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https://doi.org/10.19184/geosi.v10i1.48079 **Research Article**

Analysis of Mangrove Density Levels Change Based on Cloud Computing on Abrasion Area in the Coast of Semarang City

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ABSTRACT

The coastal areas of Semarang City have experienced land conversion due to development activities that threaten mangrove sustainability in recent years. The urgency of this research is the need to monitor mangrove density levels to be used as input in its management. The purpose of this study is to analyze changes in mangrove density levels and the occurrence of abrasion in time series using the Google Earth Engine cloud computing model. The research method used visual interpretation and spectral transformation of NDVI and MNDWI to identify spatial distribution, mangrove density and abrasion. The results showed that there was a significant decrease in mangrove area in 2019-2023 with an area of 111.74 hectares. Furthermore, the level of mangrove density is quite dynamic, especially for high density with a decrease in area from 2019 - 2023 with an area of 260.25 hectares, besides that the decline in high density mangroves also occurred in 2015 - 2023 with a decrease in area of 38.73 hectares. Abrasion in the research location was identified in 2 coastal villages, namely Mangunharjo Village with abrasion along 0.88 km (2015 - 2023) and Tugurejo Village with abrasion along 1.04 km, where both areas also experienced a decrease in mangrove area at a high-density level. In conlusion, there has been a decrease in the area and density of mangroves in the study site, one of which has an impact on abrasion.

Keywords: Mangrove density; Cloud computing; Abrasion

INTRODUCTION

Indonesia is a coastal country with a long coastline and has marine ecosystems with diverse species, including mangroves [1][2]. Mangroves can be found along coastlines in tropical regions, such as Indonesia. Indonesia has the largest mangrove area in the world at 18-23% and has the highest mangrove species diversity, where there are 40 species of the 50 true mangrove species spread throughout the world. [3] [4]. Mangrove ecosystems have a very important role in terms of coastal environmental dynamics [5][6], among others as a habitat for various types of fish and shrimp to find food, spawn, shelter and lay eggs, habitat for various types of fauna, carbon sinks in global climate change and protect the coast from erosion, wind and waves [7][8][9]. Besides that, there is still an economic value contained in the mangrove ecosystem, which amounts to US$9900/hectares [10]. Mangrove ecosystems in Indonesia are faced with the problem of damage and loss of mangroves due to massive land use change into ponds, industrial areas, and other productive land. [11][12]. Approximately 48,000 hectares of mangrove forests in Indonesia underwent land conversion between 2000-2012 resulting in the loss of approximately 49% of mangrove forests in the southeast region [13]. One intervention to mangrove survival occurred on the North Coast of Central Java, which has a strategic and potential location with a relatively flat land surface. As in the coastal city of Semarang, which is experiencing mangrove intervention due to relatively rapid land conversion from development activities [14][15]. Some development activities threaten the survival of mangroves, such as the development of industrial areas, ponds, development of trade areas and various activities oriented to other economic sectors [16][17][15].

Semarang City has a decreasing mangrove area every year, which has decreased from 2012-2014 by 343.92 hectares [18]. Illegal logging is the main cause of the decline in mangrove area on the coast of Semarang City [19]. One of the decreases in mangrove area occurred in Mangkang Kulon Village which experienced a decrease in mangrove area of 10.77 hectares which resulted in abrasion of around 6.8 meters from 2012-2019 [20]. Besides that, abrasion also occurred around Tirang Beach, where there was a decrease in the coastline of 17.14 meters / year from 2007-2021 which resulted in the western part of Tirang Beach turning into the sea [21]. Besides that, abrasion has also eroded land in Tanjung Mas, Terboyo Wetan, Terboyo Kulon, and Trimulyo villages from 1984-2008 with an average land erosion of 0.7 km/year [22]. Spatial mangrove inventory needs to be done to determine changes in mangrove area and density by direct measurement in the field, but this activity requires a lot of time, money, and energy. Mangrove inventory can use remote sensing technology, which has the ability to record data and information widely, repeatedly and in more detail to detect changes in the ecosystem. [23][24][25][26]. Remote sensing has been widely used to map mangroves with varying degrees of success. [27], one of them is by utilizing the presence of a cloud computing platform, namely GEE (Google Earth Engine). GEE has key capabilities in the provision and processing of geospatial big data and can classify complex characteristics without a supercomputer [28][29]. The use of the GEE platform in mangrove mapping has been done in large and compact areas, not small and fragmented areas such as mangroves in Semarang City [30][31]. In addition, the use of the GEE platform in mangrove mapping in Semarang City is also still limited, the majority of recent studies still discuss land use not specific to mangroves [32] [33].

The use of the GEE platform in this study greatly assisted the data collection and processing process. Table 1 compares the stages of data collection and processing between conventional methods and GEE. Conventional methods include collecting data by downloading through image provider websites such as earthexplorer.usgs.gov or browser.dataspace.copernicus.eu with processing using desktop-based spatial data processing software such as ArcMap or QGIS.

Table 1. Comparison between the conventional method and GEE on data processing

Processing	Conventional	GEE
Collecting data	Need to download the image	No need to download imagery
Image preprocessing	Need reflectance calibration Need atmospheric correction	No need for reflectance calibration No need for atmospheric correction
Image processing	NDVI and MNDWI transformations need to include the formula	NDVI and MNDWI transformations need to include formulas

The difference between the conventional method and GEE is during data collection and preprocessing, where with GEE there is no need to do these two steps. The process of collecting data in GEE is simply writing the dataset snippet code and setting the data filter, while preprocessing is not necessary because GEE also provides surface reflectance data that is ready to use. Even in GEE, the analyzed image can be directly masked based on the AOI (Area of Interest). The use of GEE is also more efficient in storage because the data is stored in the cloud, while the conventional method is less efficient because a single scene of Sentinel-2 satellite imagery is up to about 120 MB in size. GEE also provides a cloud masking algorithm so collecting cloud-free data is easier, which is very suitable for Indonesia which is a tropical region with a lot of cloud cover [34] [29].

Mangroves mapping in Semarang City is a challenge given that mangroves in the region are small and fragmented. Semarang City, which is a highly urbanized coastal area, makes mangrove areas also associated with settlement, industrial areas and fishponds, making it vulnerable to misclassification. Based on this, this study will map the dynamics of mangrove distribution and density using GEE. In addition, this research will also discuss the dynamics of mangrove ecosystems against abrasion. Based on this, this study will map the dynamics of mangrove distribution and density using GEE. In addition, this research will also discuss the dynamics of mangrove ecosystems against abrasion. The novelty of this study is the use of multi-resolution spatial imagery in identifying the distribution and density of mangroves based on cloud computing, which in this study uses Sentinel 2A multispectral image data sources (2019 and 2023) and Landsat 8 (2015). Data and information on the spatial distribution, mangrove density and abrasion dynamics are very important to support coastal ecosystem conservation activities, so that with this information conservation efforts can be carried out efficiently.

