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Research Article

The Application of Multi Temporal Satellite Data For Land Cover Mapping of Bawean Island, East Java

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ABSTRACT

Land cover dynamics in a small island can be determined using Geographic Information System (GIS) approach based on multitemporal image analysis. This study aimed to classify major land cover types and to map land cover changes of Bawean Island. Two sets of 10 meter resolution satellite data ALOS AVNIR (2010) and Sentinel-2A (2020) were used in this study. Satellite image analysis was carried out through several stages namely image pre-processing including radiometric and geometric correction, supervised image classification and accuracy test. Image classification results from 2010 to 2020 showed a significant change in land cover on Bawean Island. The forest vegetation land cover declined significantly from 13,470.5 Ha in 2010 to 8,543.4 Ha in 2020. Most of the area have been converted into paddy fields and built-up areas. The accuracy test and validation were determined by comparing the 2020 Sentinel image classification results with field observation conducted in 2021. The analysis showed good results with 82.52% overall accuracy and 79.66 Kappa coefficient. Further investigation found that changes in land cover on Bawean Island occured due to the agriculture and infrastucture development.

Keywords : Geographic Information System (GIS); land cover; satellite images; small island

1. Introduction

Bawean island is located in the Java Sea, around 80 nautical miles north of the mainland of Gresik Regency, East Java Province. Due to its beauty and preservation of coastal and underwater nature, this island has been designated as one of the East Java's marine tourist destinations (Hidayah et al., 2021). As a result, the land and water conditions on Bawean Island must be thoroughly studied in order to support the regional development plan. Several studies have been conducted in recent years, in addition to the designation of Bawean Island and its surrounding areas as a marine ecotourism zone (Noor & Romadhon, 2020). Moreover, several key factors have been identified as major issues that may influence the eco-tourism development of the island, incorporating infrastructures, economics, environment, and socio-cultural issues (Wardani et al., 2017b, Sukandar et al, 2017). Meanwhile, the previously mentioned studies are more focused on analyzing the condition of the coastal area to support marine tourism, with another study in focusing more on the hydro-oceanographic conditions of Bawean Island (Hidayah, et al., 2021).

Studies on the condition of Indonesia's small islands, particularly those with tourism and conservation potential, have been widely documented (Marasabessy et al., 2016; Santoso et al., 2020; Suryanti & Apdillah, 2022). This is integrally linked to the fact that Indonesia has thousands of small islands scattered across the country. Previous studies have explored the condition of Bawean Island particularly its coastal and marine environment, including biological diversity (Asaad et al., 2018), small island ecosystems including mangroves (Muhtadi et al., 2020), seagrass (Brodie et al., 2020), coral reefs (Hafezi et al., 2020) and vulnerability to sea-level rise as the results of global climate change (Hidayah et al., 2018; Stephenson & Jones, 2017; Jamero et al., 2017). While many studies focussed on the state of the coastal environment and ecosystems of Bawean Island, there was no studies have been reported regarding the island's land cover dynamic.

Small island's surface and bathymetry are becoming increasingly important sources of information for a variety of purposes, including spatial planning, coastal management, infrastructure development and conservation (Caballero et al., 2019). Land cover changes and dynamics are primarily caused by anthropogenic and natural factors. If it is not addressed and mitigated carefully, it will have an impact on human life and disrupt the sustainability of the environment, particularly on small islands with limited natural carrying capacity (Phiri et al., 2020). As a result, advanced and cutting-edge spatial monitoring systems are required. The most effective method for providing surface data of an area within a specific time frame is to use satellite imagery with various characteristics (Ketjulan et al., 2019; Muhammad, 2022; Wael et al., 2022). The rapid development of satellite remote sensing technology and geographic information systems for the small island is the primary reason for Indonesia's rapid development of spatial data availability (Dharmawan et al., 2020; Hidayah et al., 2019).

