic matter into nutrients that can be used for mangrove growth [3].

Besides tides, groundwater is considered a factor affecting soil moisture [4] and mangroves’ growth. However, the groundwater table also fluctuates according to the seasons and rainfall [4]. This condition suppose makes the soil moisture change and affects mangrove health. This hypothesis needs to be proven.
by performing a study that analyses the relationship between mangrove health, soil moisture, rainfall, and water table change in the wet and dry seasons.

On the other hand, recently, remote sensing methods are advanced and helpful for human life. We can identify mangrove health \cite{5} and soil moisture \cite{6} in different seasons efficiently and cheap by remote sensing method. The remote sensing method is relatively inexpensive to analyse because satellite images can be obtained quickly and freely. Not only the satellite imagery but also the software for data processing is free of charge and powerful. For example, we can use Google Earth Engine to quickly process many satellite image data by only requiring an internet connection and computer with standard specifications.

This study was conducted in Karimunjawa National Park (KNP) because, based on our observation during the field survey, mangroves in KNP grow in areas not inundated by tides. Thus, groundwater is believed to have a role in soil moisture changes and mangrove growth in this area. Therefore, this study analyses the relationship of water table changes to soil moisture and mangrove health using remote sensing methods combined with groundwater table observation data in KNP during the wet and dry seasons. Furthermore, by knowing the relationship of those parameters, we will understand the groundwater dynamics and environmental characteristics in KNP. This comprehension is necessary for taking appropriate conservation actions to preserve the mangrove forest in KNP.

2. Material and Methods

2.1 Study Area

Karimunjawa National Park (KNP) is located on Kemujan Island and Karimunjawa Island, separated by a narrow strait. These islands are in the Java Sea and about 125 Km north offshore of Semarang, the capital city of Central Java Province (Figure 1). This area is a mangrove forest under the management of Karimunjawa National Park Agency (BTNKJ), Ministry of Environment and Forestry, with the purpose, is for mangrove tourism, education, and research \cite{7}. Here, mangroves grow on the fringe of the coast, and at least 13 mangrove species have been identified \cite{8}. The dominant mangrove species are Ceriops Tagal, Rhizophora Apiculata, and Lumnitzera Racemosa \cite{8}. The environmental characteristics of mangrove forests in this area are unique because some mangroves grow even though tides do not inundate them. We observed this phenomenon during the dry season when the mangrove substrate is not inundated. In this study, the study area is only focused on the mangrove area around KNP.

Figure 1. Study area located in Karimunjawa National Park.

2.2 Rainfall Data

This study used satellite rainfall data because the observed rainfall data were not available in this area. The closest rainfall observation station from the study area is Tanjung Emas Semarang Meteorological
Station, which is about 120 km southward of Karimunjawa Island. Therefore, it is necessary to select satellite rainfall data representing the actual rainfall in the KNP area.

Thus, we compared three satellite rainfall data with the observation data in Tanjung Emas Semarang Meteorological Station (www.dataonline.bmkg.go.id) for five years, from January 1, 2015, to December 31, 2020. The three satellite rainfall data were Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS) \[9\], Global Precipitation Measurement (GPM) \[10\], and Global Satellite Mapping of Precipitation (GSMaP) \[11\] \[12\]. We choose those satellite rainfall data because these data were available in GEE Dataset and easily obtained.

The comparison was performed by using the statistic method by calculating the correlation coefficient (r), RMS Error (RMSE), Mean Absolute Error (MAE), and Normalized Mean Bias (NMB) (Table 1) of monthly rainfall data. The satellite rainfall data with a high correlation coefficient and small error was chosen as representing rainfall data in KNP.

### Table 1. Statistical Formula to Determine Suitable Satellite Rainfall Data

| Description                  | Mathematical Formula                           | Description                  | Mathematical Formula |
|------------------------------|-----------------------------------------------|------------------------------|----------------------|
| Correlation Coefficient      | \[r_{xy} = \frac{\sum(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum(x_i - \bar{x})^2 \sum(y_i - \bar{y})^2}}\] | Mean Absolute Error          | MAE = \[\frac{\sum_{i=1}^{n}|x_i - y_i|}{n}\] |
| Root Mean Square Error       | \[RMSE = \left(\frac{\sum_{i=1}^{n}(x_i - \bar{x})^2}{n}\right)^{1/2}\] | Normalized Mean Bias         | NMB = \[\frac{\sum_{i=1}^{n}(x_i - \bar{x})}{\sum_{i=1}^{n}y_i} \times 100\%\] |

\(x_i\) = satellite rainfall data; \(y_i\) = observed rainfall data. \(\bar{x}\) = mean satellite rainfall data; \(\bar{y}\) = mean observed rainfall data; \(n\) = Number of samples.