METHODS

Study Area

The study sites is on the coast of Semarang City to identify changes in mangrove density and abrasion with mangrove distribution in the west and east of Semarang City, where the following figure presents the research location.

Figure 1. Study Area

Data Source

The main data in this study are Sentinel 2A imagery (2019 and 2023) and Landsat 8 imagery (2015) through the Google Earth Engine (GEE) platform. The satellite images used with atmospherically corrected and orthorectified surface reflectance levels, so that basic geometric and atmospheric correction processes are no longer needed. Here are the specifications of the image data used in the study.

Sentinel 2A data set

The Sentinel-2 MultiSpectral Instrument (MSI) acquires 13 spectral bands ranging from Visible and Near-Infrared (VNIR) to Shortwave Infrared (SWIR) wavelengths along a 290-km orbital swath. The MSI measures reflected radiance through the atmosphere within 13 spectral bands. The spatial resolution is dependent on the particular spectral band:

- 4 bands at 10 meter: blue (490 nm), green (560 nm), red (665 nm), and near-infrared (842 nm).
- 6 bands at 20 meter: 4 narrow bands for vegetation characterization (705 nm, 740 nm, 783 nm, and 865 nm) and 2 larger SWIR bands (1,610 nm and 2,190 nm) for applications such as snow/ice/cloud detection or vegetation moisture stress assessment.
- 3 bands at 60 meter: mainly for cloud screening and atmospheric corrections (443 nm for aerosols, 945 nm for water vapor, and 1375 nm for cirrus detection).

Landsat 8 data set

Landsat 8 images have 15-meter panchromatic and 30-meter multi-spectral spatial resolutions along a 185 km (115 mi) swath. Landsat 8 carries two sensors. The Operational Land Imager sensor is built by Ball Aerospace & Technologies Corporation. The Thermal Infrared Sensor is built by NASA Goddard Space Flight Center. Nine spectral bands, including a pan band:

- Band 1 Coastal Aerosol (0.43 - 0.45 µm) 30 m
- Band 2 Blue (0.450 - 0.51 µm) 30 m
- Band 3 Green (0.53 - 0.59 µm) 30 m
- Band 4 Red (0.64 - 0.67 µm) 30 m
- Band 5 Near-Infrared (0.85 - 0.88 µm) 30 m
- Band 6 SWIR 1(1.57 - 1.65 µm) 30 m
- Band 7 SWIR 2 (2.11 - 2.29 µm) 30 m
- Band 8 Panchromatic (PAN) (0.50 - 0.68 µm) 15 m
- Band 9 Cirrus (1.36 - 1.38 µm) 30 m

Data Processing

Data processing and analysis in this research is divided into several systematic stages, the following is a series of spatial data processing stages in the research.

Mapping the Spatial Distribution of Mangroves

Mapping of spatial distribution of mangroves is done by digital interpretation (supervised classification) based on machine learning algorithm in GEE with high accuracy CART (Classification and Regression Trees) for mangrove mapping [35]. Mapping mangrove distribution using medium-resolution satellite imagery has the challenge of mixed pixels, where mangrove pixels are mixed with other objects [36]. So that, the mangrove distribution mapping process also uses visual interpretation to separate mangrove and non-mangrove objects. Visual interpretation is an interpretation that considers the elements of location, size, shape, shadow, tone/color, texture, pattern, height and association [37] [38]. The visual interpretation process was aided by high-resolution satellite imagery from Google Earth. The combination of digital interpretation and visual interpretation will produce more accurate mangrove maps from medium-resolution satellite imagery.

Mangrove Density Mapping

Mangrove density mapping using NDVI transformation (Normalized Difference Vegetation Index) with red band and NIR band being the most popular in mangrove mapping [39]. Besides that, this transformation has the best performance in mapping mangrove distribution and density [40] [41]. The NDVI transformation was processed through the GEE platform using the formula as follows.

$$NDVI = \frac{NIR - Red}{NIR + Red} \quad (1)$$

Identification of mangrove ecosystem dynamics with abrasion

This stage is done by descriptive analysis of the results of spatial distribution of mangroves and mangrove density with shoreline conditions in the study area. To facilitate the descriptive analysis process, it is necessary to visualize coastline conditions in the study area. Coastline visualization using MNDWI image transformation (Modified Normalized Difference Water Index) which was processed using the GEE platform. MNDWI is able to separate land and waters, including visualizing coastlines firmly [42], MNDWI transformation using formula as follows.

$$MNDWI = \frac{Green - SWIR\ 1}{Green + SWIR\ 2} \quad (2)$$

Mangrove Density Accuracy Test

The NDVI transformation results were then tested for accuracy based on canopy density from the field. This process is done by calculating linear regression, if the linear regression results are close to 1, it means that there is a very strong relationship between NDVI and mangrove density in the study site. Mangrove density data was taken by field survey, where the estimation of mangrove density values using hemispherical photography. Hemispherical photography is a method of estimating the extent of mangrove canopy cover using photography from below, one of the software that can be used is Canapeo which is smartphone-based [35] [43] The NDVI transformation results are then classified into several classes, where high density classes have a longer range than other density classes. The sample for validation of magrove density from hemispherical photography was 32 samples. This number considers the accessibility of the research site, in addition to several studies such as [44] using a validation sample of no more than 30 samples.

Data analysis techniques using spatial analysis with a quantitative approach to determine changes in spatial distribution and mangrove density levels and relationships with abrasion. The following figure presents the research flow chart.

