








# Agricultural and Fishery Activities on Mangrove Ecosystem Area, Bekasi Regency: Exploration Studies of Land Use Conditions in The Coastline Buffer Area

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**Abstract:** As a country with the widest mangrove forest area in the world, Indonesia has potential and challenges in preserving the mangrove ecosystem. Bekasi Regency is an area with a mangrove ecosystem that has experienced degradation, so research needs to be conducted to monitor the mangrove area and uncover land use by coastal communities. This research uses field data (including agricultural and fishing activities) in mangrove forest area in Bekasi Coastline Buffer Area, and remote sensing data from Sentinel-2 MultiSpectral Instrument (MSI) satellite data. In process analysis, using machine learning (ML) algorithm is the Support Vector Machine (SVM) and through in the advanced GEE computing platform. The analysis involves 11 indices consisting of vegetation indices, namely NDI, MNDVI, SAVI, SLAVI, and ARVI; water indices, namely NDWI, LSWI, and ANDWI; and building indices, namely IBI. The results of mangrove mapping obtained an area of 836.91 ha or equivalent to 6.57% of the area of Bekasi Regency and the Overall Accuracy (OA) results reached 90%, and Kappa Statistics (KS) were 0.8. The mapped mangrove areas have great potential in various aspects, especially playing a role in controlling land erosion, protecting against atmospheric disasters, and also contributing to controlling climate change. The silvofishery area which is a balance between mangroves and ponds, has great potential in sustainable land use and coastal ecosystem restoration. This research is expected to encourage policymakers to become one of the strategic policy supports that can quickly restore the mangrove ecosystem, thus controlling the threat of sea-level inundation that adds to the vulnerability area every year.

**Keyword:** Land Use, SVM-ML, Mangrove Ecosystem, Bekasi Coastline Buffer Area

## INTRODUCTION

Mangrove forests are coastal areas (anaerobic soil) consisting of a group of plant species along the tropical to subtropical coastlines and containing salt

(Kathiresan & Bingham 2001). The growth of mangrove forests, influenced by environmental conditions, forms both simple and complex zoning extending inland (Imron *et al.* 2024). The environmental

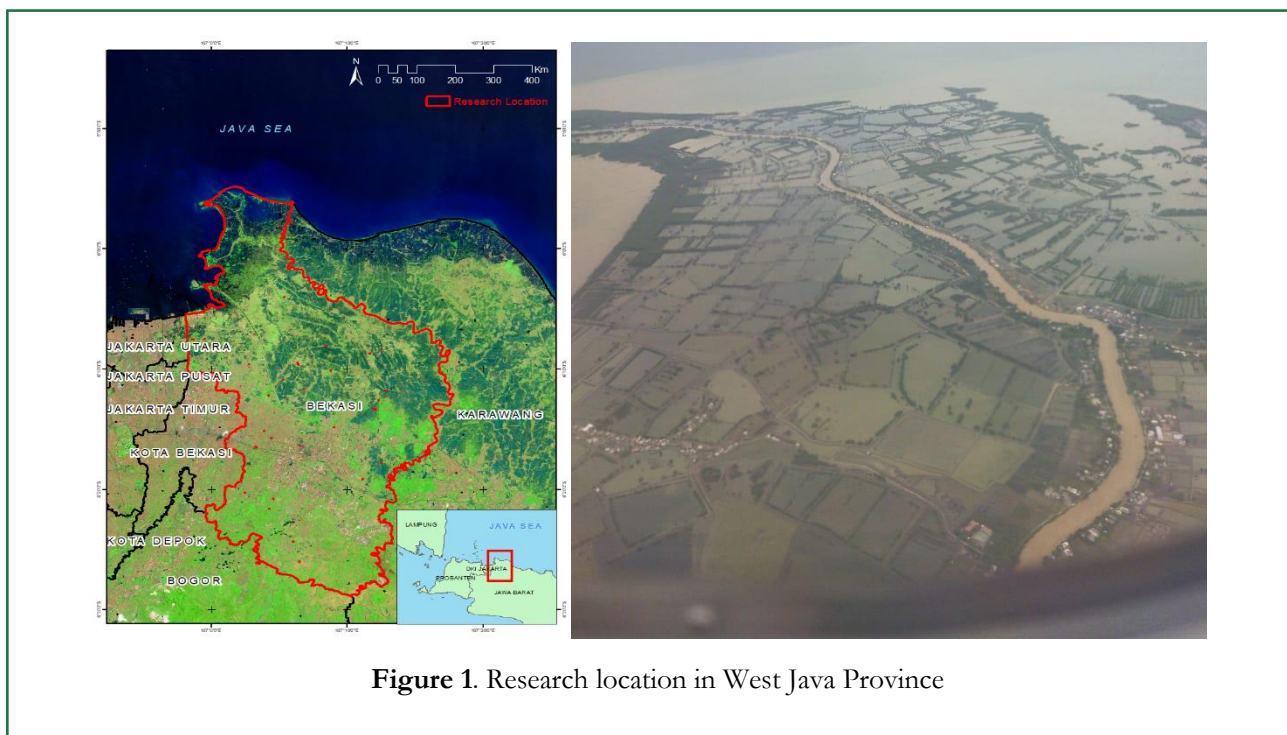


conditions include physical characteristics of sedimentation, tidal movements, soil and water salinity, soil type, temperature, acidity levels, and light (Kusmana *et al.* 2013; Raganas & Magcale-Macandog 2020; Lewis 2004; Akpovwovwo 2020). Ecologically, mangrove forests serve as habitats for various types of fauna, spawning grounds, nursery grounds, feeding grounds, and food sources for marine life such as crabs and shrimp (Eddy *et al.* 2016). The mangrove ecosystem is part of the coastline buffer area because it is a transitional area between land and sea. It helps stabilize the coastline, reducing the impact of tidal waves and cyclones (tsunamis and typhoons) (Sanford 2009). Additionally, from a socio-economic perspective, mangrove forests can be used as ecotourism areas, and then the wood and fish resources can be utilized for commercial purposes (Asy'Ari *et al.* 2021; Kusmana & Sukristijiono 2016; Hutchison *et al.* 2014).

The mangrove forests in Indonesia are scattered throughout the Indonesian archipelago and can be found in almost all 30 provinces of Indonesia. Currently, Indonesia's total area of mangrove forests is 3.367 million hectares (KLHK 2021). Indonesia's largest mangrove forests are in Papua West Papua, East Kalimantan, and Riau (Ditjen PDASRH 2021). The distribution of mangroves in Indonesia is utilized differently in each area. The community in Karawang Regency utilizes a mangrove area along the coast for economic purposes, processing parts of the mangrove tree into food products (Fikri *et al.* 2014). While

mangrove area in Jakarta is generally utilized as a fish pond (Sofian *et al.* 2020). In contrast to the mangrove area mentioned earlier, mangrove forests in North Sumatra are used by the community as ecotourism with high economic value (Purwoko *et al.* 2023). Java and Bali are islands with the most significant damage, around 88%. Previously, these two islands had about 171,500 hectares of mangrove forests, but now only about 19,577 hectares remain (Eddy *et al.* 2015). The damage to mangrove forests will lead to a reduction in the diversity of mangrove species and the abundance of marine biota that make mangrove forests as their habitat (Baderan *et al.* 2018).

Remote sensing can provide information about the extent of mangrove areas and vegetation density (Rahmawati *et al.* 2022). Remote sensing analysis that calculates the area of mangrove coverage is a supervised classification process through image processing by taking several pixel samples or regions of interest to obtain the characteristics of each pixel object or class, which are then grouped based on the characteristics of the pixel values to obtain the area of land cover closure in the form of mangrove areas (Sunkur *et al.* 2024). Previous studies have used remote sensing to determine the damage of mangrove ecosystems in Gresik Regency (Prasetyo *et al.* 2017), Hastuti *et al.* (2017) conducted research on estimating mangrove carbon stocks in Bali, identify mangrove species diversity in Karawang Regency (Sewiko *et al.* 2022), and other research. This study utilizes remote sensing for mangrove monitoring



**Figure 1.** Research location in West Java Province

to produce mangrove ecosystem mapping in Bekasi Regency and reveal the condition of mangrove forest quality and the relevance of the use of mangrove ecosystem land to coastal communities.

## METHOD

### Study Area

Administratively, the research location is in Bekasi Regency, West Java Province. While geographically the research location is located at geographic coordinates 6 10'53 "- 6 30'6" South Latitude and 106 48'28 "- 107 27'29" East Longitude. The research location borders the Java Sea to the north, Jakarta Province to the west, Karawang Province to the east, and Bogor City to the south (Figure 1). This research will take place from February to December 2023 using remote sensing media and various spatial data, while field data collection will be conducted in February 2023.

### Data

#### Spatial and Remote Sensing Data

The data used in this research consists of two types, spatial data providing information for the analysis process and remote sensing satellite imagery. The spatial data used consists of training data (image processing) and validation data (ground check), which serve to provide direction and evaluation for the analysis process. The training data was obtained from high-resolution images from the Google Earth Engine

(GEE) platform, while the validation data was obtained from GEE and field data. The selection of points as data was based on considering the representation of the classification classes: mangroves and non-mangroves. The non-mangrove land cover includes water bodies, built-up areas, barren land, agriculture and aquaculture ponds, and forests.

This research uses Sentinel-2 MSI (multispectral instrument), one of the Copernicus program satellites with a radar imaging system that is useful for obtaining geophysical parameters and improving land cover mapping accuracy (ESA 2012). The European Space Agency (ESA) is the coordinator and main party in the launch of Sentinel-2, which collaborates with other institutions, such as EUMETSAT, EEA, and ECMWF. Sentinel-2, which consists of two twin units, was first launched on June 23, 2015 (Sentinel-2A), followed by the second unit (Sentinel-2B) on March 7, 2017 (ESA 2012). The European Space Agency (ESA) is the coordinator and main party in the launch of Sentinel-2, which collaborates with other institutions, such as EUMETSAT, EEA, and ECMWF (ESA 2012). Sentinel-2 MSI consists of 13 high-resolution multispectral optical sensor bands, while in this study, the bands used are listed in Table 1.

#### Data on community conditions

In addition to secondary data sourced from spatial and remote sensing data, other primary data is also collected from field verification in the study area. Field verification involves taking validation points, observing the condition of mangrove phenomena, and

**Table 1.** List of bands in Sentinel-2 Multispectral Instrument (MSI) imagery (Li et al. 2020)

Band Number	Band Description	Wavelength Range	Resolution
B2	Blue (B)	458 nm – 523 nm	10 m
B3	Green (G)	543 nm – 578 nm	10 m
B4	Red (R)	650 nm – 680 nm	10 m
B5	Red-Edge 1 (Re1)	698 nm – 713 nm	20 m
B6	Red-Edge 2 (Re2)	733 nm – 748 nm	20 m
B8	Near Infrared (NIR)	785 nm – 900 nm	10 m
B11	Shortwave Infrared 1 (SWIR1)	1565 nm – 1655 nm	20 m
B12	Shortwave Infrared 2 (SWIR2)	2100 nm – 2280 nm	20 m

conducting deep interviews through questionnaires to coastal communities. The questionnaire aims to discover the knowledge, utilization, and dependence of the community on the mangrove ecosystem

### Data Analysis

The ability to use computation-based remote sensing has rapidly increased in recent years. According to Cracknell (2018), the ability to use data sets hosted in the cloud can perform remote sensing analysis efficiently and computation enabled by Google Earth Engine (GEE) API. GEE, developed and managed by Google, is a cloud computing-based computer instrument for geospatial scientific data analysis (Ermida et al. 2020). GEE provides ready-to-use data sets and a large-scale server set (petabyte) with high-speed capabilities by distributing them to a large number of servers (Mutanga & Kumar 2019). Spatial data processing can run as needed only by writing

JavaScript and Python-based programming languages (Wachid & Tyas 2022).