Multiple studies on Bawean Island have been conducted in the last five years, but the majority of them have focused on the condition of the coastal environment, conservation, and suitability for eco-tourism activities (Hidayah et al., 2018; Sukandar et al., 2017; Wardani et al., 2017b). Because of the abundance of coral reefs surrounding the island, more detailed studies have been conducted to determine the state of the ecosystem (Dharmawan et al., 2020; Luthfi & Anugrah, 2017). Periodic assessment of land cover change is required to understand the extent and impact of natural and human activities factors on the island (Cahyani et al., 2018; Kim, 2016; Neksidin et al., 2021). Additionally, the endemic and critically endangered species of Bawean deer (*Axis kuhlii*) was also an interesting topic of investigation regarding this island (Rahman et al., 2017). Meanwhile, this study provides a new perspective on the changes in the island's condition based on satellite imagery analysis. The objectives of this paper is to observe land cover alterations using satellite imagery, particularly those related to land conversion, from 2010 to 2020.

2. Methods

2.1 Study Area

This research was conducted on Bawean Island from July – October 2021. Bawean island is located roughly halfway between Java Island and Borneo Island. Because of its remote location and distance from the mainland, the island has some rare and distinctive flora and fauna. The coordinates of the island is 05°47'23''S and 112°39'20''E (Figure 1). The total area of Bawean island is ± 196.27 km^2 divided administratively into 2 districts namely Sangkapura in the south and Tambak on the north side of the island.

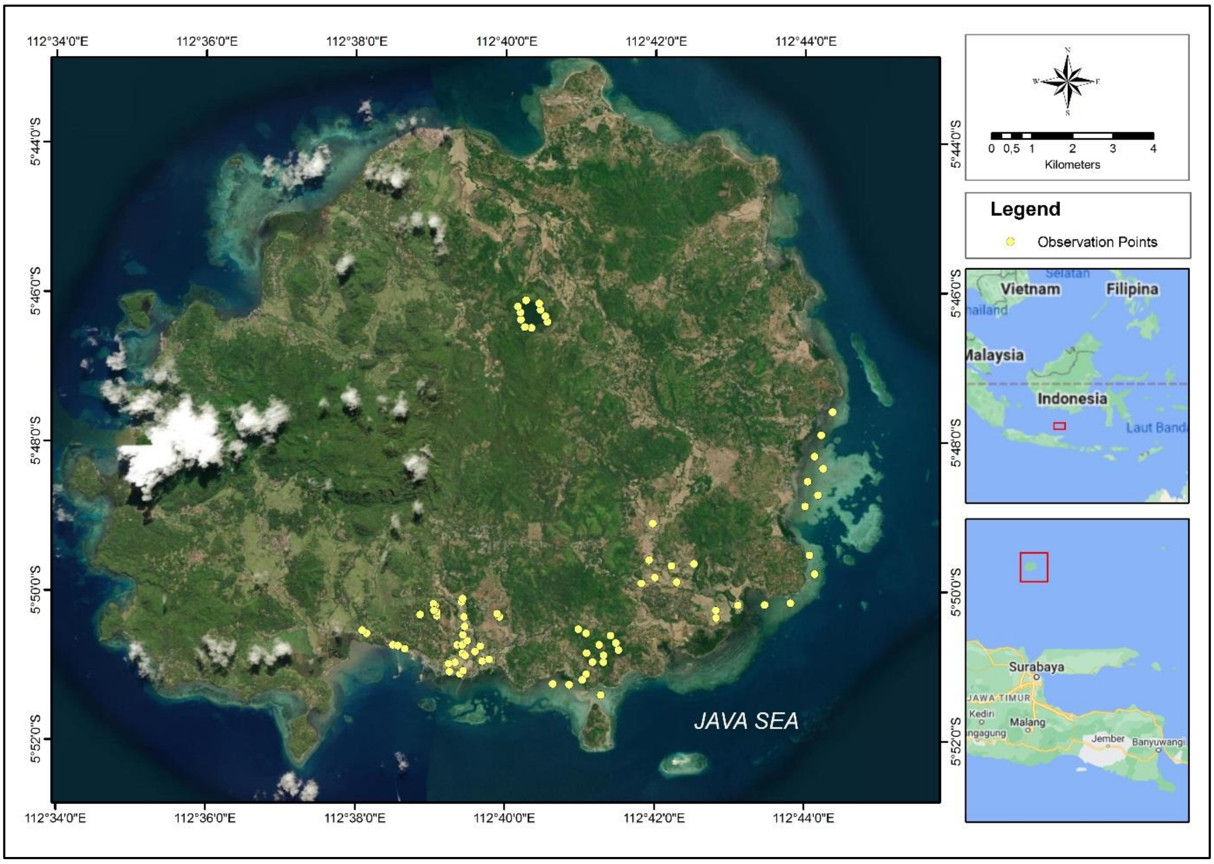

Figure 1. The map of Bawean Island (Source : Modified from Google Earth)

