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Analysis of changes in mangrove ecosystems in Banda Aceh city 17 years after the 2004 tsunami

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ABSTRACT

Mangrove has the most important role especially in the coastal area. The existence of mangrove habitats in Banda Aceh which got decreasing and loss after tsunami disaster in 2004. The purpose of this study was to the distribution of mangrove in Banda Aceh divided into five (5) sub districts including Jaya Baru, Kuta Alam, Kuta Raja, Meuraxa, and Syiah Kuala. This study the mangrove changes after tsunami 2004, began from 2005, 2010, 2015, and 2022. The main data used in this study are Landsat 5 and Sentinel 2A images. Methods of image processing applied in this study are NDVI analysis and supervised classification-based image classification. The results are able to show the changes of mangrove area in Banda Aceh from 2004 to 2022. Mangrove area in 2005 is 28.89 ha, 2010 is 81.38 ha, 2015 is 180.27 ha, and 2022 is 121.34 ha. It can be seen that there is a decreasing of mangrove area from 2015 to 2022. The analysis results are also able to show that Kuta raja sub district has the largest mangrove area of 60.11 ha or 49.54 % of the overall area. According to the overall results, it can be said that remote sensing satellite images such as Landsat and Sentinel 2A are very useful in conducting the spatio-temporal research from the long-term periods. This study is hoped to be able to become a reference data in efforts to restore the mangrove in Banda Aceh in order to create the sustainable ecosystem area.

Introduction

According to the Decree of the Directorate General of the Ministry of Agriculture No. 60/Kpts/DJ/I/1978 concerning brackish forest silviculture, mangrove forest is a type of forest found along the coast or river which is affected by tides. Meanwhile, according to Nybakkenle (1992), mangrove forest is a general term used to describe a tropical beach variety which is dominated by several distinctive tree species or shrubs that have the ability to grow in salty waters. Hirieya (2009) and Irwanto (2007) explain that mangrove forests are important natural resources in the coastal environment, and have three main functions, namely physical, biological, and economic functions. The physical functions of mangroves are as windbreaks, pollutant filters, wave barriers, flood control and prevention of seawater intrusion into the mainland, the biological functions of mangroves are as spawning areas, nursery areas, and as feeding areas for fish and other marine biotas, while the economic function of mangroves is as a producer of wood for raw materials and building materials, foodstuffs, and medicines. In addition, this function is a strategy as a primary producer that can support and stabilize marine and terrestrial ecosystems.

However, the tsunami that occurred in Aceh Province on December 26, 2004 had damaged most of the mangrove ecosystems in the coastal areas of Aceh, which had a major impact on people's lives, especially in coastal areas. The State Ministry for the Environment in Indonesian Forestry Statistics (2013) states that in addition to the loss of natural protection from mangroves, the

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impact of the tsunami on the coastal and marine areas of Aceh Province is as follows: contamination of ground and land seawater; the occurrence of shoreline changes; damage to coral reefs, reduced fish resources and coastal species, and damage to language and artificial land ecosystems. After the Aceh tsunami, the mangrove forest on the coast of the city of Banda Aceh suffered very heavy damage, so there is a need for restoration and rehabilitation of the mangrove forest to re-select the coastal ecosystem on the coast of the city of Banda Aceh. Wibisono *et al.* (2006) also stated that mangrove forests in Aceh Province experienced a decline after the tsunami, from 345,838 ha to 168,840 ha.

In the post-tsunami era, about 27,000 ha of damaged mangrove areas have been rehabilitated with mangrove plants (generally Rhizopora species). Several parties involved were the Forestry Service through the Aceh-Nias Rehabilitation and Reconstruction Agenc (BRR Aceh-Nias) project through the coastal SATKER (Work Unit), the Wetlands International Indonesia Program (WIIP) through the Green Coast program and the Aceh Fisheries and Marine Service (DKP). Restoration of mangrove forests that have been degraded is not easy to do, because in addition to requiring large costs and energy, it also takes a long time. Mukherje *et al.* (2014) divide mangrove forest restoration based on time, namely long-term (>20 years) and short-term (<20 years). Based on research that has been done that degradation due to development activities by humans, both in developed countries (Highly Developed Countries) and developing countries (Less Developed Countries), is the main damage that requires restoration time > 20 years. Therefore, awareness and concern from all parties are needed, especially in planting mangroves which are very beneficial for reducing disaster risk which can threaten public safety at any time.