This research used the GEE platform to process Sentinel-2 MSI satellite image data involving various modified indices. The Sentinel-2 image data was processed through various land use classification analyses using the Support Vector Machine (SVM) algorithm, followed by the classification of mangroves from other land uses using ArcMap software. The research flowchart is presented in Figure 2.

### Spectral Analysis with Vegetation, Water, and Build-Up Index Algorithms

This research uses several indices to assist in the process of identifying mangrove vegetation in the study area. Some of these indices are involved and selected based on their specific functions and objectives in accordance with the unique characteristics of the mangrove habitat. Therefore, the indices used include

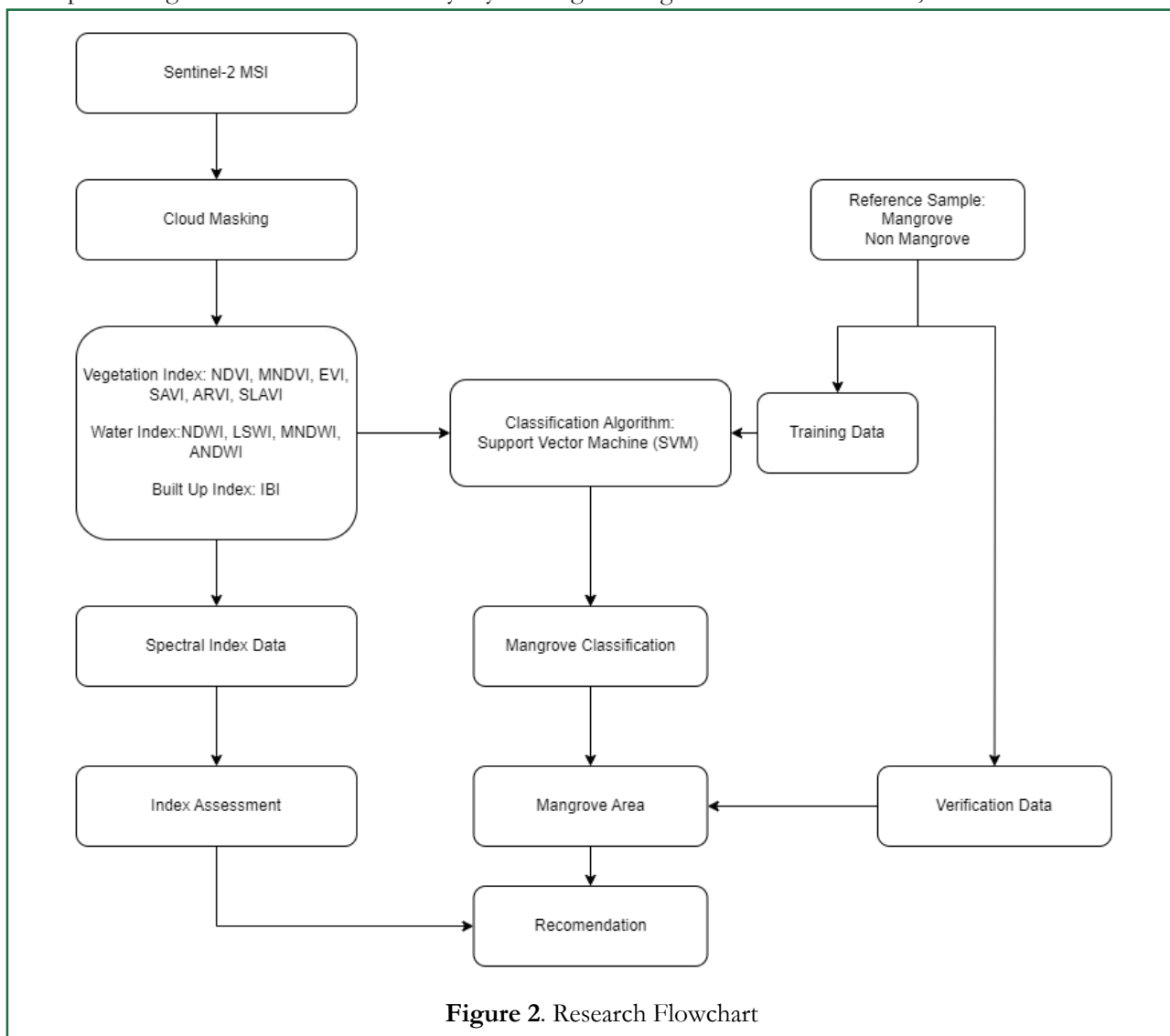


Figure 2. Research Flowchart

vegetation and water indices, while the development index is involved in distinguishing between submerged and non-submerged mangroves. The combination of these indices demonstrates improved performance in detecting the spectral reflection from the Earth's surface (Tran *et al.* 2022). The correlation between these indices shows how mangroves and other land covers are influenced by the spectral on the earth's surface and relevant environmental phenomena. In this study, the indices used are presented in Table 2.

## Accuration assessment

The classification of land use, especially mangroves, often results in data that does not match the actual conditions. Therefore, accuracy calculations are needed based on predicted and validation data comparisons. Assessment of mangrove forests and other land covers is done through evaluation indices. This study assesses the classification accuracy level using Overall Accuracy (OA) and Kappa Statistic (KS). OA is the ratio of the number of cells classified

correctly to the total number of cells. KS represents the proportion of errors reduced by classification and entirely random classification. Their formulas are listed below

$$\text{Overall Accuracy (OA)} = \frac{1}{N} \sum_{i=1}^r X_{ii} \times 100\%$$

$$\text{Kappa} = \frac{\sum_{i=1}^r X_{ii} - \sum_{i=1}^r \frac{X_{ii} (X_{i+} \times X_{+i})}{N^2}}{\sum_{i=1}^r X_{ii} (X_{i+} \times X_{+i})}$$

## RESULTS AND DISCUSSION

### Mangrove Distribution

#### Mangrove Classification Result

The classification results show mangrove areas with a total area of 836.91 ha or 6.57% of the total area of Bekasi District. Based on the mangrove distribution map (Figure 3), it can be seen that mangroves are distributed around the coastline, river estuaries, and aquaculture areas. Figure 3 also shows that the

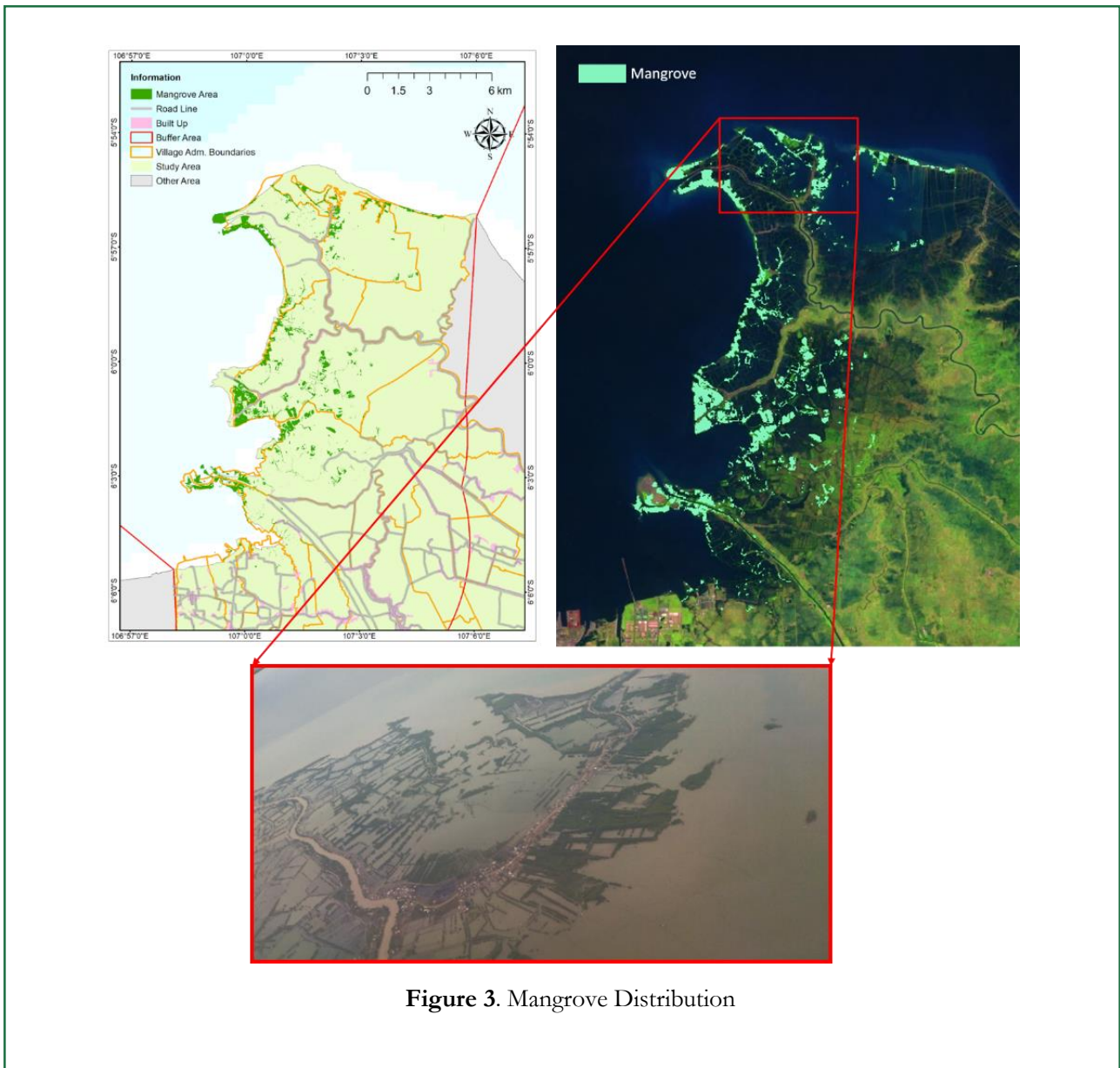
**Table 2.** List of indices used

No	Method	Formula	Reference
1	Normalized Difference Vegetation Index (NDVI)	$NDVI = (NIR - Red) / (NIR + Red)$	Rouse jr <i>et al.</i> 1974
2	Modified Normalized Difference Vegetation Index (MNDVI)	$MNDVI = (RE2 - RE1) / (RE2 + RE1)$	Jurgens 1997
3	Enhanced Vegetation Index (EVI)	$EVI = ((NIR - Red) / ((NIR + 6) * (Red - 7.5) * (Blue + 1))) * 2.5$	Huete <i>et al.</i> 2002
4	Soil Adjusted Vegetation Index (SAVI)	$SAVI = ((NIR - Red) / (NIR + Red + 0.5)) * (1.0 + 0.5)$	Rouse jr <i>et al.</i> 1974
5	Specific Leaf Area Vegetation Index (SLAVI)	$SLAVI = NIR / (Red + SWIR2)$	Lymburner <i>et al.</i> 2000
6	Atmospherically Resistant Vegetation Index (ARVI)	$ARVI = (NIR - (Red - (1 * (Red - Blue)))) / (NIR + (Red - (1 * (Red - Blue))))$	Kaufman <i>et al.</i> 1992
7	Normalized Difference Water Index (NDWI)	$NDWI = Green - NIR / Green + NIR$	McFeeters 1996
8	Land Surface Water Index (LSWI)	$LSWI = NIR - SWIR2 / NIR + SWIR2$	Xiao <i>et al.</i> 2002
9	Modified Normalized Difference Water Index (MNDWI)	$MNDWI = Green - SWIR2 / Green + SWIR2$	Xu 2006
10	Augmented Normalized Difference Water Index (ANDWI)	$ANDWI = (Blue + Green + Red - NIR - SWIR1 - SWIR2) / (Blue + Green + Red + NIR + SWIR1 + SWIR2)$	Rad <i>et al.</i> 2021
11	Index-Based Built-up Index (IBI)	$IBI = NDBI - ((SAVI + MNDWI) / 2) / NDBI + ((SAVI + MNDWI) / 2)$	Xu 2008