This study's ROI includes the entire land surface of Bawean Island and the surrounding small islands. The land cover category of this study was divided into 6 main classes, namely forests, sandy beaches, settlements, rice fields, inland water body/ lake and open field. The classification results were then compared to the results of field observations to obtain an accuracy value. A total of 103 observation points were randomly established to check the consistency of the land cover classification results and the actual condition in the field.

2.2 Satellite Images

To identify land cover changes of Bawean island, this study utilized two sets of medium resolution satellite images namely ALOS AVNIR-2 acquisition date July 15th 2010 and Sentinel-2A acquisition date August 23rd 2020. The percentage of cloud cover for both images were less then 5%. The Advanced Land Observing Satellite (ALOS) was launched in January 2006 by JAXA (Japan Aerospace Exploration Agency). This satellite has several distinctive sensors i.e (1) PRISM (Panchromatic Remote-sensing Instrument for Stereo Mapping) high precision elevation mapping; (2) AVNIR-2 (Advanced Visible and Near Infrared Radiometer type 2) for land use and land cover observation; (3) PALSAR (Phased Array type L-band Synthetic Aperture Radar) an active sencor to monitors the land in any weather conditons. To be more spesific, the AVNIR-2 sensor has 4 visible bands i.e blue (0.42-0.50 μm), green (0.52-0.60 μm), red (0.61-0.69 μm) and near infra-red (0.76-0.89 μm).

Meanwhile, the Sentinel 2A and 2B satellites were consecutively launched between June 2015 and March 2017 by the Copernicus Programme initiated by the European Space Agency (ESA). The satellites carry multispectral imaging (MSI) instruments capable of recording 13 wide-swath bands, including the 10-meter bands (blue, green, red and visible near infra-red). Sentinel 2 satellite imagery has been widely used in recent years to monitor the condition of the earth's surface, particularly in coastal areas (Artaningh et al., 2020; Kurniadin & Fadlin, 2021; Mastu et al., 2018). With higher spatial resolution in visible bands (10 meters) compare to Landsat images (30 meters), those images have been used to produce maps not only for the land surface but also sea surface and benthic environments in higher detail (Li et al., 2019; Wicaksono et al., 2019).

2.3 Image Classification and Change Detection

Land cover classes were generated from pixel values in satellite images using the supervised classification method. In supervised classification, analysts must select representative samples for each land cover class. The software then used the maximum likelihood algorithm to process these samples or training sites and applied them to the entire image. By comparing classification results based on satellite imagery from 2010 and 2020, changes in the area of each land cover class were calculated (Figure 2).

2.4 Accuracy Assesment

The precision of the classification results was calculated using the two dimensional array. The confusion matrix compares the classification results and the reference data. In order to obtain appropriate results, comparisons were made using the results of image classification in 2020, while ground truth was carried out in 2021. The confusion matrix yields the overall accuracy and Kappa coefficient (Lillesand & Kiefer, 1994). The Kappa coefficient value is divided into 4 classes (Congalton and Green, 2008), namely Kappa < 0.4 (low accuracy), 0.41< Kappa < 0.61 (medium accuracy), 0.61< Kappa < 0.80 (substantial accuracy) and Kappa > 0.81 (high accuracy).