One of the initial efforts in carrying out restoration efforts is to identify changes in mangroves over a long period of time through remote sensing data supported by a geographic information system (GIS). Remote sensing is the science and art of obtaining information about objects, areas or phenomena by analyzing data obtained using tools without direct contact with the object, area, or symptom being studied (Lillesand *et al.*, 2015). Remote sensing has the advantages to trace back the historical change of land cover / land use in a landscape by its sensors (Wang *et al.*, 2019). Geographic Information System (GIS) is a technique that is now widely used to analyze various disasters and other analyzes related to space. GIS has several meanings, one of which is a computer-based system that provides the ability to handle geographically referenced data, namely data entry, management or management (storage and reactivation), manipulation and analysis, and output or output (Aronof, 1989). The main components of GIS are computer systems, geospatial data and users (Goodchild, 2001).

Mapping of disaster risk areas using GIS can be done based on an assessment of various factors that are closely related to spatio-temporal land changes. El-Geresy (2002) explains that spatio-temporal is a form of problem analysis using periodic research methods in a fairly long range within a certain area. By using a spatio-temporal (analysis) approach, it can be seen how much land changes in a certain period of time (Yuwono and Suprajaka, 2003).

From the above background, this study aims to analyze changes in the mangrove ecosystem in Banda Aceh City after the 17-year tsunami which will produce several thematic maps that represent changes in mangrove land cover from 2005 to 2022. The results of this study are expected to be of practical use (operational) and useful academically (theoretically). As for practically, the research results can produce a new lesson for institutions, governments or coastal communities regarding mangrove ecosystem restoration activities. This research is also expected to be a reference material for the Aceh regional government, especially for the Banda Aceh City Government as consideration for development planning in coastal areas based on environmental conservation by maintaining the function of the Mangrove ecosystem.

Materials and Methods

Location and time of research

This research is located in Banda Aceh City, which includes 5 sub-districts, including Jaya Baru, Meuraxa, Kuta Raja, Kuta Alam and Syiah Kuala sub-districts, which includes 25 villages. The choice of location was based on observations made through analysis of mangrove maps prior to 2004 and post-tsunami field observations. The results of the analysis and observations show that the five sub-districts have a good distribution of mangroves and indicate the potential for sustainable mangrove development. Figure 1 shows a map of the research location.

Data and analysis

To carry out an analysis of mangrove changes, materials in the form of satellite imagery data from various years of observation and supporting data are needed as follows (Table 1).

Depik Jurnal Ilmu-Ilmu Perairan, Pesisir dan Perikanan
Volume 11, Number 3, Page 483-490

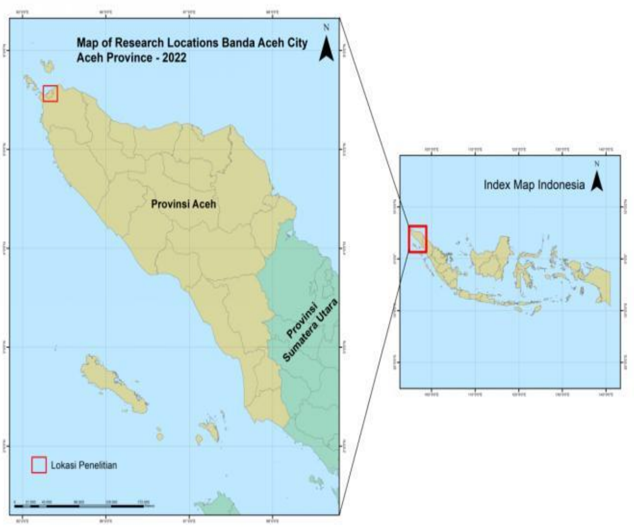

Figure 1. Study area map.