mangrove vegetation found in river estuaries has a relatively larger area compared to others. The study of [Maryantika & Lin \(2017\)](#) showed the same result that most of the mangroves in the Sidoarjo coastal area are distributed in river estuaries and around the coastline and have increased in the area due to sedimentation. Meanwhile, [Purwanto \*et al.\* \(2022\)](#) reported that mangrove vegetation distributed in river estuaries has variations in species and salinity that decrease from the coast to residential areas. Mangrove vegetation can grow well in river estuary areas because they have plant nutrient concentrations such as ammonium, phosphate, and dissolved organic matter that come from river sediments ([Tanaka & Choo 2000](#)). In addition, there is mangrove vegetation around the fish ponds. Mangrove vegetation that lives in the area of the fish ponds obtains nutrients from the metabolic waste of aquaculture commodities such as NH<sub>4</sub><sup>+</sup>. Planting mangrove

vegetation around the ponds can reduce the concentration of toxic substances that can interfere with pond production, such as NH<sub>4</sub><sup>+</sup>, NO<sub>2</sub><sup>-</sup>, PO<sub>4</sub><sup>3-</sup>, and other heavy metals ([De-Leon-Herrera \*et al.\* 2015](#)).

The mangrove area of the study location is adjacent to other land uses, such as urban areas (Figure 3). In addition, some of the mangrove areas are also scattered in the pond areas. The distribution of mangrove areas in the study location is spread across nine villages, with each area size displayed in Figure 9. The mangroves area study are spread across three beaches, namely Bahagia Beach in the northern part, followed by Mekar Beach and Makmur Beach on the western side. Based on the analysis, Bahagia Beach has the highest distribution of mangrove areas with a total area of 220.11 ha. This is quite different from the results of [Pamungkas \(2020\)](#) study, which revealed a mangrove area of 301.83 ha in Bahagia Beach. Similar results were



**Figure 3.** Mangrove Distribution

also found in other villages such as Mekar Beach, where a previous study by Hanan *et al.* (2020) revealed an area of 377.06 ha, while our study found only 197.22 ha. Meanwhile, the lowest mangrove area is in Makmur Beach with a total area of only 3.75 ha. Maulani (2021) stated that the decreasing mangrove area in these three areas is influenced by human activities, such as land conversion into pond areas, which continues to increase yearly. In addition, the mangrove area is also converted into rice fields, gardens, and even residential areas.

Mangrove plants community are divided into three groups, namely the major mangrove plants, minor mangrove plants, and mangrove associate plants (Kitamura *et al.* 1997; Tomlinson 2016). Major mangrove plants are true mangrove plants with the best

Mangrove density can be estimated using the NDVI approach or vegetation index. The findings of Ulqodry *et al.* 2021 show a high correlation between NDVI values and canopy cover or Leaf Area Index (LAI). One of the methods for monitoring mangrove vegetation is using GIS and Remote Sensing. Remote sensing is the science and art of acquiring information without direct contact with the object being studied, allowing for monitoring of the entire area without direct intervention that could potentially damage the studied object. The remote sensing subsystem is divided into two parts, data acquisition and data utilization. The data acquisition subsystem is concerned with designing and manufacturing sensors and materials, processing data recorded by the sensor until it is sent to the receiving

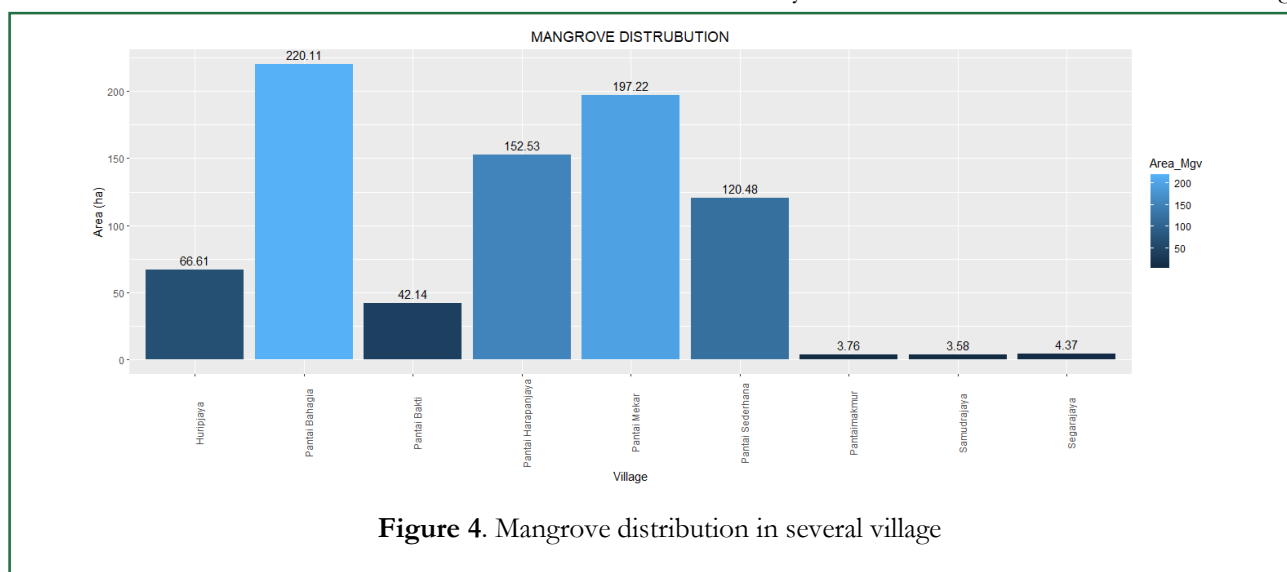


Figure 4. Mangrove distribution in several village

adaptability to tidal conditions and high salinity levels (Tomlinson 2016). This group of mangroves can form pure stands, dominantly characterize the community structure, and have physiological mechanisms to control salt (Tomlinson 2016). Minor mangrove plants are mangrove species that grow on the margins and do not form pure stands. Examples of minor mangrove species include *Bruquiera ciliandra*, *Nypa fruticans*, *Intsia bijuga*, *Xylocarpus moluccensis*, and others (Tomlinson 2016). Meanwhile, mangrove associates are a type of plants that have a lower ecological and physiological ability to survive in the mangrove ecosystem than true mangroves, characterized by the lower leaf succulence (two times lower than true mangroves), as well as the lower accumulation of Na and Cl (8-9 times lower than true mangroves) (Wang *et al.* 2011). The following plants are included in this classification: *Acrostichum* spp., *Excoecaria agallocha*, *Heritiera littoralis*, and *Hernandia nymphaeifolia* (Wang *et al.* 2011).

station and the data is ready for use by the user. Meanwhile, the data utilization subsystem is responsible for processing and analyzing remote sensing data generated by the data acquisition subsystem, the results of which can be used by decision-makers in natural resource management. The application of remote sensing in mangrove areas is very effective for monitoring the mangrove ecosystem. This application provides a lot of important information about the mangrove ecosystem, such as habitat inventory, regeneration capacity, productivity, estimation, and more. One of the methods that is often used in the application of remote sensing in mangrove areas is aerial photo mapping. Aerial photo mapping is considered effective for small and narrow coastal ecosystems. This mapping is done by identifying visual image results taken over time about changes in the environmental

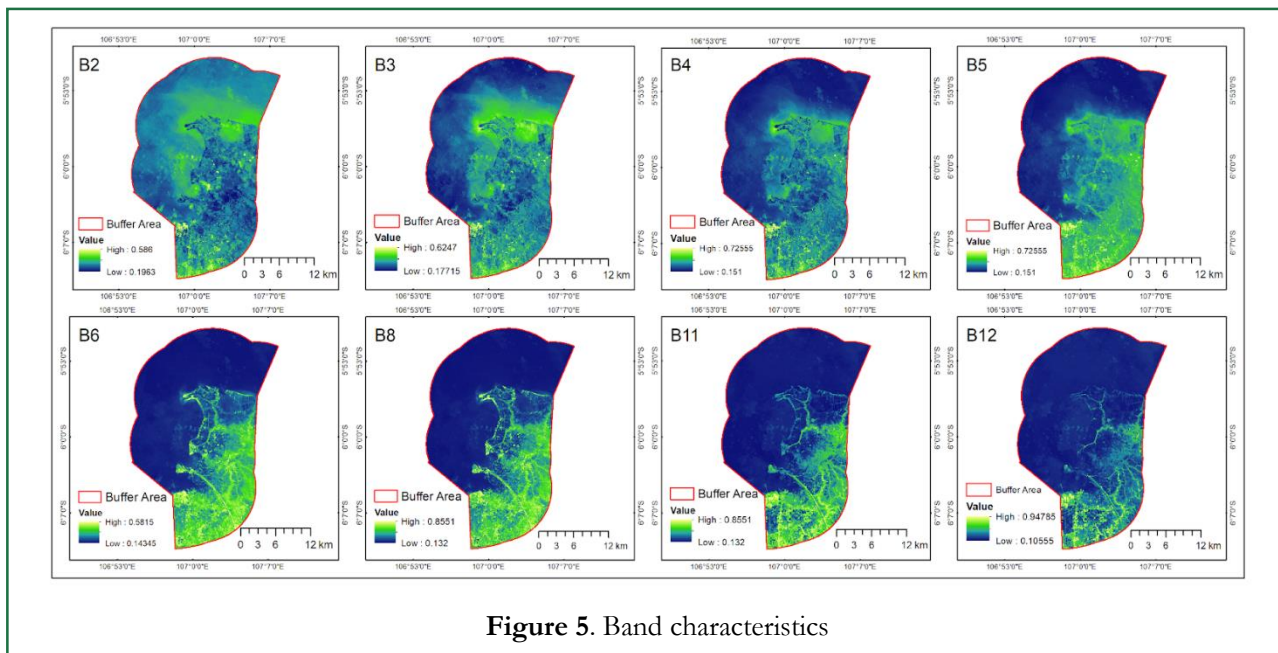


Figure 5. Band characteristics

area of the mangrove ecosystem. The detailed aspects that focus on identification in aerial mapping include color, texture, structure, and attributes so that the diversity of mangrove species in the related area can be identified more effectively (Kuenzer et al. 2011).