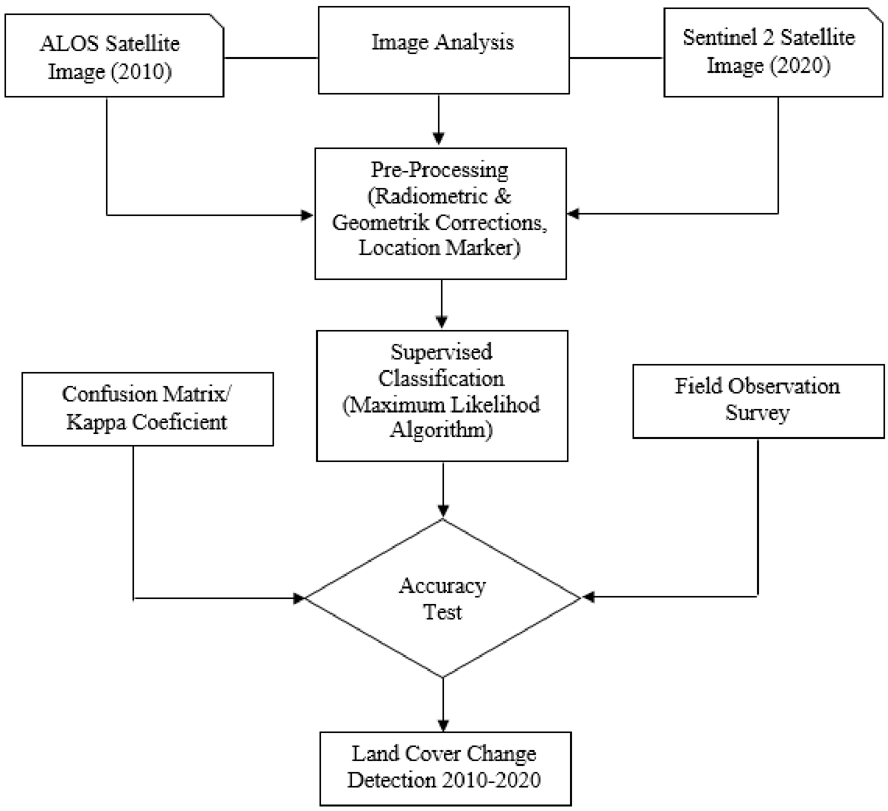

Figure 2. Flow chart of image processing

3. Results and Discussion

Bawean Island has a tropical climate, as do most of Indonesia's coastal areas. The mean daily temperature ranges from 28^{o} C – 31^{o} C with an average of 28.50 ^{o}C ± 1.05 ^{o}C. The air temperature in the dry season is slightly higher than the temperature in the rainy season (Figure 3). However, there is significant difference in the average daily temperature for each month (One Way ANOVA; $F_{calculate}$=6.82; sig <0.05). The highest rainfall occurs at the peak of the rainy season, from December to February. In 2020, the highest rainfall reached 85.57 mm to 95.1 mm occurred in January - February. Meanwhile, during the dry season there is no rain at all. The relative humidity on Bawean Island is quite high with an average of 81.40% 5.53%. The difference in air humidity every month is fairly significant (One Way ANOVA; $F_{calculate}$=21.7; sig <0.05).