#### 2.3 Vegetation Indices

We used Mangrove Vegetation Index (MVI), Normalized Difference Vegetation Index (NDVI), and Normalized Difference Water Index (NDWI) in this study. The formula and the usage of these vegetation indices are shown in Table 2. MVI is a vegetation index to estimate mangrove area \[13\], and the result is used for mangrove boundary in the study area.

### Table 2. Equation and Purpose of the Vegetation Indices in this Study

| Vegetation Index | Formula                                         | Purpose                                                      |
|------------------|-------------------------------------------------|--------------------------------------------------------------|
| MVI              | MVI = (NIR-Green)/(SWIR-Green)                  | - To map mangrove area                                       |
| NDVI             | NDVI = (NIR-RED)/(NIR+RED)                      | - To discriminate vegetation and non-vegetation area. NDVI > 0 is Vegetation. |
|                  |                                                 | - NDVI sensitive to chlorophyll this can map the vegetation greenness that associated with vegetation health. |
| NDWI             | NDWI = (NIR-SWIR)/(NIR+SWIR)                    | - To map vegetation wetness. In this paper is used as soil wetness proxy. |

MVI = Mangrove Vegetation Index; NDVI = Normalized Difference Vegetation Index; NDWI = Normalized Difference Water Index; Green = Green Band; RED = Red Band; NIR = Near Infra-Red Band; SWIR = Short Wave Infra-Red Band.

In this study, the mangrove greenness was estimated by using NDVI because NDVI is sensitive to chlorophyll \[14\][15]. Therefore, this method can map the vegetation greenness associated with mangrove health \[5\]. NDWI is a vegetation index used to estimate vegetation wetness \[16\]. Still, in this
paper, we use NDWI as a proxy for soil wetness, assuming the water content in vegetation is proportional to soil wetness [6].

These vegetation indices were applied on Sentinel-2 L2A satellite imagery. Sentinel-2 is an optical satellite operated by the European Space Agency (ESA) with a high spatial resolution (10 – 60 m) and 13 bands. Sentinel 2 can provide images over a 5-day time frame in the same place. Sentinel-2 L2A means that this satellite image is in the form of an orthoimage Bottom-Of-Atmosphere (BOA) corrected reflectance product. Sentinel-2 L2A is available in the GEE dataset, so we do not need to do the correction process manually to get the BOA reflectance image. Unfortunately, Sentinel-2 L2A in the KNP area is only available on December 15, 2018, until now.

Cloud cover will affect the image quality of Sentinel-2 and make the target object is not visible. Thus, it is necessary to filter to obtain images with minimal cloud cover in the research area. The filtering process to find images with minimal cloud cover is easier to do using GEE. The calculation of vegetation indices and image filters can be carried out in one data processing flow using GEE.

In this study, the calculation of vegetation indices was applied from January 1, 2019, to December 31, 2020, to determine the spatial pattern of vegetation indices during the wet season and dry season.

2.4 Water Table Calculation

The groundwater table, commonly mentioned as the water table, was measured using a water level logger (WLL) sensor deployed in KNP. There are six WLL data obtained from KNP, with the location is shown in Figure 1. The water level was recorded every 30 minutes from October 11, 2019, to September 29, 2020.

The WLL sensor measures pressure due to the water level and do not directly measure the water level. Therefore, we need to convert it to water elevation. To convert it, we need to know the information on the geometry of the WLL sensor position when it was installed. The WLL installation needs a case to protect the sensor from the land collapse inside the hole. Therefore, we must note the length between the top of the casing pipe to the sensor (L) and the length of the casing pipe above the ground (La), as shown in Figure 2. This information is needed to determine the water table from the ground surface.

Figure 2. Illustrated figure of the geometry of the WLL sensor position. L is the length between the top of the pipe case to the WLL sensor. H is the water head measured from the WLL sensor. La is the Length of the pipe case above the ground. GWT is a groundwater table measured from the ground surface.