### Mangrove Spatial Characteristics

Mangrove forest has different characteristics from other land covers and uses, as seen from the band characteristics and indices of the Sentinel-2 MSI satellite. Figure 3 shows the visual band characteristics

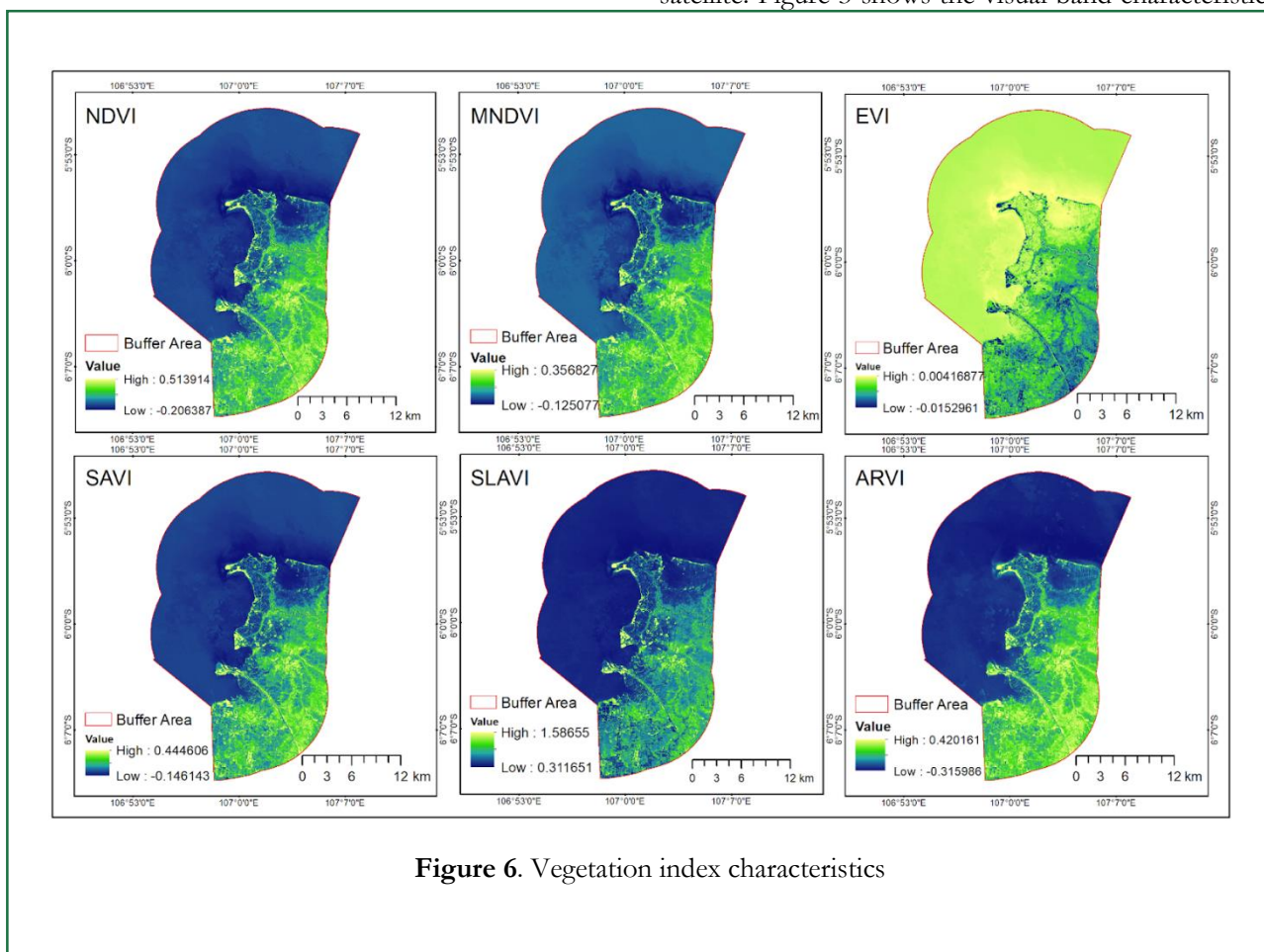


Figure 6. Vegetation index characteristics

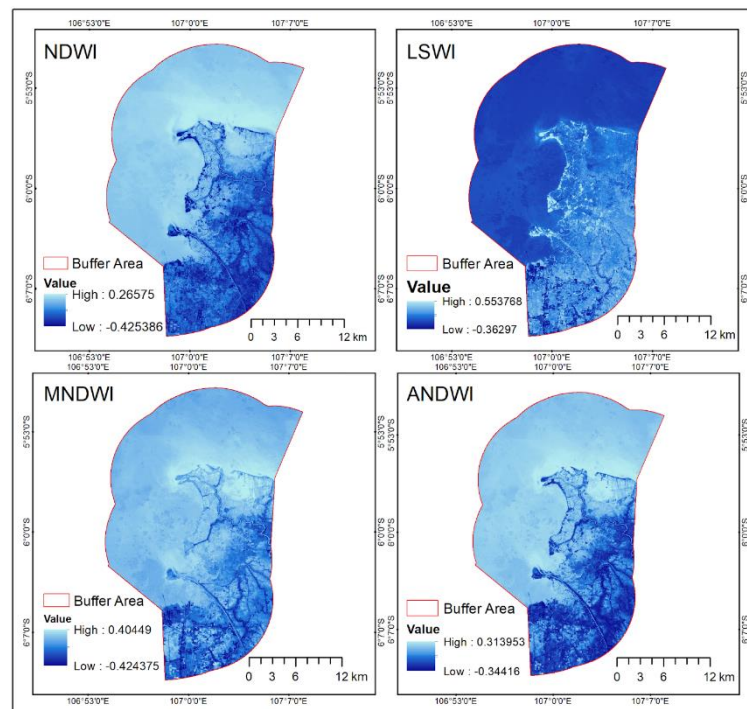


Figure 7. Water index characteristics

in distinguishing land covers in the study location. The constantly flooded condition makes mangrove forest have different characteristics from other vegetation. The band characteristics used in this study on Sentinel 2 show a darker color on the mangrove land cover. This is due to the presence of water features in the mangrove ecosystem. Water has the ability to absorb all radiation energy, so only a tiny amount of reflectance is received by the sensor (Jerome *et al.* 1996). B2, B3, B4, and B5 show a relatively high sensitivity to water sediment. Band 12, namely SWIR, has a fairly good ability to detect the health of mangrove vegetation because it is quite sensitive to the canopy's density and water content (Manna & Raychudhuri 2018). The highest spectral value is found in band 8, namely NIR, while the lowest is in B12 SWIR. The combination of bands involving these indices will result in high sensitivity to the presence of mangroves (Zhen *et al.* 2021). Wang *et al.* (2018) research results show that B6 (red-edge band) has the highest importance value in detecting mangrove areas, followed by B11 (SWIR), B8 (NIR), and B2 (blue). B2 has a correlation to surface soil biomass with an R square value of 0.49.

The vegetation index shows that mangrove forests have a different color compared to other land cover (Figure 6). In the modified NDVI index, MNDVI, SAVI, SLAVI, NDWI, LSWI, MNDWI, and IBI, mangroves show the highest values indicated by

brighter colors. However, EVI has a lower value compared to other land use classes. Nevertheless, EVI has the ability to reduce sensitivity to atmospheric effects and substrate differences, making it quite effective in the biophysical condition of mangroves (Tran *et al.* 2022). On the other hand, ARVI has a value almost similar to other vegetated land covers such as rice farming plantations. ARVI is quite effective in

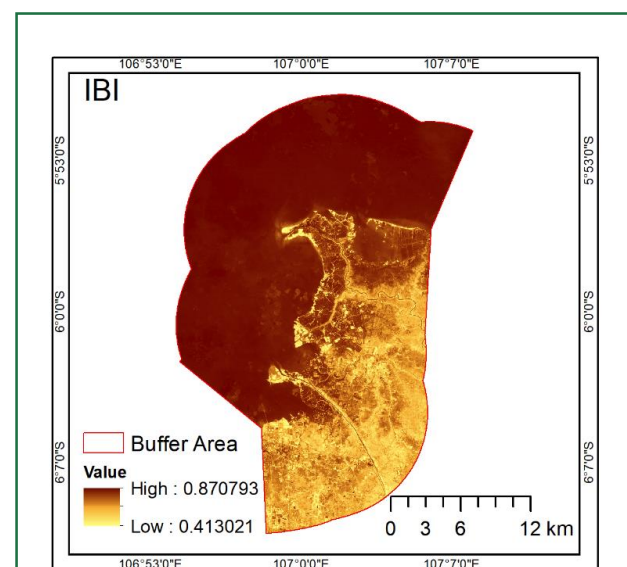


Figure 8. Built-up index characteristics

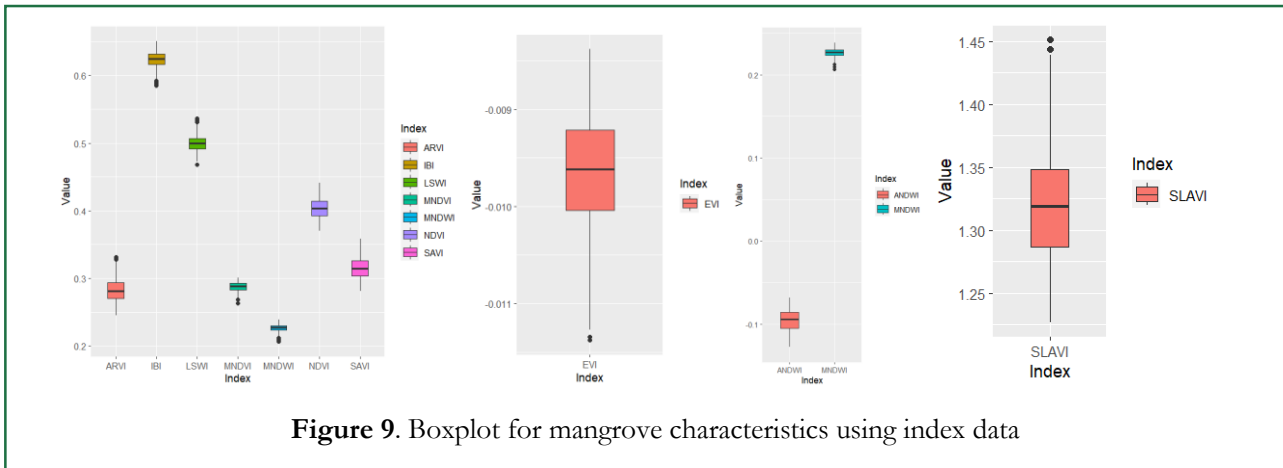


Figure 9. Boxplot for mangrove characteristics using index data

distinguishing vegetation and non-vegetation areas. ARVI has a relatively high significant value compared to other vegetation indices in detecting vegetated areas using the random forest algorithm (Asgari & Hasanlou 2020). ARVI is designed to detect scattering in industrial areas caused by atmospheric effects such as dust and smoke (Lemenkova & Debeir 2023). The high coloration in the vegetation and water indices is because the mangrove ecosystem has water and vegetation features that satellite sensors can capture.

