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The Impact of Sunda Strait Tsunami on Environmental Damage in Coastal Area of Pandeglang Regency, Banten Province

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ABSTRACT : Pandeglang Regency is an area prone to disasters, especially tsunamis, seen historically as well as from its potential adjacent to the tectonic plate and the activity of Mount Anak Krakatau (Krakatoa). The Sunda Strait tsunami in December 2018 which occurred due to volcanic activity had a huge impact, both physical and environmental impacts. The use of remote sensing for analysis of changes that occurred has advantages in terms of data speed and accuracy, by utilizing images with different temporal, namely before and after the tsunami so that it can be seen the affected area due to the tsunami wave. Using this method, an analysis can be carried out related to the distribution of impacts from the type of land cover and statistical data to determine the area, besides that it is also used as a reference in making recommendations related to mitigation efforts in the affected areas. The dominant land cover affected is plantation/farmland which is widely spread in Panimbang, Cigeulis, and Sumur Districts with a total area of >70% of the total tsunami impact area. The affected settlements with the largest area are in Carita District as a coastal tourism area, and Labuan District which has a residential area close to the coast, the affected land cover can be used as a reference in determining mitigation efforts both structurally and non-structurally in reducing disaster risk tsunami.

KEYWORDS: Disaster, Environmental, Remote Sensing, Sunda Strait, Tsunami.

I. INTRODUCTION

Indonesia is a country that is prone to tsunamis because it is an area where the three main tectonic plates of the world meet, namely the Eurasian Plate, the Indo-Australian Plate, and the Pacific Plate. A number of areas on the islands are directly opposite the subduction zone between these plates. The National Agency for Disaster Management (BNPB) added that one of the real disaster threats in Indonesia is geological hazards in the form of earthquakes and tsunamis. On a large scale, these disasters occur relatively less frequently than hydrometeorological disasters. However, the resulting impact will be very damaging and cause many casualties [1]. The historical record of tsunamis in Indonesia in the BNPB document shows that approximately 172 tsunamis occurred in the period between 1600–2012. Based on the generator source, it is known that 90% of the tsunami was caused by tectonic earthquake activity, 9% due to volcanic activity, and 1% by landslides that occurred in bodies of water (lakes or seas) or landslides from land that entered the water body [1]. According to Fauzi, et al, in the last two decades there have been at least ten tsunami disasters in Indonesia. Nine of them were tsunamis that were destructive and caused casualties and material loss [2].

The 2012 BNPB Masterplan regarding disaster reduction in the Indonesian territory, the Sunda Strait is one of the priority areas for risk reduction because this area is vulnerable to seismic activity from the collision of the Eurasia-Indo Australia plate, as well as volcanic activity from Mount Anak Krakatau. According to BNPB, three major earthquakes occurred in this zone in 1840, 1867, and 1875. In the last three hundred years, there have been no megathrust earthquakes with a scale of earthquakes of 1833 and 1861 in Sumatra that occurred in this area. With the potential for large earthquakes, it is necessary to prioritize handling both in terms of mitigation and efforts to reduce disaster risk [1]. The natural phenomenon of the tsunami occurred in the Sunda Strait with the affected areas of 2 (two) provinces, namely Banten Province (Serang Regency and Pandeglang Regency) and Lampung Province (South Lampung Regency, Pesawaran Regency, and Tanggamus Regency) [2]. Alimsuardi, M, et al. explain the tsunami disaster was triggered by the eruption of Mount Anak Krakatau with landslide slopes covering an area of 64 hectares along 312.78 km into the Sunda Strait with a depth of 0.08 km with an intensity of 255 cubic millimeters, during high tide on Saturday, December 22, 2018, at 8:56 P.M (GMT+7) [3]. Based on data from BNPB after the tsunami, the Sunda Strait tsunami on 22 December 2018, hit the coasts of Banten and Lampung Provinces with more than 437 fatalities and 23 people

missing, apart from these impacts the tsunami also damaged many infrastructures in coastal areas, where the most severe damage occurred in Pandeglang Regency, Banten Province.
As a result of the tsunami incident, it caused a lot of material and non-material losses, besides that there was also a lot of damage in the western coastal area of Banten Province, report from Regional Office for Disaster Management Agency of Pandeglang [4]. In many cases, disasters act as catalysts in the adoption of new and emerging technologies. Emphasized by the need for critical information in fast time for disaster management, technological innovations often assist emergency response efforts to assess the impact of large disasters more efficiently and quickly and to track and monitor progress in critical response and recovery operations [5]. Today's remote sensing is not only a tool in solving problems. However, it has become a kind of framework in solving various problems related to spatial, environmental, and territorial aspects due to the wide scope of remote sensing applications [6]. The use of sensing can be applied to many aspects, one of which is post-disaster, where multitemporal the appearance of an area can be known what changes have occurred so that it can be analyzed carefully to produce information related to the impact of the incident, as well as for input in disaster management. recommended in the region. The focus of this research is: 1) To analyze the distribution of the tsunami impact on the coast of Pandeglang Regency with multitemporal imagery. 2) Calculating the extent of the tsunami impact on physical and environmental changes. 3) Provide recommendations for tsunami disaster mitigation efforts in the coastal area of Pandeglang Regency, Banten Province.