Commonly water table is measured from Mean Sea Level (MSL). Because we did not have topography data in the study area, thus we only measured the water table from the ground surface of the WLL station. Therefore, we used a formula to calculate the water table as shown in equations (1) and (2). The negative sign in equation (1) is due to the opposite direction of H measurement with GWT measurement direction. In this case, The H is a water table measured from the WLL sensor (up direction). On the contrary, GWT is a water table measured from the ground surface (down direction). In this study, the atmospheric pressure was determined from the average of atmospheric pressure NCEP/NCAR Reanalysis [17] Data from 2019 to 2020 in the study area.

\[ H = \frac{P_{obs} - P_{atm}}{\rho \cdot g} \]  \hspace{1cm} (1)

\[ GWT = H - (L - L_a) \]  \hspace{1cm} (2)

Where \( H \) = Water Level from Sensor(m), \( P_{obs} \) = Observed Pressure from Sensor (Pa), \( P_{atm} \) = Pressure of Atmosphere (Pa) =101026 Pa, \( \rho \) = density of water (Kg.m\(^{-3}\)) = 1011 Kg.m\(^{-3}\), \( g \) = Acceleration of Gravity (m.s\(^{-2}\)) = 10 m.s\(^{-2}\), \( GWT \) = Groundwater Table below ground (m), \( L \) = Length between the top of the pipe and the sensor (m), \( L_a \) = Length of the pipe above the ground (m).
2.5 Linear Regression of Vegetation Indices, Rainfall, and Water Table

Linear regression between vegetation indices, rainfall, and water table in KNP was carried out to determine the value of the correlation coefficient and the coefficient of determination, which indicates the interrelationship between variables. Moreover, the pattern of the water table influence on the mangrove greenness will be easy to know by comparing the water table with the vegetation indices in the graph. In this case, we compared the average water table from the WLL station with the average vegetation indices at the WLL station coordinate.

This study neglected the evapotranspiration process. Thus, the changes in the water table are assumed entirely influenced by rainfall. Moreover, vegetation indices, rainfall, and water tables are calculated in the monthly average units due to differences in the time units of these data. Thus, in monthly units, it will obtain a consistent analysis.

3. Results and Discussions

3.1 Cloud Coverage in Sentinel-2 over Karimunjawa National Park

It was not easy to find Sentinel-2 images over KNP free of cloud coverage from January 01, 2019, to December 31, 2020. If we do not apply a cloud filter, we obtain 290 images (Figure 3a). On the contrary, if we apply a cloud filter with a cloud cover percentage of less than 20%, we obtain 82 images (Figure 3b). Usually, clear images are obtained in July, August, September, and November (Figure 3b). High cloud coverage occurred in the wet season, and low cloud coverage occurred in the dry season. In this study, we only used images free of cloud coverage and accordingly, the number of obtained images is less than using all images without cloud filtering.

![Cloud coverage in Sentinel-2 images over Karimunjawa National Park during January 1, 2019, to December 31, 2020, before filtering cloud coverage (a) and after filtering the cloud coverage (b)](image)

**Figure 3.** Cloud coverage in Sentinel-2 images over Karimunjawa National Park during January 1, 2019, to December 31, 2020, before filtering cloud coverage (a) and after filtering the cloud coverage (b)

3.2 Mangrove Area

The mangrove area in KNP obtained based on MVI shows that mangroves cover almost all Karimunjawa National Park, except in some areas (Figure 4). That area is probably swamps, exposed area, and other land vegetation.

In this study, the mangrove area was determined by summing the MVI area from free of cloud satellite images from January 1, 2019, to December 31, 2020. We did this method because the mangrove area based on the MVI changes according to the seasons. During the wet season, the mangrove area based on MVI is quite extensive, but the mangrove area is reduced during the dry season. This condition may be due to selecting a fixed MVI threshold for all images, so the results obtained are unreliable. Therefore, this needs to be corrected for future research by using adjusted MVI thresholds for each image.
3.3 Rainfall Variability in Karimunjawa National Park

Based on the comparative study of three rainfall satellite data, we select GPM satellite data because it has the highest correlation coefficient and small error (Figure 5). The correlation coefficient of GPM to the observation data is 0.93, with RMSE is 92.39, MAE is 70.45, and NMV is 42.01%. Although the CHIRPS satellite rainfall data has the smallest RMSE, MAE, and NMV values, these values are slightly different compared to GPM. In contrast, the correlation coefficient values of CHIRPS and GPM differ significantly. Therefore, GPM was chosen as the rainfall data in KNP.