The water and built-up indices have quite high differences in the value range. Visually, the water and built-up indices are shown in figures 7 and 8. The water index shows that water bodies have a real influence on the identification of mangrove vegetation. The NDWI, MNDWI and ANDWI indices show that mangroves have the highest values, which are characterized by darker hues. LSWI has a lower value compared to other land use classes so it displays mangroves with brighter color hues. Visually, MNDWI is able to distinguish between mangrove, non-mangrove and water body land cover because it has quite different spectral values for the three land covers (Asy'Ari *et al.* 2022). Meanwhile, the built index is a complement to other indices in identifying mangrove vegetation. The color of mangrove vegetation in the built index produces a different color hue from other land. With low values, the color of mangrove vegetation displays increasingly bright colors (Figure 8). However, the built index is important enough to be involved in mangrove detection. Research by Asy'Ari *et al.* (2023B) shows that IBI has a fairly high importance value in classifying land using a random forest algorithm which involves several indices. Research by Rahmawati *et al.* (2022) reported that the use of IBI alone in detecting mangroves had quite low deviations in area values compared to using a combination of indices.

The vegetation, water bodies and built-up index values are presented in boxplot form in Figure 9. Each index has different characteristics so that different ranges of values are produced. Several vegetation indices that have a similar value range are ARVI with a value range of (0.24 to 0.33), MNDWI (0.36 to 0.30), SAVI (0.28 to 0.35). The SLAVI index with a value range of 1.20 to 1.45 has the highest value among the others. NDVI has a value range of 0.37 to 0.44. On the other hand, ANDWI has the lowest value range. The other indices involved had a range of values: LSWI (0.47 to 0.54), MNDWI (0.21 to 0.24), and IBI (0.58 to 0.65). These results are not much different from the report by Asy'ari *et al.* (2022) which shows that the NDVI value in mangroves is in the range of 0.39 to 0.61; ARVI (0.16 to 0.43); MNDWI (0.32 to 0.60); and LSWI (0.60 to 0.79). The combination of these indices can provide information in identifying mangroves regarding their unique habitat suitability. Using a vegetation index alone tends to result in an underestimation of mangrove area detection, while using a water index alone results in an overestimate of mangrove area, so a combination of the two types of index is needed (Rahmawati *et al.* 2022). The research results of Jia *et al.* (2019), vegetation indices and indices in mangrove areas have a longer range of values than water bodies and are less sensitive to distinguish between submerged and non-submerged mangroves. In addition, Lemenkova & Debeir (2023) reported a range of ARVI values of -0.3 to 0.8. Muhsoni *et al.* (2018) examined the relationship between NDVI spectral values and tree biomass and obtained an average NDVI value of 0.41 and R square 0.85 using exponential regression. Water index values such as NDWI are quite sensitive to the dynamics of soil conditions. The NDWI spectral value has a positive correlation with monthly rainfall (Pastor-Guzman *et al.* 2018).

## Mangrove Accuracy

Accuracy testing is carried out by comparing prediction data with validation data as a form of assessing the level of accuracy (Fitzgerald & Lees 1994). The research results show that the OA and KS accuracy tests have mangrove classification with a good level of accuracy. The SVM algorithm carried out on the advanced GEE platform is able to produce accuracy values reaching 90% (on OA) and 0.8 (on KS). Land cover classification involving index algorithms has a fairly high ability to detect various land covers. The research results of Asy'Ari *et al.* (2023B) showed a classification of ten types of very heterogeneous land cover involving eleven vegetation and water indexes showing an OA value of 80.08%. Meanwhile, Rahmawati & Asy'ari (2021) reported that mangrove detection using a random forest algorithm involving 13 vegetation, water and built-up indices produced an OA value of 96.50%. An ideal OA value in the classification assessment validation test must be greater than 70% (Congalton 1991; Alajangi *et al.* 2021). If the OA value does not reach 70%, it is necessary to reclassify or create a new training area. Based on this, the results of this research can be categorized as worthy of testing.

According to Scepán (1999), the OA score has a set limit, namely a minimum confidence level of 85%, while the KS score has an interpretation class, namely Poor (<0.0), Slight (0.00-0.20), Fairly Good (0.21-0.40), Fair (0.41-0.60), Substantial (0.61-0.80), and Nearly perfect (0.81-1.00). Based on this statement, this mangrove classification produces a mangrove map with a good level of accuracy and a KS value that is classified as almost perfect.

## Agricultural and Fishery Activities

Based on the results of field observations, the condition of coastal Bekasi Regency is extremely concerning. Mangroves have been degraded and only a few of them remain in the area. The dominant land use is for aquaculture and rice farming (Figure 10 parts 1 and 4). The land used for aquaculture and farming is owned by the local community (private property), and there are also several mechanisms for leasing land. Fishing activities with land use systems in the form of aquaculture occupy almost all of the land in the coastline zone. Fishing activities in this area are considered to contribute significantly to Indonesia's fish production through exports and national consumption,

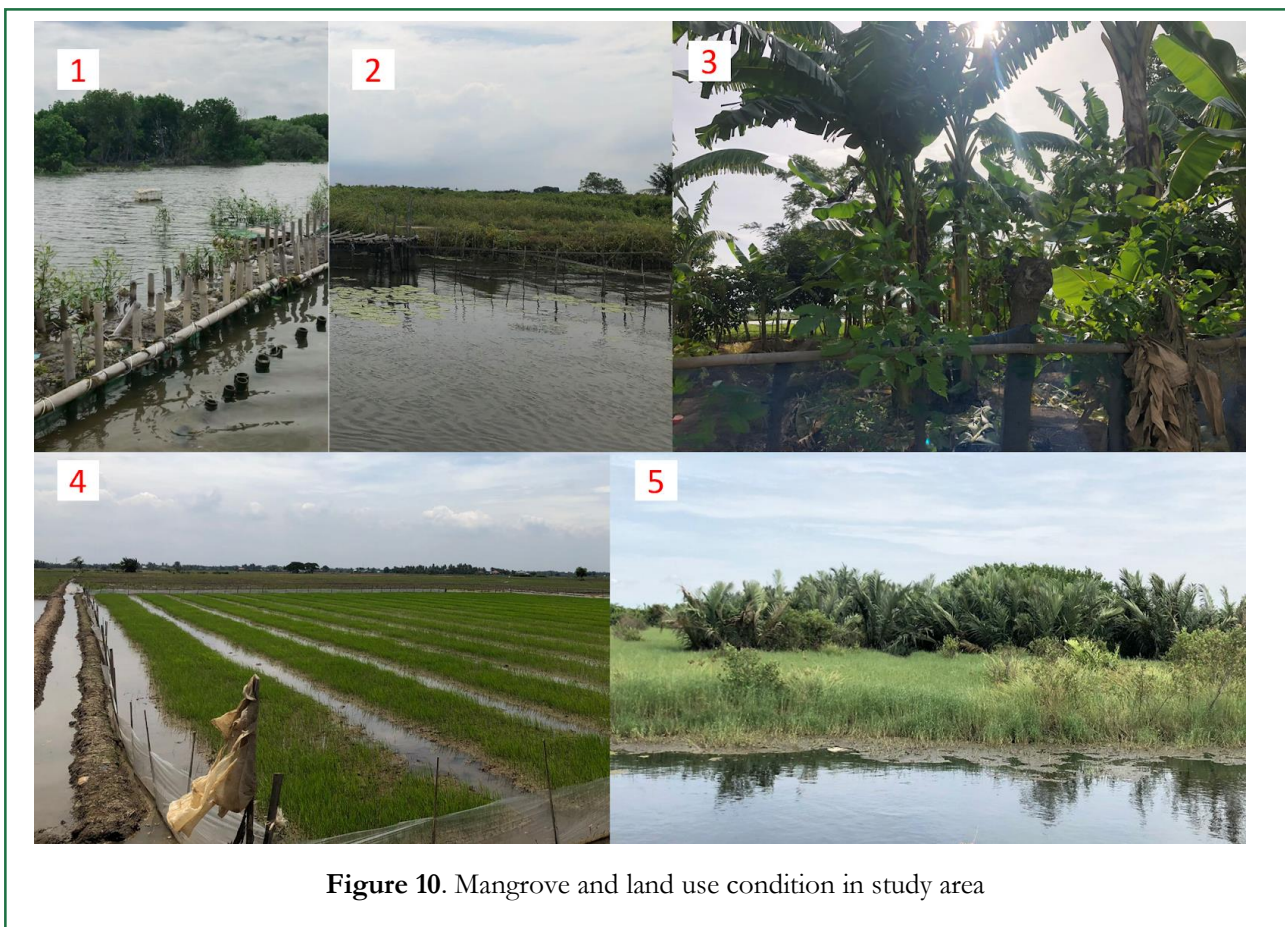
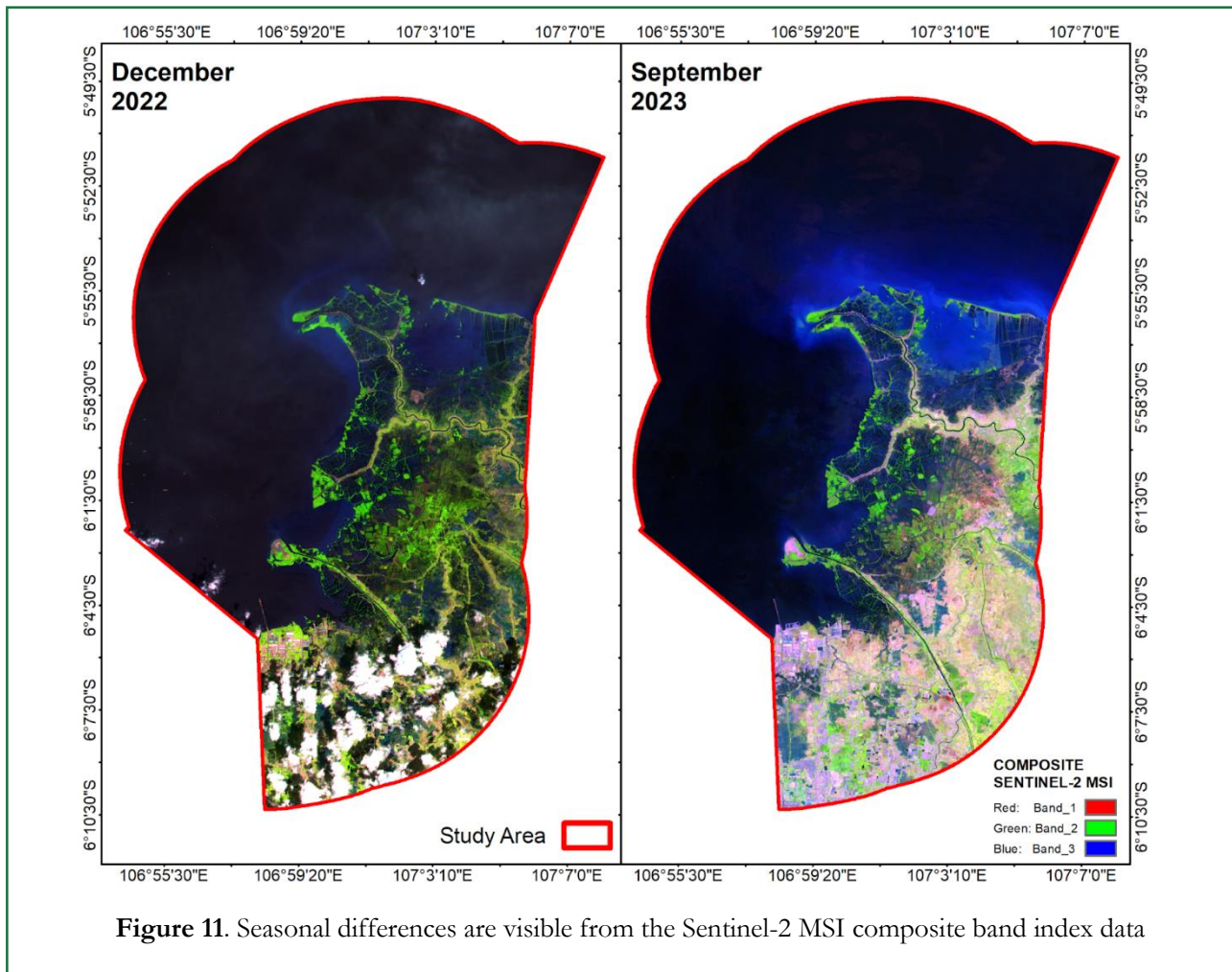