Tsunamis in the Sunda Strait can be caused by tectonic earthquakes in the waters of the Sunda Strait and the Indian Ocean; or triggered by a volcanic earthquake due to the activity of Mount Anak Krakatau. Damage due to tsunami waves mainly occurred in the bay area due to the narrowing of the wave motion which accelerated the wave motion [2]. Solihudin, T., et al. add an explanation tsunami that are triggered by volcanic activity and volcanic material avalanches such as the one in the Sunda Strait on 22 December 2018 are very rare, so it must be an important lesson for the community, local government, and central government that the source of the tsunami disaster is not only from tectonic activities such as earthquakes but also from volcanic activity. In addition, based on the results of field observations and eyewitness accounts in the affected locations, the maximum inundation coverage of the tsunami reaches 200 m from the coastline, as happened in Kertajaya Village, Sumur District, so that special attention is needed for the local government in planning and spatial planning for the coastal radius. 1-200 m from the coastline [7]. This research was conducted along the coast of Banten Province, especially in Pandeglang Regency which was the most affected by the tsunami, namely Carita and Labuhan Districts. In addition, Sumur District is located at the western tip of Banten Province as shown in Fig. 1.

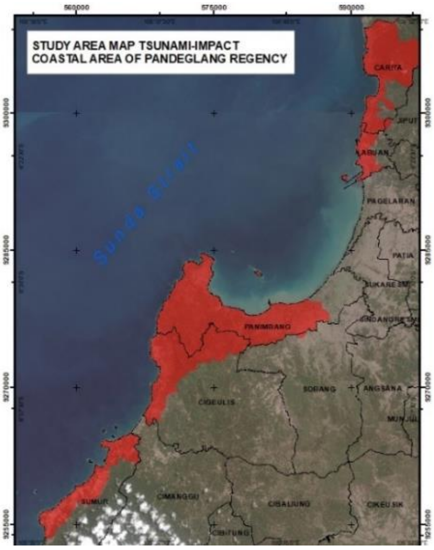

Figure 1 Study Area

II. RESEARCH METHOD

This research on the identification of damage to the coastal areas of Pandeglang Regency was carried out to determine the physical impact of the post-tsunami environment in 2018. The scope of the research area is along with the coastal areas that are most affected according to the Pusdalops BPBD Report of Pandeglang Regency [4], including Carita, Labuan, Panimbang, Cigeulis, and Sumur Districts. In this study, primary data were collected by means of observation at the research location and interviews with several respondents. Determination of respondents was carried out by purposive sampling method, namely some who had been directly affected to collect information related to the events and post-tsunami of the Sunda Strait in December 2018. Secondary data were collected from various sources, both remote sensing data and literature data for writing references. In this study, there are 2 (two) data collection techniques, namely primary and secondary data collection. Both primary and secondary data are used for secondary data processing in order to produce output data to answer research objectives. Prior to processing, this research requires data that needs to be prepared for the analysis of land cover changes that occur, namely by using remote sensing data. The data used is the Sentinel-2 Level 1T image in September 2018 for reference data before the tsunami and January 2019 for post-tsunami image data. The use of Sentinel-2 data for research is because it has a high enough resolution for analysis of changes due to tsunami events with a spatial resolution specification of 10 meters for visible spectral and 20 meters for infrared, so it has the advantage of using multispectral fusion for image analysis in the affected area. In addition, Sentinel-2 imagery is easy to obtain by accessing the Earthexplorer United States Geological Survey (USGS) to obtain it and can download according to the study area, as for the 10-day temporal scale for recording at the same location, post-disaster image data acquisition can be completed in a fast time.