Table 1. Sources of data.

Data	Source
Landsat 5 satellite images 2005, 2010	*USGS*
Sentinel 2A satellite images 2015, 2022	*Esa Sentinel 2*
Administration map Banda Aceh	BIG

Remote sensing data processing and analysis

To conduct the spatio-temporal land change analysis process, satellite image data is needed from year to year. In this study, the data taken is medium resolution satellite imagery from Google Earth Engine, with USGS science for a changing world and Esa Sentinel 2 data sources with the selected observation years being, 2005, 2010, 2015 and 2022. The selection of image was based on the availability and quality of satellite images.

The process of land use analysis and classification is carried out through the NDVI analysis method to determine the range of NDVI threshold values for each type of land (Budi and Akhyar, 2022). The results of the NDVI analysis are used as material for classifying with a supervised classification method (Maurya *et al.*, 2021), so that data on mangrove area is obtained for each year of observation based on a visual description of the object. The land cover class is divided into five, namely mangroves, ponds, settlements, vegetation and water bodies, so that the distribution of mangrove vegetation can be known. Figure 2 shows the flow chart of the research.

Results

Results of this study included maps of mangrove vegetation density and maps of mangrove distribution in Banda Aceh from 2005 to 2022 consisted of 2005, 2010, 2015, and 2022) (Figure 3).

Based on the results of the analysis, it is obtained that the mangrove vegetation density continues to improve starting from 2005 with a very dense mangrove vegetation density area of 6.07 ha to 84.86 ha in 2022, mangrove vegetation density with a dense class in 2005 with an area of 7.53 ha to 26.00 ha in 2022, then the density of mangrove vegetation with a fairly dense class only slightly changed with an area of 7.63 ha in 2005 to 8.04 ha in 2002 and the last one was the density of mangrove vegetation with a class of rarely with an area of 7.67 ha in 2005 decreased to 2.49 ha in 2022.

Based on Table 2, it can be seen that the density mangrove vegetation continues to change for the better from time to time. The results of analysis presented the distribution of mangrove vegetation density with the levels of high-dense vegetation, medium-dense vegetation, rather low-dense vegetation, and low-dense vegetation.

In Table 2, it can be seen that the comparison of the density of mangrove vegetation that has been analyzed in Banda Aceh City between 2005 and 2022 can be seen. The comparison of the density of mangrove vegetation means that the denser the mangrove vegetation, the healthier the mangrove ecosystem in the area. A mangrove vegetation can be interpreted that the mangrove ecosystem is not healthy in the area.

The comparison of the increase in the density of mangrove vegetation with very dense classes in 2005 to 2010 was 25.33 ha, then the ratio of the increase between 2010 to 2015 was 31.61 ha and the last was the increase in the area of the comparison of mangrove vegetation density from 2015 to 2022 to 21.85 ha. The comparison process of mangrove vegetation density with dense class from 2005 to 2010 increased to 31.09 ha followed by an increase in mangrove vegetation density from 2010 to 2015 to 10.78 ha and from 20015 to 2022 there was a decrease in vegetation density with dense class to -23.40 ha. The comparison of the density of mangrove vegetation with moderately dense classes between 2005 and 2010 rose to 2.71 ha in 2010 to 2015 the density of mangrove vegetation continued to increase to 32.73 ha, in contrast to the comparison year 2015 to 2022, the percentage of mangrove vegetation density with moderately dense classes occurred. decreased to -35.02 ha. The density of mangrove vegetation in the rare class in 2005 to 2010 decreased to -6.64 ha and from 2010 to 2015 there was an increase to 23.74 ha, then in 2015 to 2022 there was another decline in mangrove vegetation to -22.77 ha.