GPM is an international satellite mission by NASA that provides precipitation data with 0.1° spatial resolution and 30 minutes and monthly temporal resolution. On this paper we used GPM data with monthly temporal resolution, because the monthly data is the research level product that means it is better data for rainfall estimation. To obtain the precipitation data, GPM used IMERG (The Integrated Multi-Satellite Retrievals for GPM) algorithm. This algorithm provides rainfall estimates combining data from all passive-microwave instruments in the GPM constellation and precipitation gauge analysis [10].

The monthly average of GPM rainfall data during 2015 - 2020 (Figure 6a) shows that the rainfall pattern in KNP is monsoonal rainfall. The monsoonal rainfall pattern has one peak of the wet season. The wet season occurred in December-January-February-March-April-May and the dry season occurred in June-July-August-September-October-November. The peak of the wet season occurred in December, and the peak of the dry season occurred in August.

The monthly average rainfall from the GPM satellite during 2019 – 2020 (Figure 6b) shows that the average rainfall in 2019 is lower than the average rainfall in 2020. The average rainfall in 2019 is 146.77 mm/month and the average rainfall in 2020 is 205.74 mm/month. This is probably caused by the cooling effect of sea surface temperatures in 2019, as indicated by the thinning of the thermocline layer on the southern coast of Java [18]. This phenomenon occurred when the east monsoon, El Nino, and positive Indian Ocean Dipole (IOD) conditions coincided [18]. When the sea surface temperature is cold, the evaporation process will decrease and cause less rainfall.
3.4 Vegetation Indices.

Spatially, NDVI value in different seasons in 2019 – 2020 is shown in Figure 7. In the wet season (Figure 7a, Figure 7b, Figure 7e), NDVI values ranged from 0.8 – 1 with an average value of 0.8. Meanwhile, in the dry season (Figure 7c, Figure 7d, Figure 7f, Figure 7g), the NDVI value ranges from 0.4 – 1 with an average value of 0.6. In the dry season, the NDVI value in the middle area of KNP is lower than the NDVI in the area near the shoreline.

Figure 7. NDVI in the Karimunjawa National Park in February 2019 (a), May 2019 (b), August 2019 (c), November 2019 (d), May 2020 (e), July 2020 (f), and November 2020 (g).

On the other hand, NDWI shows a consistent result with the NDVI pattern. The NDWI in the wet season (Figure 8a, Figure 8b, Figure 8e) has a higher NDWI value than in the dry season (Figure 8c, Figure 8d, Figure 8f, Figure 8g). The NDWI in the wet season ranges from 0.4 – 1, with an average of 0.7. While in the dry season, NDWI ranges from 0 – 1, with an average of 0.3. This condition shows that rainfall affects soil moisture. In addition, the NDWI in the middle of KNP has a lower value than the NDWI in the shoreline area in all seasons. It shows that the soil in the shoreline area is more humid due to the tides. Based on these findings, soil moisture, which is affected by tides and rainfall, impacts mangrove greenness.
3.5 Relationship of Rainfall, and Water Table

The monthly average value of the water table for each observation station is shown in Figure 9a. We can see that the water table values for Stations 1 to Station 5 are different. The graph shows the position of the water table relative to the ground surface at the station observation. Thus, the position of the monthly average water table, which is almost always below ground level, is at Station 1, Station 2, and Station 4. This condition indicates that the area around this Station is not inundated by water, or if it is inundated, it may not be high and not in longer time. Meanwhile, the water table at Station 3 and Station 6 was above the ground level from December to July or during the rainy season. This condition indicates that the area around this Station is inundated during the rainy season and becomes dry during the dry season. The water table at Station 5 was below the ground surface in October or a very dry condition. It suggests that the area around Station 5 is always inundated except in extremely dry conditions.

In chronological order, the monthly average value of the water table in October 2019 was at the lowest position from the ground surface. Then the water table increases gradually from November to December 2019. After that, from December 2019 to June 2020, the water table looks constant at the ground surface. However, the water table began to decline from July 2020 to September 2020. This condition shows that the variability of the water table is influenced by rainfall.