Figure 10. Mangrove and land use condition in study area



**Figure 11.** Seasonal differences are visible from the Sentinel-2 MSI composite band index data

especially in the Jabodetabek mega urban area. According to [Rimmer \*et al.\* \(2013\)](#), fishing activities in Indonesian aquaculture are capable of making a significant contribution to global production and are able to dominate the international market. In the study area, the coastal community of Bekasi Regency produces commodity products such as shrimp (wild shrimp and tiger shrimp), milkfish, tilapia, and a small amount of seaweed cultivation. The results of the aquaculture production are sold directly in the market or the community has a purchase agreement with the middleman. However, there are non-functional pond areas due to inadequate water supply and contamination caused by industrial and livestock activities.

On the mainland, land is used for rice commodity which is directly adjacent to the aquaculture activities. Based on the interview results, land use other than rice includes the cultivation of watermelon and cantaloupe. The surrounding community carries out land cultivation in agriculture, and there is also cultivated land that is not owned by the locals but belongs to entrepreneurs in the surrounding large cities. In addition, there are several intercropping businesses

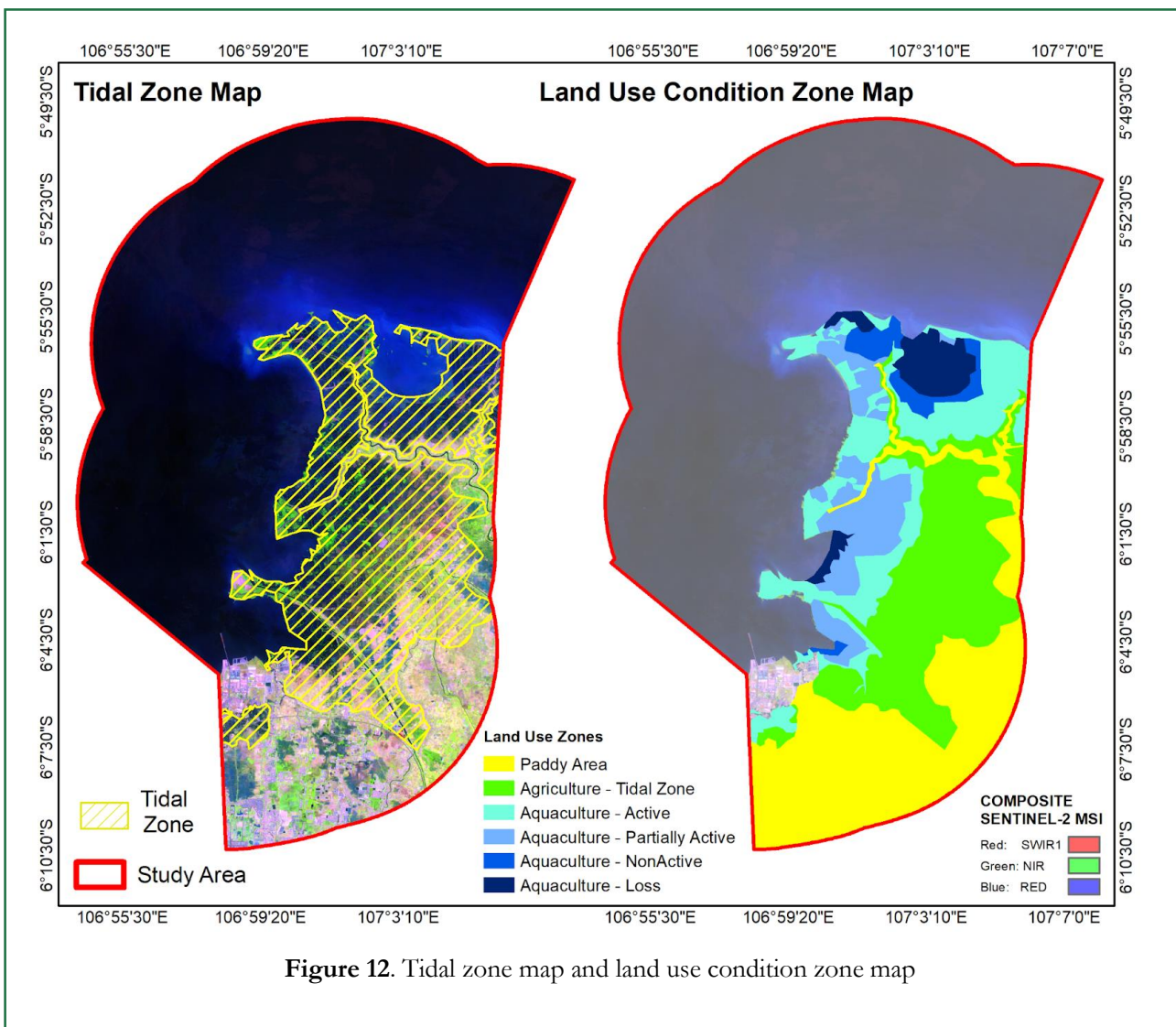
that utilise the remaining space in the aquaculture and agriculture area (Figure 10 part 3). Land use with this intercropping system is planted with various crops such as bananas, cantaloupes, watermelons, chilli, and other crops. The implementation of this intercropping system is often found on land near riverbanks. The selection of crops is carefully considered based on the specific conditions of the land, including salinity levels and tidal patterns. This is because in certain tidal wave land conditions, agricultural crops will experience iron (Fe) poisoning that affects growth, formation of tillers, and grain filling ([Mawardi \*et al.\* 2020](#)).

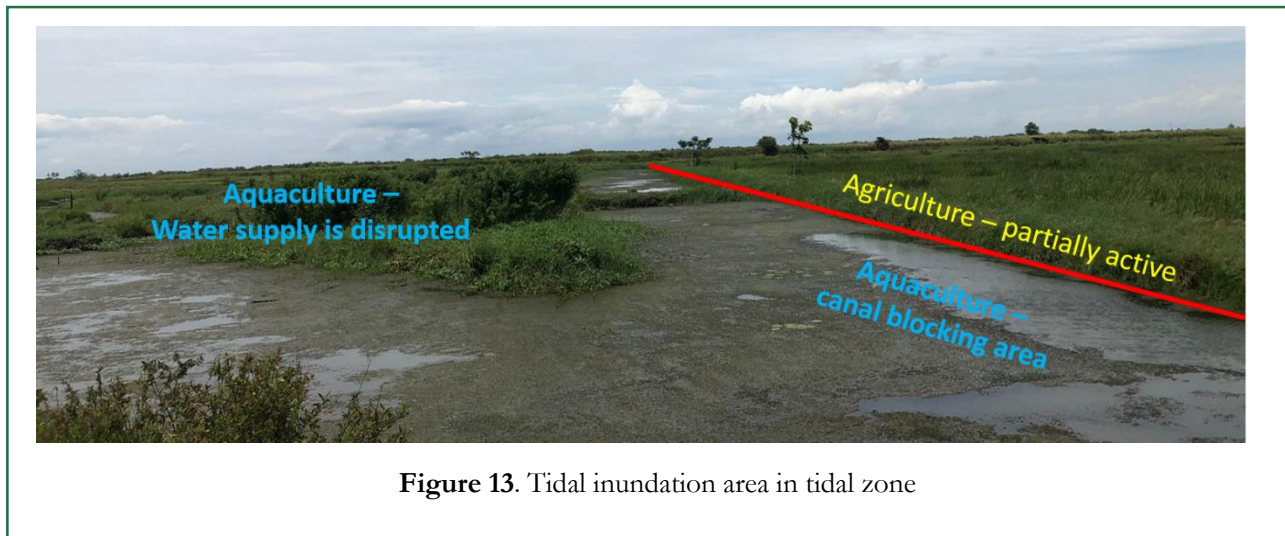
Coastal areas have a tidal zone that extends up to 5-10 km from the outermost mangroves on the coastline. This zone experiences tides every year caused by sea breezes, with the highest tides occurring at the end of the year (December to be precise). A meteorological phenomenon known as the west monsoon, which occurs from October to April causes the rise in sea level. According to [Wicaksana \*et al.\* \(2015\)](#), significant sea waves occur in the Java Sea in January, reaching heights of 0.5-2.5 meters. This can be seen from Figure 11 and Figure 12, which show the

inundation conditions that spread far at the end of the year (December 2022 to be precise). This is very different from the dry season month (September 2023), where the sea water level does not reach agricultural areas (Figure 11). Figure 13 shows the current picture during the dry season, with the boundary between the pond and agricultural areas. At the highest tide, sea water submerges the pond area and spreads to the rice farming area. Figure 14 shows an increase in NDVI values during the rainy season (December 2022), characterized by the sensitivity of NIR and RED values in submerged vegetation and the possible effects of rising tidal water reaching agricultural areas. *Lee et al. (2017)* explained that the increase in sea tides resulted in the pooling of sea water in coastal areas on land. The same thing was also found by research by *Marfai (2014)* and *Pattanaik et al. (2011)*, that fish farming ponds, agriculture, and plantations have great potential to be affected by tidal flooding. Rising sea levels and tidal

waves can potentially damage several supporting infrastructures for ponds and other agricultural businesses. High tide flooded the pond and damaged the water circulation system, which was limited by the pond embankment. Apart from that, the impact felt by coastal communities is the lack of access to pond land due to the inundation of road infrastructure. This provides vulnerability to the productivity of coastal ponds. This vulnerability will always occur and can expand after a coastal disaster occurs.