Other secondary data needed to support this research is Indonesian topographical (RBI) digital data which has information on the land cover of the study area. The land cover data is updated for the latest land cover, according to the recording time of the image before the tsunami occurs, so that with a comparison of the temporal image that undergoes post-tsunami changes it will be known the variations and distribution of land cover affected by the tsunami waves. Suppasri, A., et al. explained that in the first stage, general damage information, such as tsunami inundation boundaries, can be obtained immediately using analysis combined with original information in the field using GIS. Tsunami inundation areas are one of the most important types of information that must be generated immediately after a tsunami as they can help estimate the scale of the tsunami's impact. Travel to the tsunami-affected area for the field survey took a lot of time, given the roads and bridges were damaged, with a lot of debris also as a barrier. In the second stage, a detailed damage interpretation can be analyzed; such as the classification of the level of damage to buildings [8].

Satellite image processing consists of several stages, namely: pre-processing and object classification and post-processing, namely field observations. Data pre-processing consists of rectifying the data or making geometric corrections to the image, where the use of multitemporal data needs to be corrected so that the data has an accurate geometric value. The radiometric correction process is needed to reduce cloud interference which will affect the image pixel value so that it can affect the multispectral classification process. The use of Sentinel-2 imagery with Level 1T automatically does not require geometric, radiometric, or atmospheric correction, because the image level 1T has been corrected automatically by the image provider.Analysis of images affected by tsunami waves uses visual interpretation methods on Sentinel-2 remote sensing data, while these images use 832 multispectral band fusion (near-infrared, green, and blue) to provide sharper visuals in identifying affected coastal objects. Fig. 2 is a step for interpreting images before and after being impacted, after that doing on-screen digitization for the affected area. On-screen digitization really refers to the researcher's ability to know the elements of interpretation, therefore the accuracy in the use of visual methods is very dependent on the level of professionalism of the interpreter.

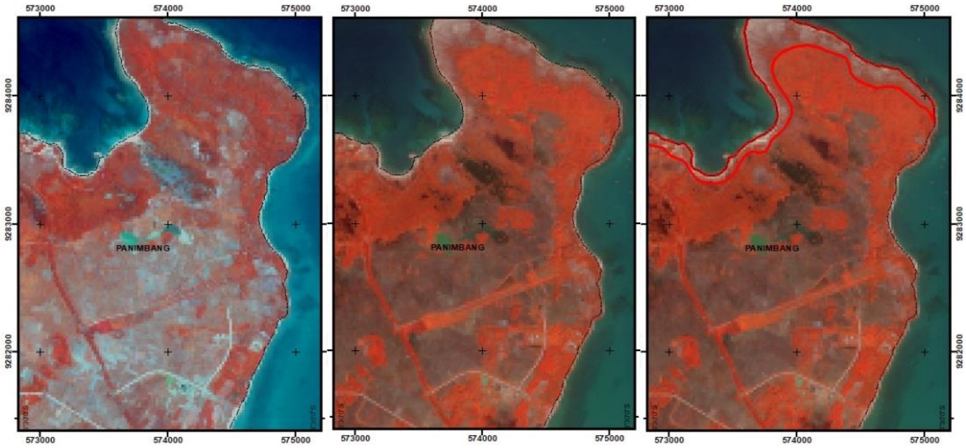

Figure 2 Sentinel-2 image appearance (a) Before, (b) after and (c) the results of visual interpretation of the affected areas in Panimbang District

III. RESULTS AND DISCUSSION

Land cover of study area : Identification of affected objects through images is carried out with the existence of land cover object classification data before overlaying with the area of impact resulting from on-screen digitization. The area of updating the land cover and impact overlay is used as a reference to determine the extent of the affected coastal areas so that the type of land cover affected is known and analyzed based on the distribution and area as a basis for recommendations for disaster mitigation efforts in the coastal area of the Sunda Strait, Pandeglang Regency. In the past, obtaining tsunami damage information was limited to field surveys and/or using aerial photographs. In the last decade, remote sensing has been applied in many tsunami studies, such as the detection of tsunami damage. Satellite remote sensing can help us survey tsunami damage in a number of ways. In general, the application of remote sensing for a tsunami disaster can be classified into three stages depending on time and disaster-related information [8].

Wikantika, K., et al. describes that damage assessment before and after the disaster has attracted significant attention among researchers and practitioners of disaster management. Recent advances in remote sensing and application technology allow the use of remote sensing image data to assess the vulnerability of an area and to capture the distribution of damage caused by disasters. To obtain spatial information before and after the incident in the built and natural environment, there are several methods, such as field surveys, aerial remote sensing, and satellite remote sensing [9]. The method of using satellite remote sensing has many advantages, apart from relying on its fast temporal resolution, satellite remote sensing has a temporal that can be adjusted to a large study area, which generally uses satellite imagery with a wide imaging area coverage.Due to its ability to cover a large area in one acquisition time, remote sensing satellites have become a very powerful tool for monitoring the conditions of the earth's surface. High-resolution satellite imagery, which has become available in recent years, has made sensing satellites much more useful in disaster management because even the damage status of each building and infrastructure can be identified without visiting the disaster site [9]. One of the most widely used satellite images for land degradation analysis is Sentinel-2, with a wide area coverage in one imaging scene with a temporal time of 10 days which can be applied during an emergency (when a disaster occurs and data needs must be fast).