Statistically, we can estimate the relationship between rainfall and the water table by performing linear regression (Figure 9b). Based on the linear regression result, the correlation coefficient value is 0.61, and the determination coefficient is 0.37. This result shows that rainfall and the water table have a positive correlation. That is, if the rainfall increases, the water table will also increase, and vice versa. Although positively correlated, the magnitude of the correlation coefficient and the coefficient of

Figure 9. (a) The monthly average water table at each observation station (solid color line) and monthly average rainfall in KNP (histogram). (b) linier regression of rainfall and water table in KNP
determination show a weak relationship. This result indicates another factor that affects the water table change.

Furthermore, decreasing the water table from the wet season to the dry season is not as fast as increasing the water table during the dry season to the wet season. The increasing rapidly of the water table is observed from the dry season to the wet season. On the other hand, from the wet season to the dry season, the decline is slow. This condition indicates that the water table change may not be entirely influenced by rainfall. However, it may be influenced by the evapotranspiration rate, infiltration, and percolation in this area, as explained in the water cycle theory. In this case, the evapotranspiration rate is influenced by vegetations, and the magnitude of the land surface temperature. In contrast, infiltration and percolation is influenced by the permeability of the soil and the unsaturated zone depth in this area. Thus, studies on water balance involving evapotranspiration, infiltration, and percolation need to be carried out in future studies.

3.6 Relationship of Vegetation Indices and Water Table

The relationship between the vegetation indices and the water table was estimated using linear regression, as shown in Figure 10. The linear regression NDVI and NDWI (Figure 10a) shows a positive and strong correlation with a correlation coefficient of 0.94 and a determination coefficient of 0.88. In addition, the relationship between NDWI and the water table (Figure 10b) also shows a relatively strong positive correlation with a correlation coefficient of 0.79 and a determination coefficient of 0.63. Likewise, the water table and NDVI (Figure 10c) is positively correlated with a reasonably strong correlation coefficient of 0.76 and a coefficient of determination of 0.58.

![Figure 10. Linear regression showing the relationship of NDVI and NDWI (a), NDWI and groundwater level (b), NDVI and groundwater level (c).](image)

Based on the correlation coefficient value, we can see that the relationship between NDVI and the water table is weaker than the relationship between the water table and NDWI. This condition suggests that the water table has a more substantial effect on soil moisture than mangrove greenness. On the one hand, mangrove greenness has a very close relationship with soil moisture. Thus, the relationship between the water table and mangrove greenness is not directly related. However, the water table will cause the soil moisture to be high, and then the high soil moisture will cause the mangroves to be greener. Because the water table affects soil moisture, it is necessary to know the water table threshold that affect soil moisture and mangrove greenness. Based on the scatter plot analysis of the NDWI and the water table at each WLL station (Figure 11a to Figure 11b), we can see that the low NDWI value is below the annual average of the water table. Besides, the high NDWI is above the annual average of the water table. This condition indicates that the soil moisture will be high and cause the mangroves to be greener when the water table is above the annual average value of the water table and vice versa. Thus, we can say that the annual average of the water table is a threshold that can be used to determine the level of soil moisture and mangrove greenness.
Figure 11. A graph showing the threshold of the water table for appropriate soil moisture conditions for mangroves at station 1 (a), station 2 (b), station 3 (c), station 4 (d), station 5 (e), and station 6 (f). NDWI is significantly low when the water table is lower than the annual average of the water table.

4. Conclusions
This study shows that rainfall, water table, soil moisture, and mangrove greenness are interrelated. This study shows that increased rainfall will cause a rising water table, high soil moisture, and greener mangroves. On the other hand, when the rainfall decrease, the water table will decline, the soil moisture will be lowered, and the mangrove less green. Although areas around the coastline have higher soil moisture than areas in the inner part of KNP, this soil moisture declines as rainfall decreases. Thus, we can conclude that the mangrove greenness in KNP is strongly influenced by rainfall. It means that during the wet season, the mangroves will be greener than during the dry season. This condition shows that mangroves in KNP are vulnerable to drought.

Furthermore, Mangrove is in healthy condition when the water table is higher than the annual average of the water table. Conversely, mangroves tend to dry when the water table is lower than the annual average of the water table. Therefore, the annual average of the water table can be used as a threshold to determine mangrove greenness.