Figure 3 shows a map of changes in mangrove vegetation cover in Banda Aceh based on spatio-temporal analysis using Landsat 5 and Sentinel 2A images.

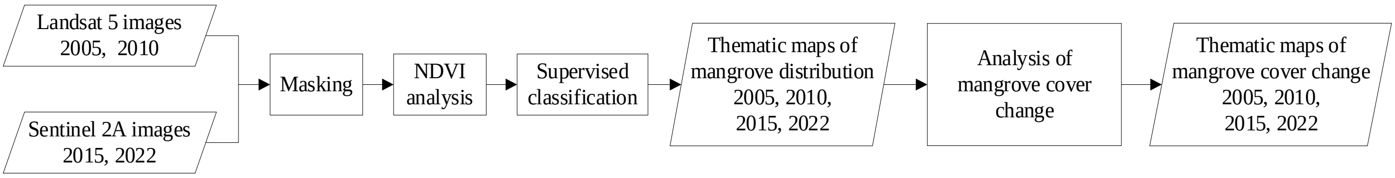

Figure 2. Study flowchart.

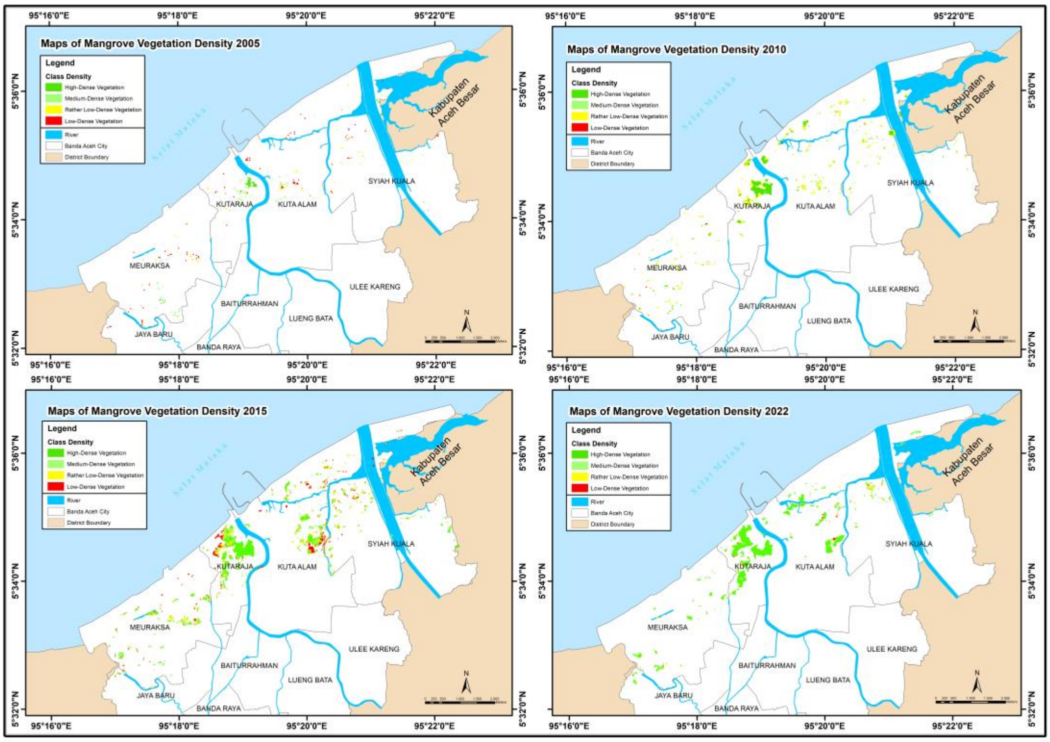

Figure 3. Maps of mangrove vegetation density change 2005-2022.