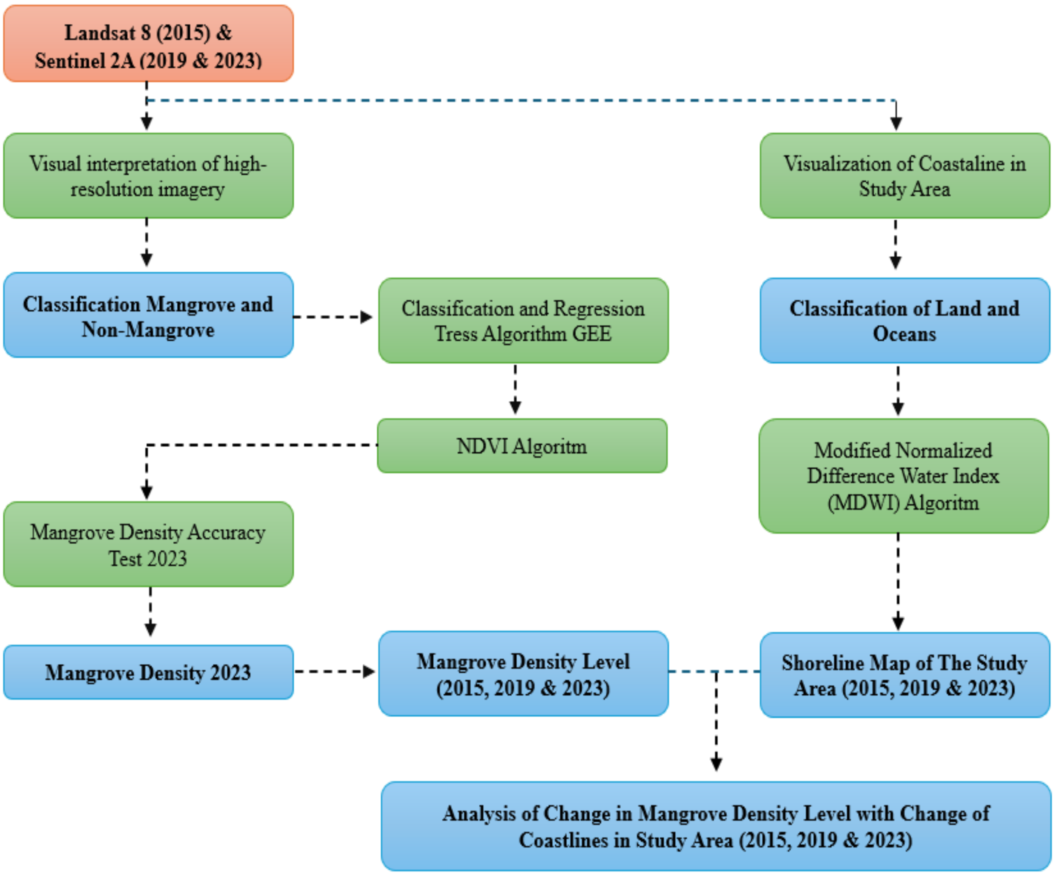

Figure 2. Research flowchart

RESULTS AND DISCUSSION

Spatial Distribution of Mangrove

Mapping the distribution of mangroves using digital interpretation (supervised classification) based on machine learning algorithms in GEE. The machine learning algorithm used is CART (Classification and Regression Trees) to obtain spatial distribution data of mangroves in 2015, 2018, and 2023, such as the study of [35] [31]. Visual interpretation was also done with the help of high-resolution satellite imagery accessed from Google Earth. The combination of digital interpretation and visual interpretation will produce a better mangrove distribution map from medium-resolution satellite imagery. The results of data processing show that the spatial distribution of mangroves in the study area is in seven coastal villages, including Mangkang Kulon Village, Mangkang Wetan Village, Mangunharjo Village, Randu Garut Village, Tugurejo Village, Tanjung Mas Village and Trimulyo Village, with various types of mangrove species, including Avicennia Marina, Rhizophora Apiculata, Rhizophora Mucronata, Rhizophora Stylosa, Bruguiera, Ceriops Tagal, Sonneratia, dan Xylocarpus granatum. In 2015, mangroves in the study site had an area of about 527.20 hectares with a pattern of clustering and extending along the pond embankment, where in 2019 mangroves increased to 138.73 hectares due to mangrove growth in 2015. The following graph presents mangrove area information in a time series.

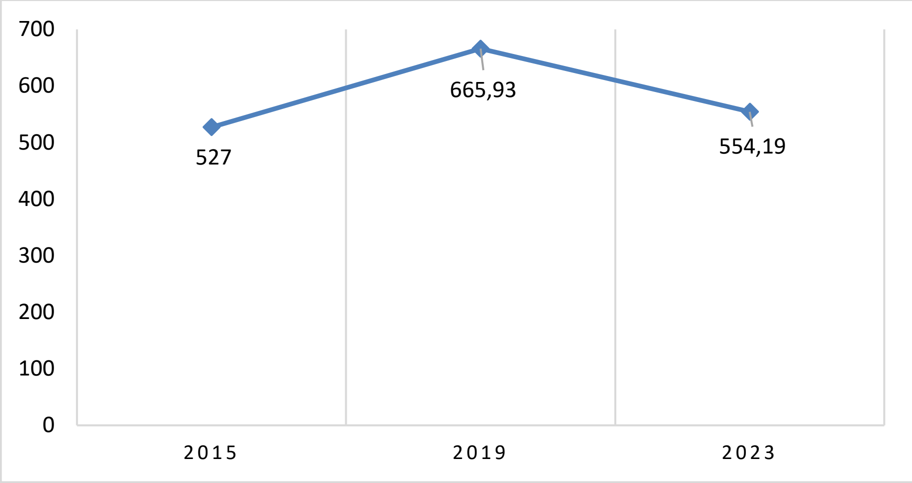

Figure 3. Mangrove area (hectar) time series

The results of mangrove mapping in 2023 had an area of 554.19 hectares, which decreased by 111.74 hectares from 2019. Most of the mangroves lost in 2023 are on the beach due to erosion by sea waves, such as in Mangunharo Village and Tugurejo Village which are dominated by young mangroves with unstable roots. Large ocean waves are still an obstacle to the growth of mangrove ecosystems in various coastal areas [45][46], where dynamic ocean waves are influenced by climate change phenomena that generate high-speed winds that cause an increase in ocean waves and threaten the balance of coastal areas [47][48]. The following figure presents changes in the spatial distribution of mangroves in the study area.

Figure 4. Spatial distribution of mangrove time series (2015, 2019 & 2023)

Mangrove Density Level

Processing of mangrove density levels obtained from the results of NDVI processing using java script in GEE with Landsat 8 (2015) and Sentinel 2A (2019 & 2023) image data. NDVI is a spectral transformation that can convert digital numbers into vegetation density with a value range of -1 - 1 so that it can be used to identify land cover changes in an area [23][49]. The results of NDVI processing in 2015 show that the level of mangrove density varies into two density classes, namely high density with an area of 176 hectares (33.39%) and medium density with an area of 351 hectares (66.61%). Meanwhile, low and very low density mangroves were not identified due to the limited resolution of the Landsat 8 image which is too small (30 meters). The following table presents the time series mangrove density in the study area.

Table 2. Density level of mangrove time series

No	Density level	Area (hectar & percent)					
		2015		2019		2023	
1	High	176.00	33.39 %	397.52	59.69 %	137.27	23.86 %
2	Moderate	351.00	66.61 %	126.04	18.92 %	92.04	16.59 %
3	Low	-	-	124.83	18.74 %	154.56	27.88 %
4	Very low	-	-	130.37	19.57 %	268.32	48.41 %
Total		527.00	100	665.93	100	554.19	100

Furthermore, the level of mangrove density in 2019 can be identified in four density classes, namely very low, low, medium and high. Based on the NDVI processing results, 397.52 hectares (59.69%) had a high density level and 130.37 hectares (19.57%) had a very low density level. While the level of mangrove density in 2023 will mostly have a low density level with an area of about 268.32 hectares (48.41%), while for mangroves with high density has an area of about 137.27 hectares (23.86%). This shows that there is a decrease in mangrove density from 2023-2019, especially for high-density mangroves with an area of about 260.25 hectares, but there is also a decrease in mangroves with a medium density of about 34 hectares. Furthermore, during 2019-2023, there was an increase in mangroves with a low density level of around 137.95 hectares. Based on the dynamics that occur at each density level, it shows that there is a degradation of the mangrove ecosystem in the study location.