In the tidal zone, two alternating activities are found throughout the year, namely farming and fish farming. During high tide, the land in this zone is used for fish farming, as well as for other livelihoods such as fishing. The fishing activity referred to here is not ocean fishing, but rather the search for various marine biota that enter the tidal zone which can be utilized and have commercial value. This is because fishing activities in the ocean will be interrupted during high waves and





**Figure 13.** Tidal inundation area in tidal zone

strong winds (peak rainy season, between November - April). Meanwhile, during the dry season, precisely from May to September, the community utilizes the land for agriculture. On the other hand, there is also paddy land that does not function during the high tide season (located in the agricultural utilization zone - tidal zone, Figure 12). This is because paddy land is not physically designed to accommodate fish farming activities. Another case that is also found is that in some places, the high tide waves reach the river banks which are the banana plantations owned by the surrounding community. This certainly has a significant impact on agricultural and plantation businesses owned by the surrounding community. The effects of meteorological and oceanographic activities certainly temporarily halt the livelihoods of the surrounding community, especially those who do not have fishing equipment.

The condition that occurs on the coast in the study area is considered a threat to the productivity of rice crops in the rice granary area and shrimp production in Bekasi Regency. In the case of rice commodities, the same thing happened in the agricultural areas around the Ganges, Mekong, Nile, Yangtze, and Yellow River in the Republic of China. The quality of paddy agricultural land decreased due to the impact of tidal waves (Nguyen 2002). Previous studies have explained that the annual increase in sea level will have fatal consequences, where it will flood wetlands (including agriculture) and low-lying coastal areas, erode the coast, increase the risk of floods, and increase the salinity of estuaries, aquifers, and wetlands (Titus 1990; Chen *et al.* 2012; Spencer *et al.* 2016; Nicholls *et al.* 1999; Nicholls 2002). This has happened in some of the northern Bekasi Regency shrimp farming areas, Figure 12 (Aquaculture - Loss section) shows former shrimp farms that have disappeared and are

covered by the sea. In this case, if it happens continuously, agricultural areas and shrimp farming areas in this zone will experience erosion due to the changing tidal patterns every year. Lubis & Yosi (2012) explained that strong winds and heavy rain in the northern coastal waters of West Java resulted in significant changes in tidal patterns and ocean currents. The same case happened in Pekalongan Regency and Demak Regency which experienced erosion of agricultural and shrimp farming areas due to the rise in sea level (Marfai 2014; Muskananfolo *et al.* 2020). Meanwhile, Abdillah *et al.* (2022) and Silveira *et al.* (2022) explained that extreme winds (Hurricane) are a natural disaster that often occurs in Indonesia and are destructive.

### Silvofishery

The utilization of land with simple systems in shrimp farming indirectly has a negative impact on the environment, especially in terms of potential loss of carbon storage in wetlands. This is due to the opening of shrimp ponds on the coast, which eliminates mangrove vegetation (Primavera 2006). The destruction of the world's mangrove ecosystems is partly due to land occupation by shrimp farming (Hamilton 2013; Veetil *et al.* 2019; Herbeck *et al.* 2020; Luo *et al.* 2022). Although the presence of mangroves is one of the initial factors underlying the spatial expansion of shrimp farming (Akber *et al.* 2020), Asy'Ari *et al.* (2023A) found that some mangroves had been converted and damaged due to land clearing for shrimp farming in the coastal Subang region. Several follow-up studies have discussed various applications of the latest systems, namely silvofishery, which become a solution to land use on the coast. Shrimp pond land with silvofishery patterns

ecologically receives a high supply of organic material from mangrove stands, making it a source of income for residents around the mangrove forest (Sulistiyorini *et al.* 2018). Based on field observations, in several locations, shrimp pond land with silvofishery concepts was found. Information from the community shows that the silvofishery program has been carried out in the coastal area of Bekasi and has been socialized by the government. Planting is carried out on a large scale in the pond and embankments are provided for planting routes. This can be seen in Figure 15 part 1, where there are new embankments formed for planting preparation, and on the far left, there is a row of mangroves with this scheme. Figure 15 shows the physical differences of the shrimp pond in 2001 when it was left unused (and may have been a former pond), in 2006 it depicts the area that has been cleaned and embankments have been constructed, while in 2023 there are mangroves around the embankment. The area obtained from measuring satellite images (GE) on shrimp pond with silvofishery scheme is 34.1 hectares with a circumference of 2.48 km

(Figure 15 parts 2-3-4). The shrimp pond has 22 mangrove embankments, with the longest embankment being approximately 0.5 km long and 6-12 meters wide. The vertical section of the silvofishery system is shown in Figure 16. Based on field surveys and satellite images from the past two decades, it can be seen that the application of silvofishery systems is capable of saving abandoned shrimp ponds from the threat of seawater flooding during high tide. The mangroves inside the silvofishery shrimp pond are part of the 836,921 hectares that have been mapped.

The utilization of ponds with silvofishery scheme is considered to provide many environmental benefits. The study by Nesperos *et al.* (2021) found that pond land with the implementation of the aquasilviculture (AQS) system has higher carbon reserves compared to other systems. This system can support sustainable pond land use and help increase carbon reserves in wetland areas on the coast of West Java. In addition, the study by Matsui *et al.* (2014) explains that the

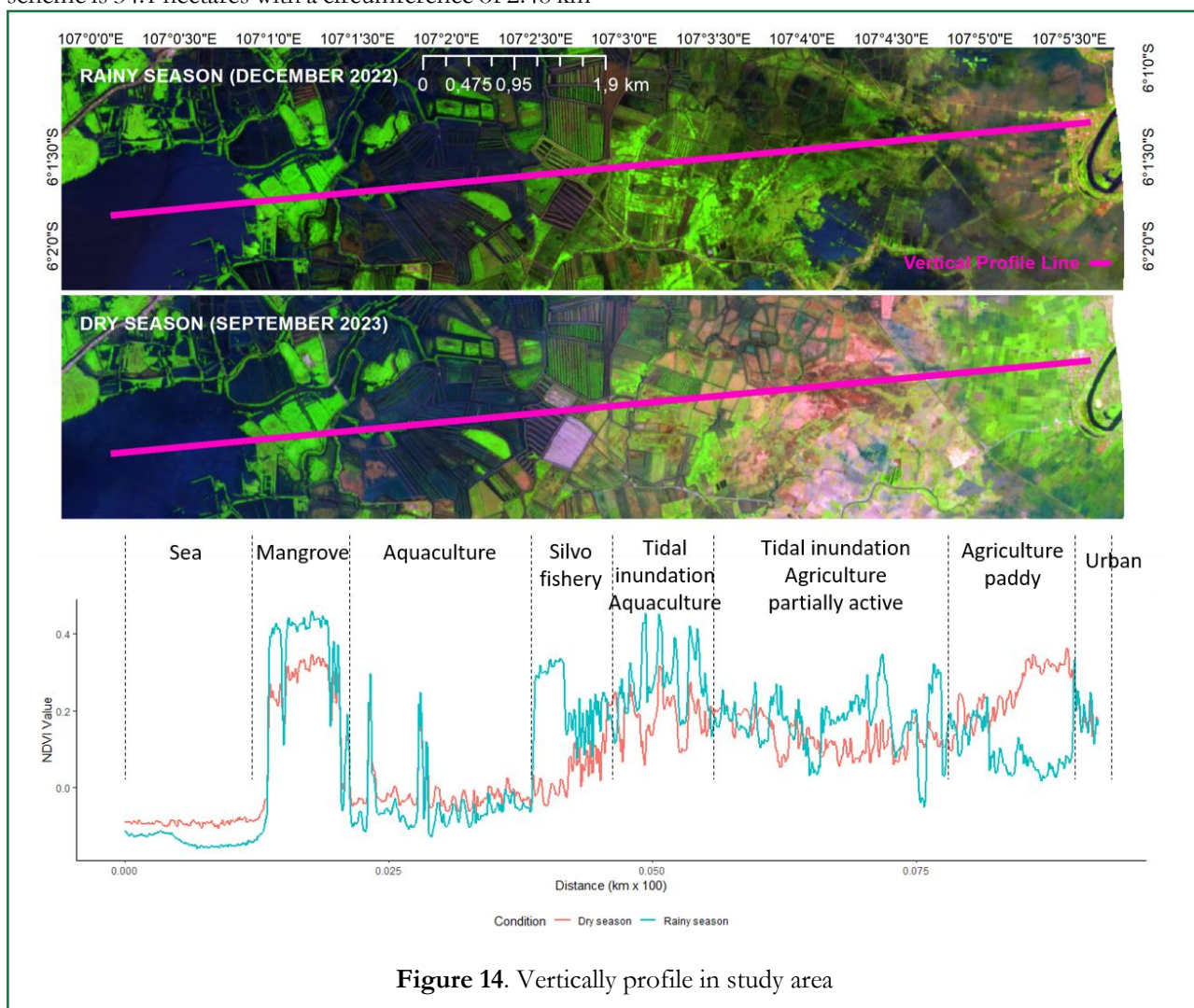
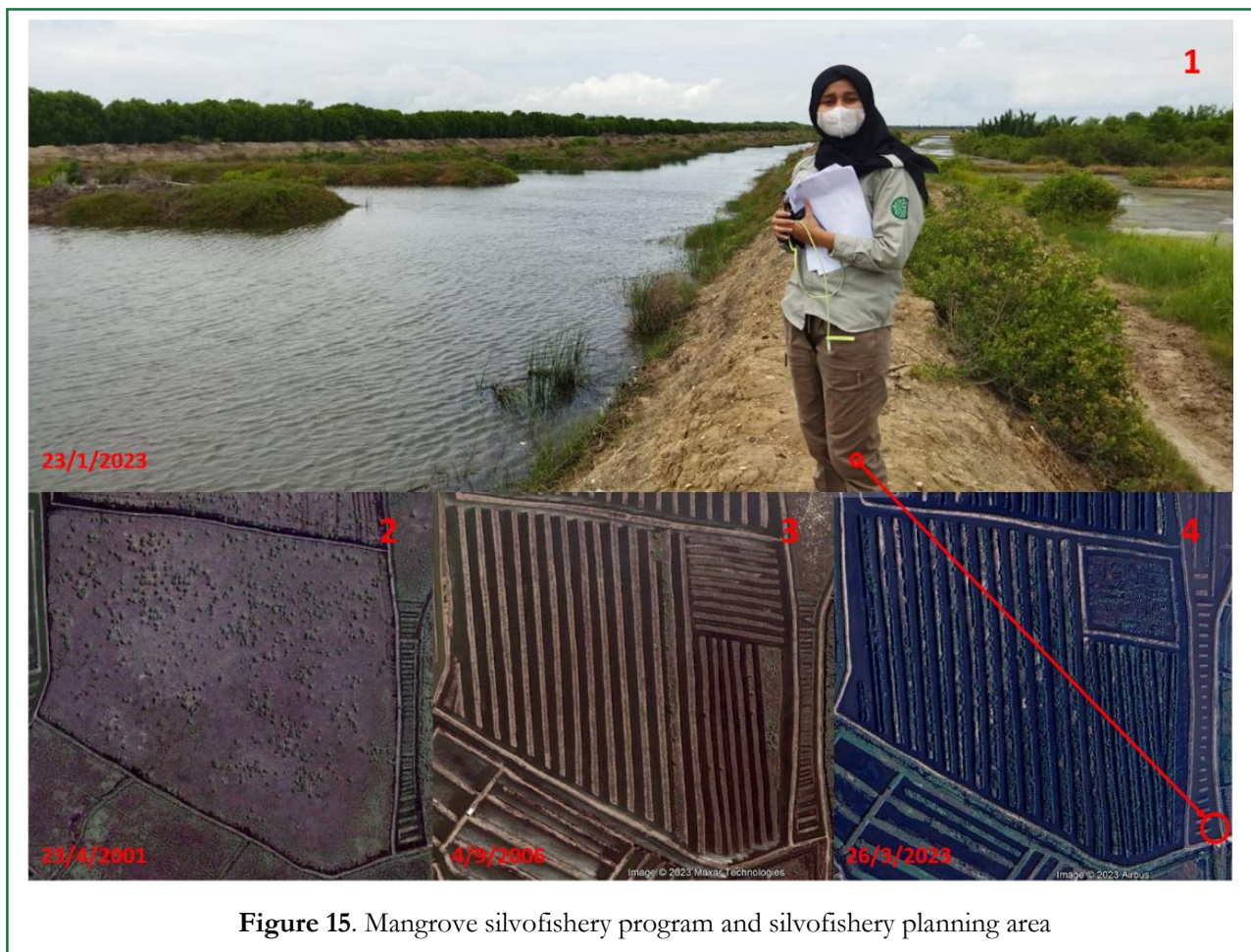