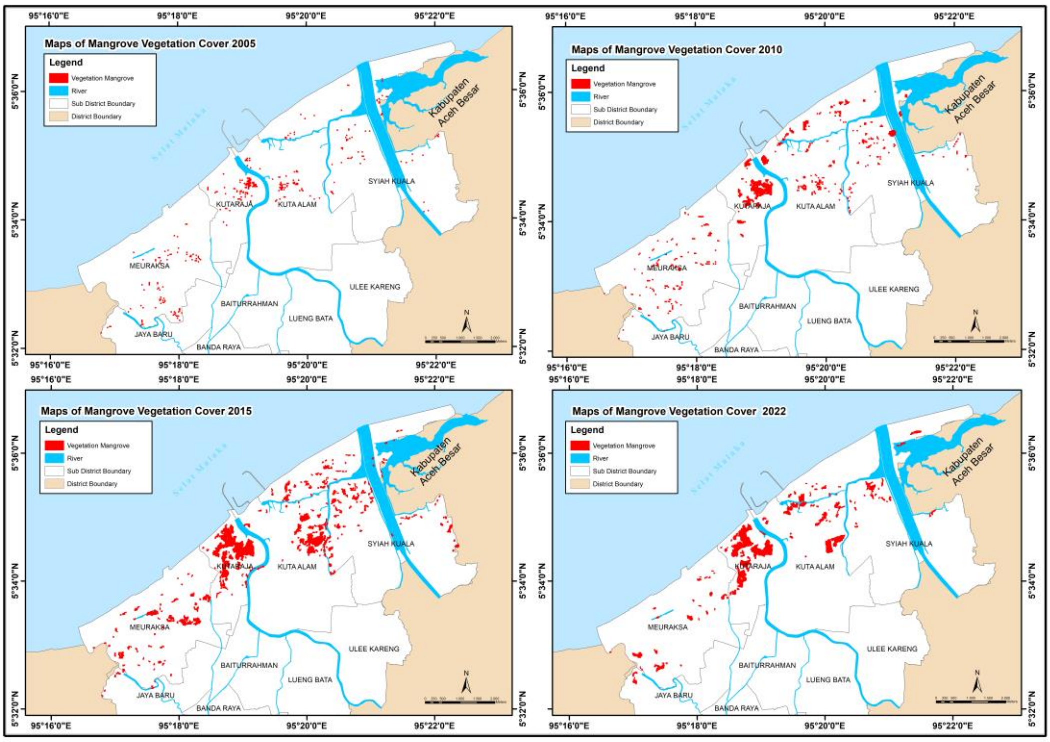

Figure 3. Maps of mangrove vegetation cover change in Banda Aceh 2005, 2010, 2015, 2022.

Depik Jurnal Ilmu-Ilmu Perairan, Pesisir dan Perikanan
Volume 11, Number 3, Page 483-490

Then, the results of analysis also presented the area of mangrove distribution in each sub district of Banda Aceh from 2005 to 2022 (Table 3). Based on the results, changes in mangrove vegetation in Banda Aceh can be obtained 17 years after the 2004 Tsunami, where each year observations of mangrove vegetation have different values in each sub-district.

In Table 3, it can be seen the value of the change in mangrove area for 17 years after the tsunami in Banda Aceh City. Data obtained using the Supervised Classification method shows changes of mangroves distribution in five sub-districts, Banda Aceh with the detailed rate.

Based on the results of data processing Landsat 5 satellite image in 2005 as shown in Figure 4, it was found that the total area of mangrove was 28.89 ha spread over five sub-districts including Jaya Baru sub district as much as 0.38 ha, followed by Kuta Alam sub district 5.85 ha, sub district Kuta Raja 8.37 ha, Meuraxa sub district 7.81 ha, and Syiah Kuala sub district 6.48 ha.

Table 2. Data of mangrove vegetation density 2005-2022.