The distribution of mangroves in each coastal village shows a level of density that varies greatly in each coastal village, where the year 2023 shows high density mangroves have an area of 119.06 hectares with the largest area in 2 villages including Trimulyo Village with an area of 25.36 hectares (21.30%) and Mangkang Wetan Village with an area of 25.14 hectares (21.11%), Meanwhile, very low density mangroves are mostly located in Tugurejo Village with an area of 70.63 hectares (31.40%) and Mangkang Kulon Village with an area of 36.43 hectares (16.19%). The high density of very low density mangroves in these two areas is more due to the mangrove planting pattern that extends the pond so that the pixel value read by the sensor is biased. The following figure shows the changes in mangrove density.

Figure 5. Density mangrove time series (2015, 2019 & 2023)

Furthermore, an accuracy test was conducted to assess the level of mangrove density in each class of NDVI values, where the accuracy test used linear regression between NDVI values and mangrove density values in the field of hemispherical photography. The linear regression results show an R (correlation) value of 0.86 and an R2 (coefficient of determination) value of 0.75 (Fig 6). This indicates that there is a moderate relationship between NDVI and mangrove density in the field. The accuracy of mangrove density in the study area is relatively moderate, this is because some mangroves in the study area have a pattern that extends the pond so that it does not meet the pixel size of the image used. This phenomenon has an impact on the reflection bias of objects around mangroves, such as water bodies and soil recorded on the sensor so that it becomes a mixed pixel. Mapping mangrove density levels and species with medium resolution imagery has limitations, especially for mangroves with elongated patterns, such as the study of mangrove density in coastal Semarang with SPOT 7 imagery which resulted in a moderate-low accuracy of 52% because some mangrove density classes have small patches mixed with other uses [50]. Mangrove mapping with 10-meter or higher resolution imagery has the potential to misrepresent fragmented mangrove areas and experience sampling bias, with accuracy ranging from 25% for mapping results with 30-meter resolution imagery [51].The following graph shows the relationship between mangrove density and NDVI values.

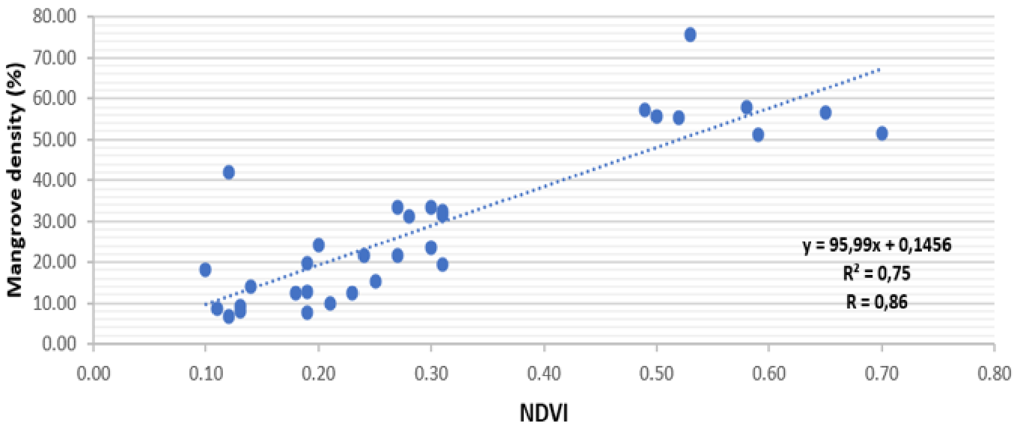

Figure 6. Relationship between field mangrove density and NDVI

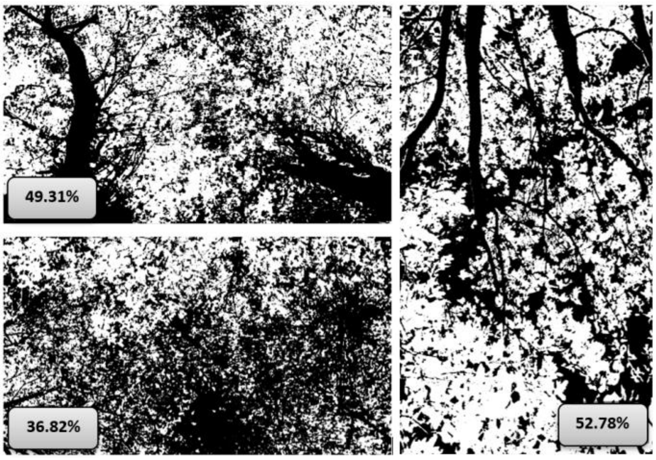

Figure 7. Accuracy test results of mangrove density in research location

Transverse profile measurements were also taken to determine changes in mangrove cover using the long cross method along 1.45 km from 2019 - 2023. The processing results show that the Mangunharjo Village area experienced the largest decrease in area, especially in high-density mangroves, which from 2019-2023 decreased by 45.41 hectares, while very low-density mangroves experienced an increase in area of around 13.98 hectaresThe decrease in the area of high density mangroves is also seen in the longitudinal time series profile, where from the graph (Fig 8) it can be concluded that there is a decrease in mangrove area in the high density class. The use of cloud computing such as GEE is very helpful in mangrove mapping. Its ability to provide data will make it easier to map changes from previous decades. This research still has limitations such as the transformation used is only NDVI. Whereas NDVI has weaknesses in relation to the soil background [52]. So it also needs to be compared with transformations related to soil backgorund such as SAVI (Soil Adjusted Vegetation Index), EVI (Enhanced Vegetation Index) and EVI-2 (Enhanced Vegetation Index 2) [53] [54]. This research should also be expanded by utilizing GEE to improve our understanding of mangrove dynamics. Monitoring mangrove dynamics normally includes seasonal and annual changes that require a series of historical and regular imagery. By addressing the limitations of single-date images and employing averaged optical data, we can reduce the impact of environmental variability such as tides on the accuracy of mangrove mapping [52], as well as research on the dynamics of carbon stocks using GEE such as the study [55], whose information can be used to inform the impact of current and future activities and national policies aimed at conserving these important ecosystems.