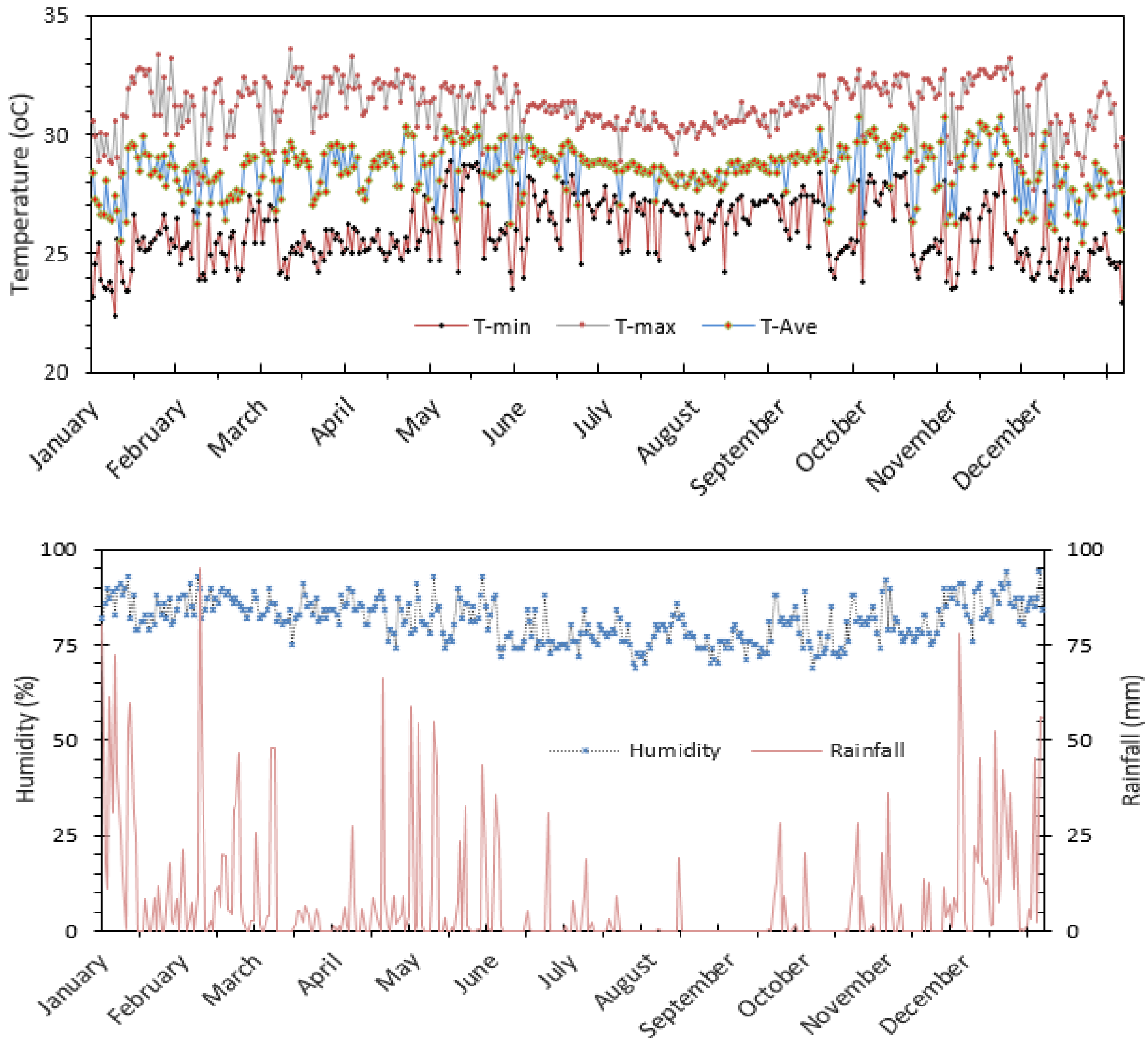

Figure 3. Temperature, Humidity and Rainfall of Bawean Island 2021

The map in Figure 4 shows the results of land cover classification based on satellite imagery of ALOS (2010) and Sentinel 2A (2020). It can be seen that most of the land cover on Bawean Island is forest/vegetation cover which is distributed mostly in the middle of the island. The forest types on this island are lowland primary and secondary tropical rainforests (Trimanto & Hapsari, 2016). Forests on Bawean Island have been designated as nature reserves and wildlife reserves with the dominance of teak forests (*Tectona grandis*) (Rahman et al., 2017). Moreover, a botanical survey conducted in 2015-2016 have identified 432 species of plants from 287 genera and 103 families in the forests of Bawean Island at elevations ranging from 8 to 572 meters above sea level (Trimanto & Hapsari, 2016). The natural forest condition on Bawean Island support the life of various plant species, therefore the island has a considerably high plant diversity.