Figure 14. Vertically profile in study area



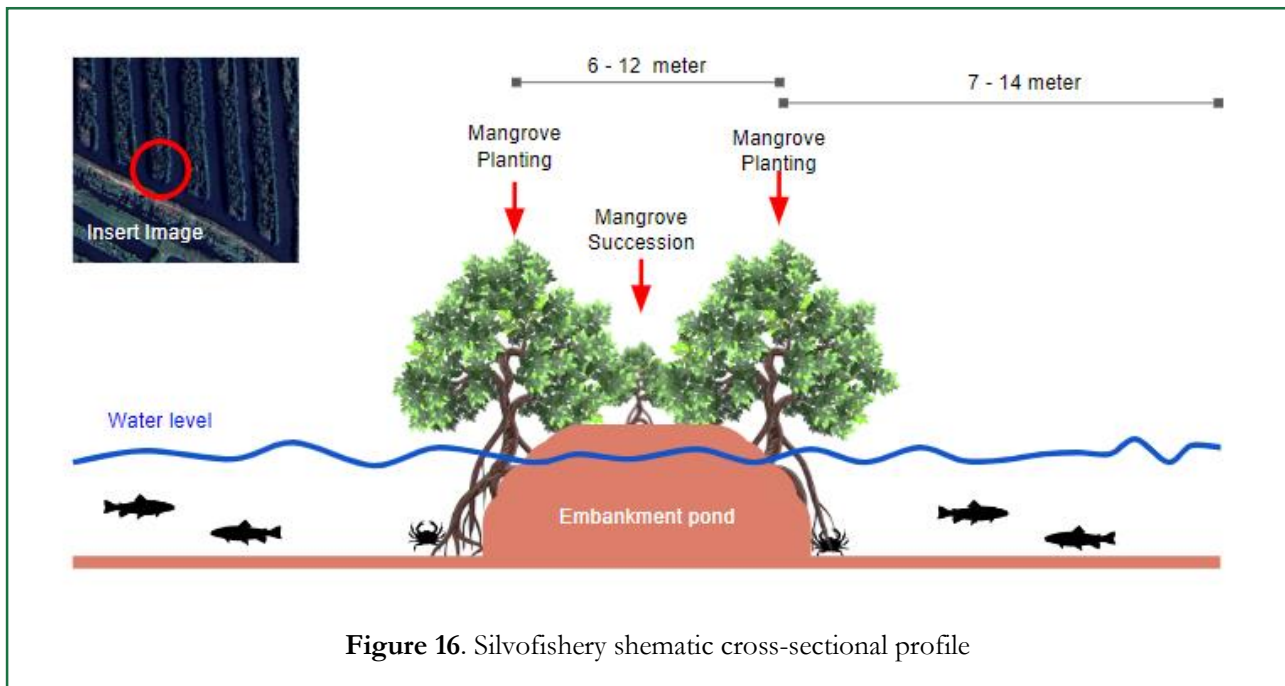
**Figure 15.** Mangrove silvofishery program and silvofishery planning area

implementation of this system can help save feed and has been replaced by detritus substitution obtained from mangrove plants. This certainly has an economic impact on pond owners and at the same time helps to save water quality and the environment on the coast. However, in the review that has been carried out, it shows that the community does not want the implementation of silvofishery. This is due to the incompatibility of production commodities with the silvofishery scheme, and shows a decrease in pond productivity. Pond owners must switch production commodities to maintain maximum pond productivity in the silvofishery system. This certainly requires a strategy for implementing the silvofishery system from the government and academics, as well as targeted socialization to the community.

### Mangrove Recovery and Rehabilitation

Mangroves play a significant role in combating changes in land boundaries (due to strong tidal currents and winds) and rising sea levels (Gilman *et al.* 2008; Zhang *et al.* 2012; Chow 2018; Gijsman *et al.* 2021). Mangrove forests can prevent land subsidence and hold back lost erosion (Malik *et al.* 2017; Minderhoud *et al.*

2018). The eroded sediment from the land is stored in the mangrove forest, forming SOC (sediment organic carbon) (Suella *et al.* 2022). Lovelock *et al.* (2022) explain that mangrove conservation is considered important in maintaining coastal resilience, which is constantly changing every year due to climate change. Large-scale mangrove reforestation is impossible, given that coastal areas have become the focus of coastal communities in their aquaculture efforts. This land use transformation will have an impact on the livelihoods of the surrounding communities that rely on coastal areas. Mangrove barriers can be installed in some of the outermost aquaculture areas, and silvofishery systems can also be applied as an alternative solution. Mangroves that act as barriers on the outermost part of the coastline provide protection against wave currents during high tide (Abe *et al.* 2015). This is considered capable of providing protection for aquaculture and tidal agricultural land. In addition, the presence of mangrove forests on the coastline can stimulate marine biota activity and contribute about >10% of dissolved organic carbon (DOC) to the surrounding ocean (Malik *et al.* 2017; Dittmar *et al.* 2006). This ecological service certainly has great potential indirectly and can be



**Figure 16.** Silvofishery schematic cross-sectional profile

utilized by the surrounding communities, especially fishermen, to support their families without having to own aquaculture land. Therefore, mangroves are concluded to be forest vegetation with a role in sustaining seafood for coastal communities in Indonesia (Ickowitz *et al.* 2023).

The mangrove ecosystem in the study area is currently showing improvement. Several mangrove barriers are found at the outermost boundary, specifically in the coastline area. However, the absence of natural mangrove barriers has resulted in the loss of many fishpond lands. In the backswamp area, mangroves grow along the embankment of the fishponds, which is a silvofishery implementation program (see Figure 15 and Figure 16). In addition, several abandoned community fishponds were found where natural succession of dominant mangrove shrub species was discovered, along with a few trees and nipah species (see Figure 10 part 5 and Figure 17). This process forms a tidal swamp ecosystem with great potential in restoring the mangrove ecosystem on the coast of Bekasi Regency. Wetlands also contribute by encouraging the movement of carbon and nutrients to the surrounding waters through the tide that enters this zone (Xin *et al.* 2022). The expanse of wetland vegetation is very important with its role in preventing seawater intrusion into the surrounding agricultural areas (Zhang *et al.* 2022; White & Kaplan 2017). Moreover, this vegetation is capable of holding back the seawater waves that enter the agricultural area and can increase biodiversity (Li *et al.* 2018; An & Verhoeven

2019; Saenz-Agudelo *et al.* 2021). Several studies also report that wetland restoration on the coast contributes significantly to restoring soil organic carbon that was previously lost due to human activities (Fu *et al.* 2020; Xu *et al.* 2019). Meanwhile, Sutton-Grier & Sandifer (2019) explained that wetlands play an important role in controlling natural disasters that threaten coastal residents.

### Statement and Recommendation

The coastal condition in the area is critically evaluated and threatened by climate change, which continuously erodes the land and impacts the utilization of the area. Climate change warns the coastal communities in various developing countries of the danger of rising sea levels, and this requires serious action (Dasgupta *et al.* 2009). Nurhidayaha & Mcllgorm (2019) explained that Jakarta and its surrounding areas, which have low topography, are vulnerable to the impact of climate change resulting in rising sea levels. This requires adaptation of coastal communities and support from government policies to reduce threats to coastal land use in various provinces in Indonesia (Forster *et al.* 2011). Esteban *et al.* (2020) assessed that the impact of climate change disasters threatens the financial well-being of coastal communities due to rising sea levels. Joseph *et al.* (2013) explained in the case of Central Java that coastal communities have adapted to respond to rising sea levels and tidal flooding, but if there is a massive transformation in the adaptation process, it could have fatal consequences for their



**Figure 17.** Wetland and mangrove recovery in tidal zone

livelihoods, and this requires support from the government. The same thing was also found in the research of [Buchori \*et al.\* \(2018\)](#) that communities do not choose to leave the area (relocate) in the adaptation process, due to social relationships within the long-established community.

The coast of Bekasi Regency needs strategic policy support that can restore the mangrove ecosystem quickly so that it can control the threat of seawater inundation, which increases the area of vulnerability every year. This effort will increase the area of mangroves, which currently only covers 836,921 hectares (Figure 3). The rise in sea level has a long-term effect on the potential intrusion of seawater into freshwater aquifers if prevention measures are not taken ([Zhang \*et al.\* 2022](#); [White & Kaplan 2017](#)). Implementing silvofishery systems also requires government policy intervention to save unproductive or threatened ponds (as shown in Figure 15). The most important thing is that there is potential for carbon stocks in mangrove sediment resulting from rehabilitation in the form of SOC in mangrove roots. [Deb & Mandal \(2021\)](#) explained that wetlands, including coastal areas, have a large and varied capacity for carbon storage according to their constituent components, and the influence of salinity in the soil results in carbon being stored in large amounts due to slowing decomposition. If carbon reserves continue to increase, it represents an excellent opportunity to help absorb excess carbon in the atmosphere ([Xiong \*et al.\* 2018](#)). [Crowther \*et al.\* \(2016\)](#) explained that the impact of global warming depends on the soil organic carbon

reserves available in a given area. Additionally, this effective solution considers the large number of industries in the Jabodetabek region that contribute to GHG emissions yearly.

## CONCLUSIONS

Mangroves in Bekasi Regency cover an area of 836.91 ha or 6.57% of the total area of Bekasi Regency and are distributed along the tidal area. This data is the result of remote sensing approach capabilities, with cloud computing-based integration, and a combination with field data. This mangrove distribution is key important role in the social, economic, and ecological aspects of coastal areas, especially as a protector of coastal community activities from oceanographic disasters. Mangroves in the study area also an important role in controlling climate change in Indonesia ambition and climate action target, with the existing agrosilvofishery concept providing great potential in reducing CO<sub>2</sub> emissions in the atmosphere. In addition, the silvofishery system in the pond area is also a great potential in reducing coastal erosion, which has been shown to change every year due to rising sea levels. Bekasi mangroves with less than 10% certainly have a strategic role in protecting the coast from the dangers of erosion, creating business opportunities that can help coastal communities, and protecting agriculture in the northern coastal area of this study area. This scientific information is expected to be an initial database related to the role of mangroves and useful for the basis of

policy making for stakeholders at the national and regional levels.

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