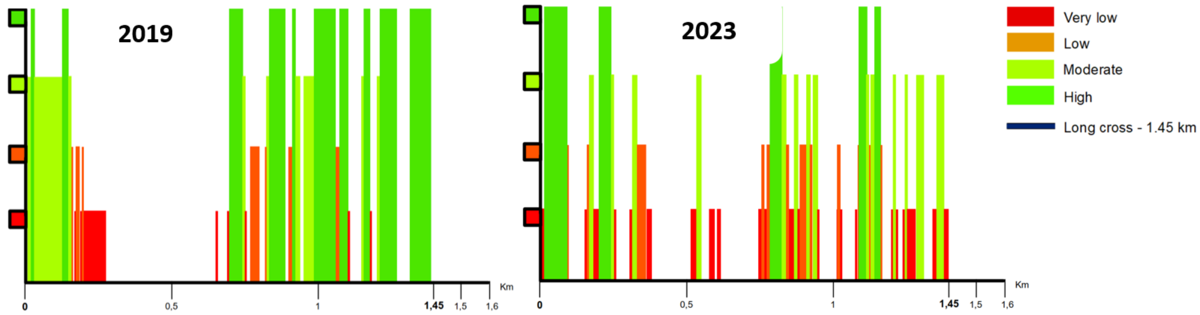

Figure 8. Transverse profile mangrove density in Mangunharjo (2019 & 2023)

Abrasion Dynamics

Mangrove ecosystems in coastal areas have many functions, including protecting the coastline from ocean waves that can impact abrasion [56][57]. Large mangroves have the ability to bind mud, which can reduce erosion of land by ocean waves [58][59], Besides that, this plant can function as a natural fortress in resisting sea waves so that it can prevent abrasion. Based on the results of MNDWI image transformation processing using the GEE platform to separate land and waters, including visualizing the coastline firmly [60][61] shows that abrasion occurs in the coastal area of Kelurahan Mangunharjo, where in the 2015-2023 time interval there was 0.88 km of coastline erosion due to sea waves. This erosion has caused the loss of several pond areas located on the beach.

One of the causes of abrasion that occurs in this area is a decrease in mangrove density, where in the 2018-2023 time interval there was a decrease in mangrove area with a high density level of around 45.51 hectares and a medium density of around 2.99 hectares. Furthermore, abrasion also occurs in the coastal area of Tugurejo Village, where the results of MNDWI processing show the erosion of the coastline with a length of about 1.04 km due to sea waves, especially at high tide. Abrasion that occurs on the coast of Tugurejo Village is caused by a decrease in mangrove density which functions as a coastal belt, especially in the 2019-2023 period, where in that period there was a decrease in mangrove area with a density of around 86.45 hectares. Besides that, abrasion has also resulted in the loss of mangroves around the ponds due to large waves. The following picture shows the abrasion that occurs on the coast of Kelurahan Mangunharjo and Kelurahan Tugurejo.

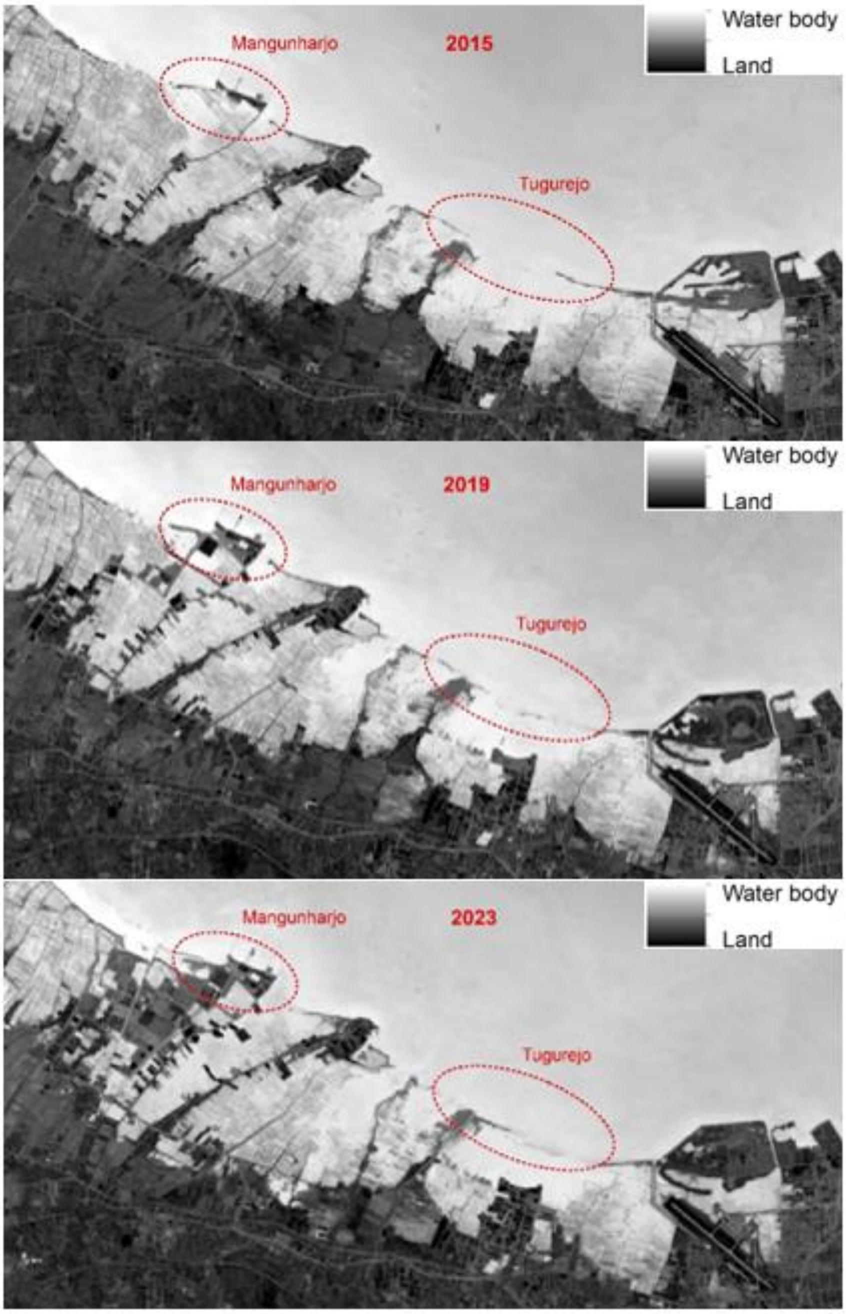

Figure 9. Abrasion in Mangunharjo and Tugurejo coast (2015–2023)

CONCLUSION

Based on the results of the study, it can be concluded that mangroves in the coastal areas of Semarang City are scattered in 7 coastal villages with an area of about 554.19 hectares in 2023, where the area has decreased compared to 2019 with an area of 665.93 hectares, where the decline in area mostly occurred in Mangunharjo Village and Tugurejo Village. The level of mangrove density in the study site shows that most of them are at a low - medium density level with a spatial distribution clustered along the coastline and extending along the pond embankment. Furthermore, the level of mangrove density experienced a significant decrease from 2019-2023 with an area of 260.25 hectares, in addition to a decrease in high mangrove density also occurred from 2015-2023 with a decrease in area of around 38.73 hectares. The decrease in the area of high-density mangroves correlates with abrasion in the research location, where 2 coastal villages were identified that experienced abrasion

(2015-2023), namely Mangunharjo Village with abrasion extending along 0.88 km and Tugurejo Village with abrasion extending along 1.04 km (2015-2023). Suggestions from the results of the study can be carried out further research on the identification of mangrove health levels at the research site and species identification using remote sensing spectral transformation.

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DECLARATIONS

Conflict of Interest

The writing of this article has no conflict of interest and only focuses on presenting research results.