Mangrove density	2005		2010		2015		2022	
	Ha	%	Ha	%	Ha	%	Ha	%
high-dense vegetation	6.07	21.00	31.40	38.58	63.01	34.96	84.86	69.90
medium-dense vegetation	7.53	26.06	38.62	47.46	49.40	27.41	26.00	21.42
rather low-dense vegetation	7.63	26.41	10.34	12.71	43.07	23.89	8.04	6.63
low-dense vegetation	7.67	26.53	1.02	1.26	24.77	13.74	2.49	2.05
Total	**28.89**	**100.00**	**81.38**	**100.00**	**180.24**	**100.00**	**121.39**	**100.00**

Table 3. Data of mangrove distribution in Banda Aceh 2005-2022.

Sub-district	2005		2010		2015		2022	
	Ha	%	Ha	%	Ha	%	Ha	%
Jaya Baru	0.38	1.32	0.34	0.41	1.41	0.78	1.93	1.59
Kuta Alam	5.85	20.25	13.88	17.06	37.39	20.74	28.15	23.20
Kuta Raja	8.37	28.97	31.63	38.87	67.80	37.61	60.11	49.54
Meuraxa	7.81	27.02	13.44	16.51	30.35	16.83	13.58	11.19
Syiah Kuala	6.48	22.44	22.10	27.15	43.32	24.03	17.57	14.48
Total	**28.89**	**100.00**	**81.38**	**100.00**	**180.27**	**100.00**	**121.34**	**100.00**

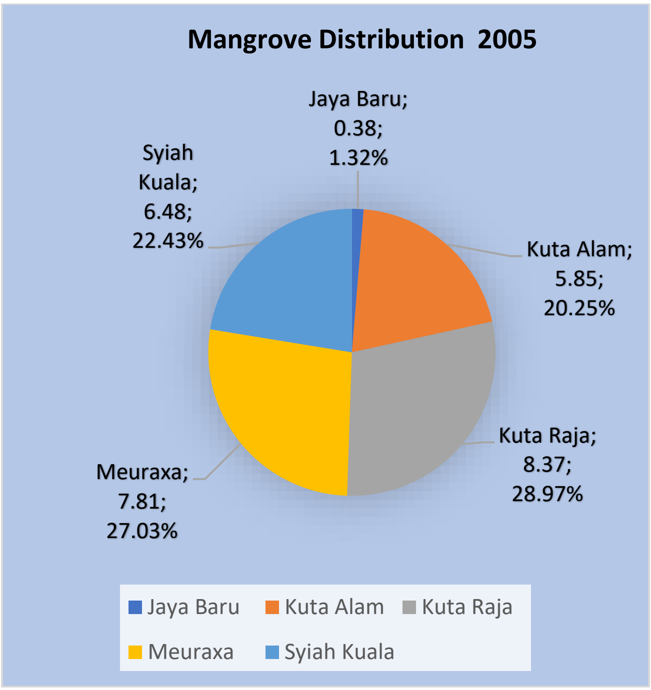

Figure 4. Graphic of mangrove distribution 2005.

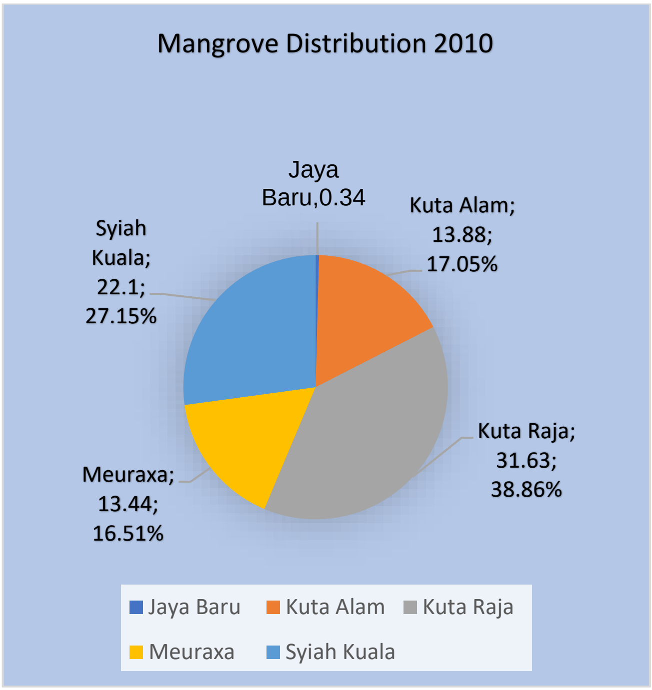

Figure 5. Graphic of mangrove distribution 2010.