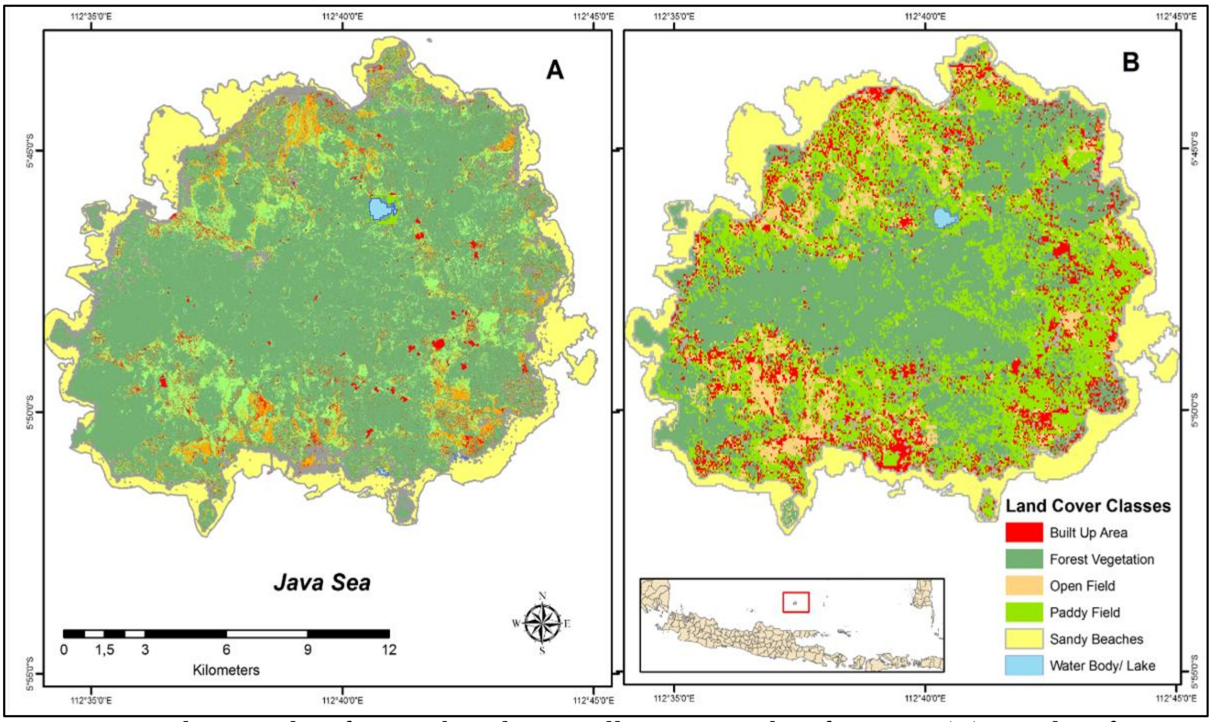

Figure 4. Land cover classification based on satellite images classification : (A) Results of ALOS-AVNIR 2010 image classification; (B) Results of Sentinel 2A 2020 image classification

Results of land cover classification based on multi temporal satellite images (2010 and 2020) of Bawean Island is shown in Figure 4. Six land cover classes were identified, namely forest, built up area, paddy field (agriculture area), open field, sandy beaches and in-land water body from Lake Kastoba. In 2010 forest dominated the island's land cover comprising approximately 56.6% (13,470.5 Ha) of the total area. Sandy beaches and paddy field were the next dominant classes, covered about 16.2 % (3,851.2 Ha) and 16.1 % (3,816.8 Ha) respectively. Meanwhile there was only about 863.9 Ha or 3.6% of the island's classified as built up area and mostly concentrated on the coastal area.