Ethical Approval

On behalf of all authors, the corresponding author states that the paper satisfies Ethical Standards conditions, no human participants, or animals are involved in the research.

Informed Consent

On behalf of all authors, the corresponding author states that no human participants are involved in the research and, therefore, informed consent is not required by them.

DATA AVAILABILITY

Data used to support the findings of this study are available from the corresponding author upon request.

REFERENCES

[1] M. L. Martínez, A. Intralawan, G. Vázquez, O. Pérez-Maqueo, P. Sutton, dan R. Landgrave, "The coasts of our world: Ecological, economic and social importance," *Ecol. Econ.*, vol. 63, no. 2, hal. 254–272, 2007, doi: https://doi.org/10.1016/j.ecolecon.2006.10.022.

[2] L. Sui, J. Wang, X. Yang, dan Z. Wang, "Spatial-Temporal Characteristics of Coastline Changes in Indonesia from 1990 to 2018," *Sustainability*, vol. 12, no. 8. 2020. doi: 10.3390/su12083242.

[3] K. W. Krauss dan M. J. Osland, "Tropical cyclones and the organization of mangrove forests: a review," *Ann. Bot.*, vol. 125, no. 2, hal. 213–234, Feb 2020, doi: 10.1093/aob/mcz161.

[4] P. R. Marlianingrum, T. Kusumastanto, L. Adrianto, dan A. Fahrudin, "Valuing habitat quality for managing mangrove ecosystem services in coastal Tangerang District, Indonesia," *Mar. Policy*, vol. 133, hal. 104747, 2021, doi: https://doi.org/10.1016/j.marpol.2021.104747.

[5] L. Y. F. Gaw, M. Linkie, dan D. A. Friess, "Mangrove forest dynamics in Tanintharyi, Myanmar from 1989–2014, and the role of future economic and political developments," *Singap. J. Trop. Geogr.*, vol. 39, no. 2, hal. 224–243, Mei 2018, doi: https://doi.org/10.1111/sjtg.12228.

[6] K. A. Hapsari, T. C. Jennerjahn, M. C. Lukas, V. Karius, dan H. Behling, "Intertwined effects of climate and land use change on environmental dynamics and carbon accumulation in a mangrove-fringed coastal lagoon in Java, Indonesia," *Glob. Chang. Biol.*, vol. 26, no. 3, hal. 1414–1431, Mar 2020, doi: https://doi.org/10.1111/gcb.14926.

[7] Ismail, Sulistiono, S. Hariyadi, dan H. Madduppa, "Condition and mangrove density in Segara Anakan, Cilacap Regency, Central Java Province, Indonesia," *AACL Bioflux*, vol. 11, no. 4, hal. 1055–1068, 2018.

[8] A. Irsadi, N. E. Kartijono, P. Partaya, M. Abdullah, L. N. Hadiyanti, dan H. S. Aji, "Carbon Stock

Profiling of Mangrove Ecosystem in the Semarang-Demak Coastal Area for Global Warming Mitigation," *Int. J. Environ. Res.*, vol. 16, no. 5, hal. 86, 2022, doi: 10.1007/s41742-022-00465-y.

[9] D. M. Alongi, "Global Significance of Mangrove Blue Carbon in Climate Change Mitigation," *Sci*, vol. 2, no. 3. 2020. doi: 10.3390/sci2030067.

[10] M. N. Arkham, S. Riadi, Y. Wahyudin, dan Y. Krisnafi, "Economic value of mangrove ecosystem services in the coastal area of Bintan Island, Indonesia," *Wetl. Ecol. Manag.*, hal. 1–19, 2023, doi: 10.1007/s11273-023-09955-y.

[11] M. Ilman, P. Dargusch, P. Dart, dan Onrizal, "A historical analysis of the drivers of loss and degradation of Indonesia's mangroves," *Land use policy*, vol. 54, hal. 448–459, 2016, doi: https://doi.org/10.1016/j.landusepol.2016.03.010.

[12] T. B. Sanjoto, V. N. Husna, dan W. A. B. N. Sidiq, "Analysis of Mangrove Species Distribution Mapping and the Environmental Problem in Mangkang Kulon, Semarang City," *Proc. 6th Int. Conf. Educ. Soc. Sci. (ICESS 2021)*, vol. 578, no. Icess, hal. 334–339, 2021, doi: 10.2991/assehr.k.210918.062.

[13] D. R. Richards dan D. A. Friess, "Rates and drivers of mangrove deforestation in Southeast Asia, 2000-2012," *Proc. Natl. Acad. Sci. U. S. A.*, vol. 113, no. 2, hal. 344–349, 2016, doi: 10.1073/pnas.1510272113.

[14] N. K. T. Martuti, S. M. E. Susilowati, W. A. B. N. Sidiq, dan D. P. Mutiatari, "Peran Kelompok Masyarakat dalam Rehabilitasi Ekosistem Mangrove di Pesisir Kota Semarang," *J. Wil. dan Lingkung.*, vol. 6, no. 2, hal. 100, 2018, doi: 10.14710/jwl.6.2.100-114.

[15] A. Sabdaningsih, D. Adyasari, S. Suryanti, S. Febrianto, dan Y. Eshananda, "Environmental legacy of aquaculture and industrial activities in mangrove ecosystems," *J. Sea Res.*, vol. 196, no. September, hal. 102454, 2023, doi: 10.1016/j.seares.2023.102454.

[16] F. Sidik, B. Supriyanto, H. Krisnawati, dan M. Z. Muttaqin, "Mangrove conservation for climate change mitigation in Indonesia," *WIREs Clim. Chang.*, vol. 9, no. 5, hal. e529, Sep 2018, doi: https://doi.org/10.1002/wcc.529.

[17] A. W. Sejati, I. Buchori, S. Kurniawati, Y. C. Brana, dan T. I. Fariha, "Quantifying the impact of industrialization on blue carbon storage in the coastal area of Metropolitan Semarang, Indonesia," *Appl. Geogr.*, vol. 124, no. June, hal. 102319, 2020, doi: 10.1016/j.apgeog.2020.102319.

[18] A. S. Grivina Yuliantika, Andri Suprayoga, "Jurnal Geodesi Undip April 2016 Jurnal Geodesi Undip April 2016," *J. Gedesi Undip*, vol. 5, no. April, hal. 200–207, 2016.

[19] A. P. Cahyaningsih, A. K. Deanova, C. M. Pristiawati, Y. I. Ulumuddin, L. Kusumawati, dan A. D. Setyawan, "Review: Causes and impacts of anthropogenic activities on mangrove deforestation and degradation in Indonesia," *Int. J. Bonorowo Wetl.*, vol. 12, no. 1, hal. 12–22, 2022, doi: 10.13057/bonorowo/w120102.

[20] W. A. B. N. Sidiq, Nana kariada Tri Martuti, dan Dhita Prasisca Mutiatari, "Development of Maroon Mangrove Education Park (MMEP) in Supporting Mangrove Conservation in Coastal of Semarang City Development of Maroon Mangrove Education Park (MMEP) in Supporting Mangrove Conservation in Coastal of Semarang City," *IOP Conf. Ser. Earth Environ. Sci. Vol. 747, 3rd Int. Conf. Environ.*, 2021, doi: 10.1088/1755-1315/747/1/012067.