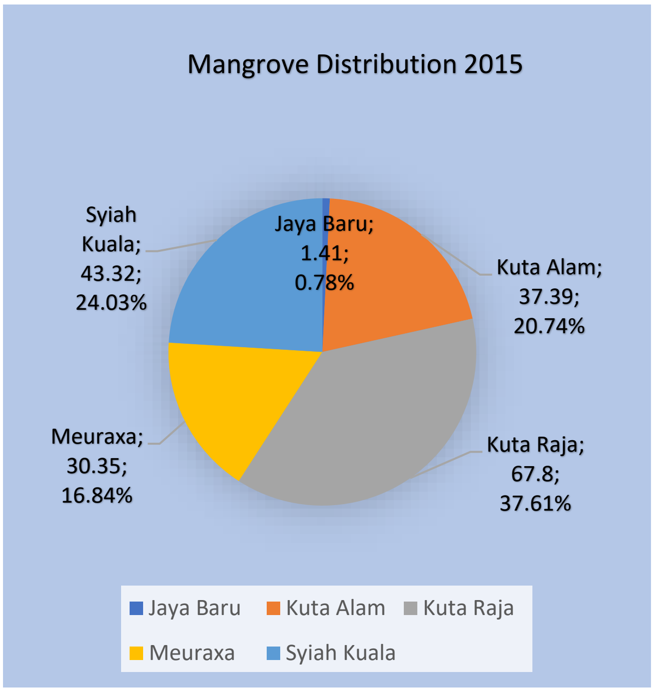

Figure 6. Graphic of mangrove distribution 2015.

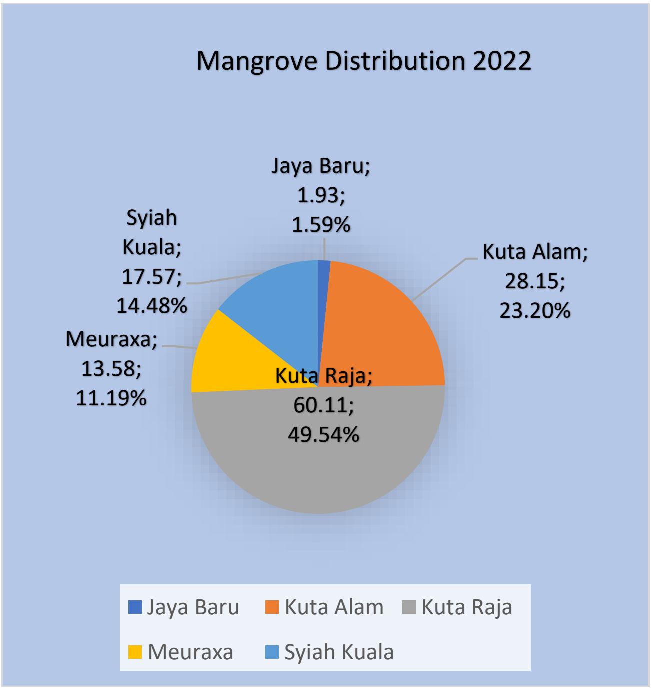

Figure 7. Graphic of mangrove distribution 2022.