Although this study shows that rainfall is the primary driver of water table change, the rainfall is not entirely affecting the water table change. Based on hydrologic cycle theory, evapotranspiration rate, infiltration, and percolation in this area also affect the water table change. Because evapotranspiration rate, infiltration, and percolation were not considered in this study, it is necessary to perform an additional study considering those parameters.

5. Supplementary Materials
The GEE script used in this paper is used to obtain raw rainfall and vegetation index (MVI, NDVI and NDWI) data. Users can access the GEE script through the GEE Repository with the following link: https://code.earthengine.google.com/?accept_repo=users/prihantono/MangroveGreennessKNP. In addition, the data that has been processed and presented in this paper can be accessed via the following link: https://drive.google.com/drive/folders/1neWlzzCxDANsdDVs2XHVlA7pZZm8Wt7Yj?usp=sharing © 2021. This data is an open access data distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (http://creativecommons.org/licenses/by/4.0/). By using this data, Users agree to cite this paper in any publications.

Please note: “Supplementary Materials” is generally not peer reviewed. Any queries (other than missing materials) should be directed to the corresponding author.
6. References

[1] Wakushima S, Kuraishi S and Sakurai N 1994 *J. Plant Res.* **107** pp 39–46
[2] Peters R, Walther M, Lovelock C, Jiang J and Berger U 2020 *Wetlands Ecol. Management* **28** pp 697–712
[3] Sharma S, Yasuoka J, Nakamura T, Watanabe A and Nadaoka K 2014 *Proc. of the Intl. Conf. on Advances in Applied Science and Env. Engineering* pp 44-48
[4] Chen X and Hu Q 2004 *Journal of Hydrology* **297** (1-4) pp 285-300
[5] Akbar M R, Arisanto P A, Sukirno B A, Merdeka P H, Priadhi M M and Zallesa S 2020 *IOP Conf. Series: Earth and Environmental Science* vol 584 pp 1-7
[6] Serrano J, Shahidian S and Silva J M 2019 *Water* **11** (1) 1-20
[7] Mulyadi, Susanto H, Devi D Y and Sahwan F F 2019 *Interpretasi Trekking Mangrove Taman Nasional Karimunjawa* (Semarang: Balai Taman Nasional Karimunjawa)
[8] Winata A and Rusdiyanto E 2016 *Sem. Nas. Tahunan Matematika, Sains, dan Teknologi 2016* (Tangerang Selatan: Universitas Terbuka) pp 81-94
[9] Funk C, Peterson P, Landsfeld M, Pedreros D, Verdin J, Shukla S, Michaelsen J 2015 *Scientific Data* **2** 1-21
[10] Huffman G J, Stocker E F, Bolvin D T, Nelkin E J and Tan J 2019 *GPM IMERG Final Precipitation L3 1 month 0.1 degree x 0.1 degree V06 (GES DISC))*
[11] Okamoto K, Iguchi T, Takahashi N, Iwanami K and Ushio T 2005 *25th IGARSS Proc.* pp 3414-16
[12] Kubota T, Shige S, Hashizume H, Aonashi K, Takahashi N, Seto S, Okamoto K 2007 *IEEE Trans. Geosci. Remote Sens.* **45** (7) 2259-75
[13] Baloloy A B, Blanco A C, Ana R R and Nadaoka K 2020 *ISPRS Journal of Photogrammetry and Remote Sensing* **166** 95-117
[14] Kriegler F, Malila W, Nalepka R and Richardson W 1969 *Proc. of the Sixth Int. Symp. on Remote Sensing of Environment* pp 97-131
[15] Rouse J, Haas R, Scheel J and Deering D 1974 *Proc. 3rd Earth Resource Technology Satellite (ERTS) Symp.* Vol 1 pp 48-62
[16] Gao B 1996 *Remote Sensing of Environment* **58** 257-266.
[17] Kalnay E, Kanamitsu M, Kistler R, Collins W, Deaven D, Gandin L, Dennis J 1996 *Bulletin of the American Meteorological Society* **77** (3) 437-472
[18] Ramadhan F, Kunarso, Wirasatria A, Maslukah L and Handoyo G 2021 *Indonesian Journal of Oceanography* **3** (2)

Acknowledgments
This field survey in KNP was fund by the SATREPS-BlueCARES project, the Cooperation between the Ministry of Marine Affairs and Fisheries (MMAF), Indonesia, with Japan's Government sponsored by JICA. The authors would like to thank Diponegoro University students who assisted in collecting WLL data at KNP.