[21] Y. S. Prahmani, D. Deanova, T. R. Fariz, dan A. P. Heriyanti, "Dampak Abrasi Kawasan Pesisir Pantai Tirang Terhadap Lingkungan Fisik di Kecamatan Tugu," *Uniplan J. Urban Reg. Plan.*, vol. 3, no. 2, hal. 52, 2022, doi: 10.26418/uniplan.v3i2.56675.

[22] H. P. I. Buchori, "Mitigasi Yang Diinisiasi Masyarakat Akibat Abrasi Di Kawasan Pesisir Kota Semarang," *Tek. PWK (Perencanaan Wil. Kota)*, vol. 7, no. 1, hal. 44–55, 2018.

[23] M. M. Aburas, S. H. Abdullah, M. F. Ramli, dan Z. H. Ash'aari, "Measuring Land Cover Change in Seremban, Malaysia Using NDVI Index," *Procedia Environ. Sci.*, vol. 30, hal. 238–243, 2015, doi: 10.1016/j.proenv.2015.10.043.

[24] S. Niculescu, "Application of Deep Learning of Multi-Temporal Sentinel-1 Images For The

Classification of Coastal Vegetation Zone of The Application of Deep Learning of Multi-Temporal Sentinel-1 Images For The Classification of Coastal Vegetation Zone of The Danube," no. May, 2018, doi: 10.5194/isprs-archives-XLII-3-1311-2018.
[25] J. M. M. Yancho, T. G. Jones, S. R. Gandhi, C. Ferster, A. Lin, dan L. Glass, "The google earth engine mangrove mapping methodology (Geemmm)," *Remote Sens.*, vol. 12, no. 22, hal. 1–35, 2020, doi: 10.3390/rs12223758.
[26] A. O. Numbere, "Chapter 20 - Application of GIS and remote sensing towards forest resource management in mangrove forest of Niger Delta," M. K. Jhariya, R. S. Meena, A. Banerjee, dan S. N. B. T.-N. R. C. and A. for S. Meena, Ed. Elsevier, 2022, hal. 433–459. doi: https://doi.org/10.1016/B978-0-12-822976-7.00024-7.
[27] E. Zimudzi, I. Sanders, N. Rollings, dan C. W. Omlin, "Remote sensing of mangroves using unmanned aerial vehicles: current state and future directions," *J. Spat. Sci.*, vol. 66, no. 2, hal. 195–212, Mei 2021, doi: 10.1080/14498596.2019.1627252.
[28] K. E. Herndon *et al.*, "Journal of Archaeological Science : Reports Google Earth Engine for archaeologists : An updated look at the progress and promise of remotely sensed big data," *J. Archaeol. Sci. Reports*, vol. 50, no. December 2022, hal. 104094, 2023, doi: 10.1016/j.jasrep.2023.104094.
[29] A. V. Amalia, T. R. Fariz, F. Lutfiananda, H. M. Ihsan, R. Atunnisa, dan A. Jabbar, "Comparison of Swat-Based Ecohydrological Modeling in the Rawa Pening Catchment Area, Indonesia," *J. Pendidik. IPA Indones.*, vol. 13, no. 1, hal. 1–11, 2024, doi: 10.15294/jpii.v13i1.45277.
[30] M. H. Nguyen, N. T. Nguyen, G. Yedaya, I. Ryadi, dan M. Van Nguyen, "Google Earth Engine-based Mangrove Mapping and Change Detections for Sustainable Development in Tien Yen District , Quang Ninh Province , Vietnam," vol. X, no. August, hal. 6–8, 2024.
[31] X. Xie, G. Li, dan L. Wu, "Investigation of Freeway Incident Duration Using Classification and Regression Trees Based on Multisource Data," 2024.
[32] M. A. Kelly-fair, "Sustainable urban planning : change detection of Land Use and Land Cover in Semarang , Indonesia by," 2022.
[33] R. Khoirunisa dan B. D. Yuwono, "Smart City Urban Flood and Its Correlation with Built-up Area in Semarang , Indonesia Urban Flood and Its Correlation with Built-up Area in Semarang , Indonesia," vol. 3, no. 2, 2023, doi: 10.56940/sc.v3.i2.2.
[34] R. D. Dimyati dan P. Danoedoro, "A Minimum Cloud Cover Mosaic Image Model of the Operational Land Imager Landsat-8 Multitemporal Data using Tile based," vol. 8, no. 1, hal. 360–371, 2018, doi: 10.11591/ijece.v8i1.pp360-371.
[35] T. Ridho Fariz, F. Daeni, dan H. Sultan, "Pemetaan Perubahan Penutup Lahan Di Sub-DAS Kreo Menggunakan Machine Learning Pada Google Earth Engine," *J. Sumberd. Alam dan Lingkung.*, vol. 8, hal. 85–92, Agu 2021, doi: 10.21776/ub.jsal.2021.008.02.4.
[36] A. Ghorbanian, "Application of Artificial Neural Networks for Mangrove Mapping Using Multi-Temporal and Multi-Source Remote Sensing Imagery," 2022.
[37] A. Darvishi Boloorani *et al.*, "Visual interpretation of satellite imagery for hotspot dust sources identification," *Remote Sens. Appl. Soc. Environ.*, vol. 29, hal. 100888, 2023, doi: https://doi.org/10.1016/j.rsase.2022.100888.
[38] T. R. Fariz, A. V. Amalia, R. Atunnisa, dan A. Jabbar, "Estimation Of Changes in Water Quality Parameters in Rawa Pening Lake Based on Remote Sensing Data," vol. 13, no. 1, hal. 1–7, 2024.
[39] T. V Tran dan R. Reef, "A Review of Spectral Indices for Mangrove Remote Sensing," 2022.
[40] F. Muhsoni, A. B. Sambah, M. Mahmudi, dan D. Wiadnya, "Comparison of different vegetation indices for assessing mangrove density using sentinel-2 imagery COMPARISON OF DIFFERENT VEGETATION INDICES FOR ASSESSING MANGROVE DENSITY USING SENTINEL-2 IMAGERY," no. June, 2018, doi: 10.21660/2018.45.7177.
[41] S. Aldiansyah, "SPATIAL TEMPORAL MAPPING OF VEGETATION COVER INDICES USING SENTINEL-2 MULTISPECTRAL INSTRUMENT IN UNAAHA CITY (Pemetaan Spasial Temporal Indeks Tutupan Vegetasi," hal. 1–10, 2024.

[42] Z. Al-ali *et al.*, "International Journal of Applied Earth Observation and Geoinformation Examining the potential and effectiveness of water indices using multispectral sentinel-2 data to detect soil moisture as an indicator of mudflow occurrence in arid regions," *Int. J. Appl. Earth Obs. Geoinf.*, vol. 130, no. May, hal. 103887, 2024, doi: 10.1016/j.jag.2024.103887.