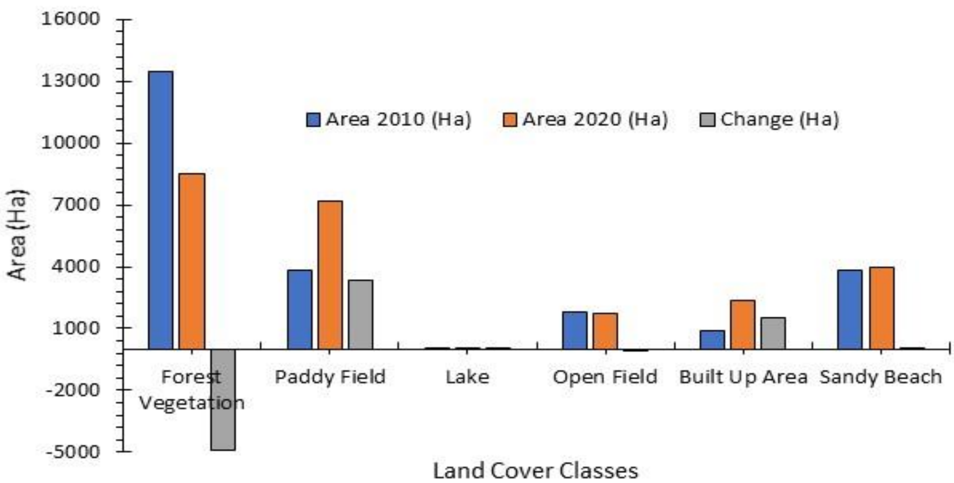

Figure 5. Land cover area change of Bawean Island 2010-2020

Significant changes occurred of land cover in 2020 compared to the previous 10 years (Figure 5). Although forest cover remained dominant on the island (35,9%), its area experienced a sharp decline. Around 4,927.1 Ha of forest has been converted into other types of land cover in the last 10 years. Rice fields and sandy beaches occupy the next position with around 30.2 % (7,186.7 Ha) and 16.5% (3,935.3 Ha) of land cover area. The development of paddy fields was rapid and has doubled in 10 years. The built-up area expanded from the coastal area to the center of the island with the percentage reached nearly 10% (2,388.1 Ha) of the total island area.

Table 1. The dynamic of land cover change of Bawean Island (2010-2020)

Land Cover Class	Land Cover Area (%)		Changes (%)
	2010	2020	2010-2020
Forest Vegetation	56.59	35.89	-20.70
Paddy Field	16.03	30.19	14.16
Lake	0.14	0.16	0.03
Open Field	7.43	7.19	-0.24
Built Up Area	3.63	10.03	6.40
Sandy Beach	16.18	16.53	0.35

The temporal analysis revealed that the most significant changes occurred in the land cover classes of forest vegetation, paddy fields, and built-up areas (Table 1). In the 2010-2010 period, the area of forest vegetation decreased by 20.70%, while paddy field cover increased by 14.6%. The built-up area also experienced a significant increase in land cover area, which was around 6.40%. Further investigation revealed that 70.91% of the total lost forest was converted into paddy fields, while 20.33% was converted into developed areas. In addition, based on a rigorous spatial review the reduction in forest area occurs primarily in the lowlands. Meanwhile, primary forest in the highlands in the island's center is relatively undisturbed. As a result, forest loss can be justified as a result of agricultural and settlement needs rather than illegal logging. However, the rate of deforestation is relatively high (around 400 Ha/year) and must be controlled in order to preserve the remaining forest.

Table 2. Confusion matrix of classification

Classification Results (Pixel)	Ground Truth Data (Pixel)						
	Lake	Open Field	Sandy Beaches	Built Up Area	Paddy Field	Forest Veg	Total
Lake	**10**	2	0	0	0	0	12
Open Field	0	**14**	0	2	0	0	16
Sandy Beaches	0	0	**14**	0	0	0	14
Built Up Area	1	2	0	**15**	0	0	18
Paddy Field	0	1	1	0	**17**	3	22
Forest Veg	0	0	1	2	3	**15**	21
Total	11	19	16	19	20	18	**103**

The confusion matrix is the most common method used to quantify classification accuracy. A confusion matrix compares the relationship between known reference data (ground truth) and the corresponding classification procedure results on a class-by-class basis. The values along the diagonal of the table represent the correct pixel classification based on image analysis and field observations.

According to the confusion matrix (Table 2), the majority of the pixels tested have a match between the image classification results and the actual land cover conditions on Bawean Island.

Table 3. Statistical parameters of classification

Classes	User's Accuracy (%)	Producer's Accuracy (%)	Error of Comission (%)	Error of Omission (%)	Overall Accuracy (%)	Kappa Coefficient
Lake	83.33	90.91	16.67	9.09	82.52	79.66
Open Field	87.50	73.68	12.50	26.32		
Sandy Beaches	100.00	87.50	0.00	12.50		
Built Up Area	83.33	78.95	16.67	10.53		
Paddy Field	77.27	85.00	22.73	15.00		
Forest	71.43	83.33	28.57	16.67		
Average ± Stdev	83.81 ± 9.72	83.23 ± 6.16	16.19 ± 9.72	15.02 ± 6.20		