The increase in the number of mangrove areas began to occur in 2010 or five years after the tsunami with a total area of 81.38 as shown in Figure 5. The increase in the total area of mangroves increased by 181.68% spread over the Jayabaru sub district with an area of 0.34 ha of mangrove then Kuta Alam sub district 13.88 ha, Kutaraja sub district 31.63 ha, Meuraxa sub district 13.44 ha, and Syiah Kuala sub district 31.63 ha. Overall, in observations in 2010 there has been an increase in mangrove area, this is a good impact from the mangrove restoration and rehabilitation program activities that began five years after the Aceh tsunami.

The analysis of mangrove vegetation in 2015 using Sentinel 2A satellite imagery data can be seen in Figure 6. Mangrove distribution increased a lot from the previous year of observation, 2010. In 2015, the total area of mangroves in Banda Aceh reached 180.27 ha or an increase of 121.52% from 2010. The distribution of each mangrove vegetation is spread in Jaya Baru sub district 1.41 ha, Kuta Alam sub district 37.39 ha, Kuta Raja sub district 67.80 ha, followed by Meuraxa sub district 30.35 ha, and Syiah Kuala sub district 43.32 ha.

Based on the results of the changes analysis in mangrove ecosystems that have been carried out in 2022 in five sub-districts in Banda Aceh, it can be seen in Figure 7. There is a decrease in the total area of mangroves in 2022 by 32.69% which includes each sub-district, namely, Syiah Kuala sub district by 17.57 ha or decreased by 59% from 2015, from the analysis of Sentinel2A satellite imagery recording in 2022, the decline is caused by the large number of new housing developments that have been built in the mangrove ecosystem area in Syiah Kuala sub district.

In Kuta Raja sub district there is only a slight change in mangrove, from 67.80 ha in 2015 it fell to 60.11 ha in 2022, similarly to what happened in Kuta Alam sub district, mangrove changes decreased from 37.39 ha in 2015 to 28.15 ha in 2022. Compared to 2015 in 2022, Jaya Baru sub district increased the mangrove area to 1.59 ha.

Discussion

The method applied in this study to detect mangrove ecosystem through the change analysis are needed for mangrove conservation management strategies in local and global scale (Romanach *et al.*, 2018). The change analysis methods in shoreline areas including NDVI change analysis and land cover / land use change analysis derived from time series satellite images are crucial to estimate the change rate (Rumahorbo *et al.*, 2022; Tran *et al.*, 2022; Cabello *et al.*, 2021).

Results of NDVI analysis were used as the reference in mangrove classification using the land cover / land use classification method through the threshold values of NDVI (Toosi *et al.*, 2020). The decline in mangrove area occurred in Meuraxa sub district by 13.58 ha, down by 55.26% from 2015, from the analysis, the decline occurred as a result of changes in mangrove ecosystem land into ponds and housing areas which continued throughout 2015 to 2022. These results are different with the study of Trishiani *et al.* (2022) that showed that there was the increasing value of vegetation distribution represented by NDVI values. It is assumed that the image used had the medium resolution (Landsat) that possibly provided the different results from Sentinel-2A image.

It shows that time series Landsat images combined with fine resolution image such as Sentinel-2A are able to show the distribution of mangrove forest cover that has changed from 17 years after the 2004 tsunami (Chamberlain *et al*., 2021). Furthermore, supervised classification method has the advantages over unsupervised classification to divide the classes according to the study area conducted by Pujiono *et al*. (2012).

From the results of the analysis, the difference in the area of mangroves in each sub-district that has been researched is the activity of mangrove restoration and rehabilitation activities which began to be carried out in 2005 to 2022 by the community, government and international institutions.

Conclusion

Based on the results of the analysis represented in the form of changes in mangrove vegetation cover, it can be said that mangrove restoration efforts in Banda Aceh after the tsunami were carried out on a massive scale even though it decreased from 2015 to 2022. This can be a concern for policy makers as well as from various agencies and researchers to jointly support mangrove restoration efforts in Banda Aceh, especially by using the advantages of remote sensing and GIS. For suggestions on the research conducted, the analysis of mangrove cover will produce better results if it is carried out with a narrower time span or can be done every year so that the conditions that occur each year can be known.

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