[43] J. Nicolas, W. Schaduw, T. E. Tallei, dan D. A. Sumilat, "Mangrove Health Index , Community Structure and Canopy Cover in Small Islands of Bunaken National Park , Indonesia : Insights into Dominant Mangrove Species and Overall Mangrove Condition Authors : Mangrove Health Index , Community Structure and Canopy Cover in Small Islands of Bunaken National Park , Indonesia : Insights into Dominant Mangrove Species and Overall Mangrove Condition," vol. 35, no. 2, 2024.

[44] T. Ridho Fariz, H. Muhammad Ihsan, F. Lutfiananda, J. Sartohadi, Y. Darmajati, dan A. Syahputra, "PERBANDINGAN PENGUKURAN KERAPATAN KANOPI DARI HEMISPHERICAL PHOTOGRAPHY DAN UAV UNTUK PEMETAAN MENGGUNAKAN CITRA SENTINEL-2," *J. Hutan Trop.*, vol. 11, hal. 123, Mar 2023, doi: 10.20527/jht.v11i1.16000.

[45] S. Dasgupta, M. S. Islam, M. Huq, Z. H. Khan, dan M. R. Hasib, "Quantifying the protective capacity of mangroves from storm surges in coastal Bangladesh," *PLoS One*, vol. 14, no. 3, hal. 1–14, 2019, doi: 10.1371/journal.pone.0214079.

[46] E. Damastuti, B. K. van Wesenbeeck, R. Leemans, R. S. de Groot, dan M. J. Silvius, "Effectiveness of community-based mangrove management for coastal protection: A case study from Central Java, Indonesia," *Ocean Coast. Manag.*, vol. 238, no. March, hal. 106498, 2023, doi: 10.1016/j.ocecoaman.2023.106498.

[47] F. J. Vázquez Pinillos dan J. A. Chica Ruiz, "Coastal management and climate change on the island and the sea of Chiloé (Chile): An evaluation of policies, regulations, and instruments," *Environ. Sci. Policy*, vol. 156, no. March, 2024, doi: 10.1016/j.envsci.2024.103758.

[48] T. Zhang, H. Liu, Y. Lu, Q. Wang, Y. C. Loh, dan Z. Li, "Impact of climate change on coastal ecosystem: A comparative analysis among four largest coastline covering countries," *Environ. Res.*, vol. 250, no. January, 2024, doi: 10.1016/j.envres.2024.118405.

[49] A. Zaitunah, Samsuri, dan F. Sahara, "Mapping and assessment of vegetation cover change and species variation in Medan, North Sumatra," *Heliyon*, vol. 7, no. 7, hal. e07637, 2021, doi: 10.1016/j.heliyon.2021.e07637.

[50] T. B. Sanjoto, V. N. Husna, W. Akhsin, dan B. Nur, "Spectral Angle Mapper Algorithm for Mangrove Biodiversity Mapping in Semarang Indonesia," hal. 1–18, 2022.

[51] H. Zhang, S. Wei, X. Liang, Y. Chen, dan H. Zhang, "International Journal of Applied Earth Observation and Geoinformation Scale effects in mangrove mapping from ultra-high-resolution remote sensing imagery," *Int. J. Appl. Earth Obs. Geoinf.*, vol. 136, no. December 2024, hal. 104310, 2025, doi: 10.1016/j.jag.2024.104310.

[52] T. Van Tran dan S. Gyeltshen, "Characterizing Spatiotemporal Patterns of Mangrove Forests in Can Gio Characterizing Spatiotemporal Patterns of Mangrove Forests in Can Gio Biosphere Reserve Using Sentinel-2 Imagery," no. June, 2020, doi: 10.3390/app10124058.

[53] M. A. P. Aji, M. Kamal, dan N. M. Farda, "Mangrove species mapping through phenological analysis using random forest algorithm on Google Earth Engine," *Remote Sens. Appl. Soc. Environ.*, vol. 30, hal. 100978, 2023, doi: https://doi.org/10.1016/j.rsase.2023.100978.

[54] S. Pamungkas, "Analysis Of Vegetation Index For Ndvi, Evi-2, And Savi For Mangrove Forest Density Using Google Earth Engine In Lembar Bay, Lombok Island," *IOP Conf. Ser. Earth Environ. Sci.*, vol. 1127, hal. 12034, Jan 2023, doi: 10.1088/1755-1315/1127/1/012034.

[55] M. Bajaj, N. Sasaki, T. W. Tsusaka, M. Venkatappa, I. Abe, dan R. P. Shrestha, "Innovation and Green Development Assessing changes in mangrove forest cover and carbon stocks in the Lower Mekong Region using Google Earth Engine," *Innov. Green Dev.*, vol. 3, no. 3, hal. 100140, 2024, doi: 10.1016/j.igd.2024.100140.

[56] R. Indarsih dan M. S. Masruri, "Mangrove conservation as an abration strategy risk reduction based on ecosystem in the coastal area of the Rembang Regency," *IOP Conf. Ser. Earth Environ.*

Sci., vol. 271, no. 1, hal. 0–9, 2019, doi: 10.1088/1755-1315/271/1/012021.

[57] E. Whidayanti, T. Handayani, Supriatna, dan M. D. M. Manessa, "A spatial study of mangrove ecosystems for abrasion prevention using remote sensing technology in the coastal area of Pandeglang Regency," *IOP Conf. Ser. Earth Environ. Sci.*, vol. 771, no. 1, 2021, doi: 10.1088/1755-1315/771/1/012014.

[58] J. C. Winterwerp *et al.*, "Managing erosion of mangrove-mud coasts with permeable dams – lessons learned," *Ecol. Eng.*, vol. 158, no. June, hal. 106078, 2020, doi: 10.1016/j.ecoleng.2020.106078.

[59] E. Infantes, S. Hoeks, A. MP, van der H. T, dan van K. MM, "Seagrass roots strongly reduce cliff erosion rates in sandy sediments ," *Mar. Ecol. Prog. Ser.*, vol. 700, hal. 1–12, 2022, [Daring]. Tersedia pada: https://www.int-res.com/abstracts/meps/v700/p1-12

[60] M. Hasan, P. Citra, dan A. S. Nugraha, "Monitoring Perubahan Garis Pantai Di Kabupaten Jembrana Tahun 1997 – 2018 Menggunakan Modified Difference Water Index (Mndwi) Dan Digital Shoreline Analysis System (DSAS)," vol. 7, hal. 93–102, Nov 2019, doi: 10.23887/jjpg.v7i3.21507.

[61] S. A. Alzurqani, H. A. Zurqani, D. White, K. Bridges, dan S. Jackson, "Google Earth Engine application for mapping and monitoring drought patterns and trends : A case study in Arkansas , USA," *Ecol. Indic.*, vol. 168, no. April, hal. 112759, 2024, doi: 10.1016/j.ecolind.2024.112759.