The calculation of accuracy of image classification is explained in Table 3. User's accuracy refers how actually classified map is real on the ground. The average of user's accuracy of this study is considerably high with percentage of 83.81% ± 9.72%. Sandy beaches land cover class has the highest invidual percentage of user's accuracy, while paddy field and forest vegetation have the lowest percentage with 77.27% and 71.43% respectively, with error of comission reached more than 20%. These findings indicate that there are significant differences between the classification results of paddy fields and forest vegetation and the actual land cover. Furthermore, the spectral signatures of paddy field cover and vegetation are relatively similar therefore they are difficult to distinguish. This is particularly the case of pixels that are located adjacent to each other. Furthermore, the producer's accuracy represents class-wise accuracies from the map maker's perspective. As a result, it provides a probability that a specific sample of a specific land cover is corresponding as the same class in the classification map. Based on the calculation, the average of producer's accuracy of this study is fairly high in the range of 83.23% ± 6.16% with the average of omission error around 15% (Table 3). These results confirm the analyst's ability to classify land cover classes based on the training area created according the spectral appearance on satellite imagery.

The overall accuracy of 82.52% indicates that the results of land cover classification in this study are considerably good. The total accuracy value obtained in this study is not significantly different from the classification results obtained in several research studies, which are in the range of 80% or higher, despite the use of images with lower resolutions such as Landsat 8 with spatial resolution of 30 meters (Derajat et al., 2020; Rini, 2018; Siregar & Asbi, 2020; Wulansari, 2017). Moreover, Kappa coefficient value produced by the confusion matrix is 79.66 and categorized as substantial (61.00 < Kappa < 80.00). Previous research suggests combining the Kappa coefficient and the overall accuracy value to validate land cover classification results (Wulansari, 2017). In contrast to overall accuracy, which is calculated by dividing the number of diagonal values by the total number of cells in the matrix, the Kappa coefficient considers non-diagonal elements (Marlina, 2022; Putri et al., 2018). In addition, the Kappa coefficient measures the difference between the suitability of the classified data and the probability of a random classification match being compared with the reference data.

Several factors influence land use/land cover change in a limited environment such as a small island. The primary factor is population growth, which raises the demand for housing and food (Kim, 2016; Purbani et al., 2020). As a result, land clearing is carried out in order to provide settlements and agricultural land. The decline in fisheries production due to overfishing or climate change may also be a driving factor in small island land changes (Pinuji et al., 2018). Bawean Island is a small island with abundant resources (Wardani et al., 2017a). Coastal communities depend on fishery products, while people who live inland depends on agriculture. If the decline of fisheries production happen for a long period, it is possible that there will be a shift in the profession of fishermen in to farmers (Pinuji et al., 2018). As a result, more agricultural land must be provided. Furthermore, the lack of land use regulation based on regional spatial planning is a contributing factor to uncontrolled land use changes that endanger environmental sustainability.

Bawean Island provide a distinct model for nature conservation that differs from the mainland in general. Economic and social development are both major concerns in areas with small economies that rely heavily on external markets, high transportation costs, and small populations. As a result, a distinctive strategy is required to balance the development of small islands without risking their natural sustainability. The presence of diverse ecosystems on Bawean Island is the main draw for visitors. However, due to the island's limited carrying capacity, tourism activities on the island must be carefully managed. Economic and population growth will result in the development of new lands. The major concern should be the balance between built-up areas to support development and conservation areas to maintain the island's natural biodiversity.

4. Conclusion

This study has demonstrated the use of satellite images to identify land cover changes on a small island. The results of image classification in 2010 - 2020 show a significant change of land cover on Bawean Island. Forest vegetation land cover experienced a significant degradation from 13,470.5 Ha in 2010 to 8,543.4 Ha in 2020. On the other hand, there is an increase of built-up area and paddy fields in the same period. Changes in land cover on Bawean Island due to the population growth and infrastuctures construction. The rapid development on the island requires larger residential and agricultural areas to be provided. The development on Bawean Island must be regulated based on regional spatial planning in order to provide optimal results for the welfare of the community while at the same time preserving its rich natural diversity and ecosystems.

Conflicts of Interest

The authors are not involved in a conflict of interest from funds, personal and institutional or any other relationships from this article.

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