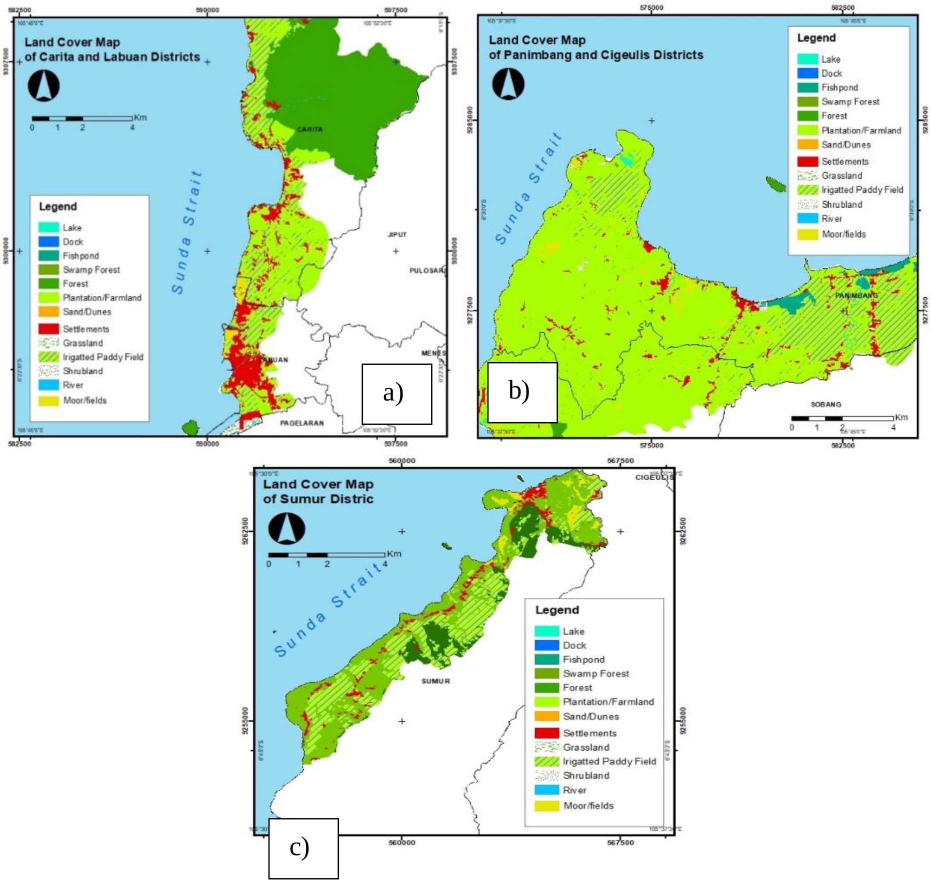

Figure 3 Land Cover Map a) Carita and Labuan b) Panimbang and Cigeulis, and
c) Sumur District, Pandeglang Regency

The land cover of Pandeglang Regency as a result of the updating is based on remote sensing images data acquisitions in September 2018 before the tsunami, updating is done on the image with a 432 visible band composite to make it easier to identify land cover. According to land cover data that has been renewed for the affected areas, namely Carita, Labuan, Panimbang, Cigeulis, and Sumur Districts as in Fig. 3, the dominant land cover as a whole is plantation/farmland located in Sumur and Panimbang Districts, for more Settlements. found in tourist areas, such as the northern part of Sumur sub-district, and along the coast of Carita District, most of which are villas and hotels (accommodation/lodging) because they are well-known tourism areas. According to Fauzi, et al. the description of the impact of the tsunami disaster, among others, is as follows: 1) The impact of the first tsunami, the damage referred to is physical damage to both buildings and non-buildings. The large waves that arise due to the tsunami can sweep the entire land area, both the coastal area and the areas around the coast. 2) Agriculture and fisheries land is damaged. A large tsunami wave can also cause damage to agricultural and fisheries land. 3) Obstruct economic activity. Tsunami natural disasters can disrupt all economic activities in a region. The damage and losses caused by the tsunami waves can paralyze economic activity for some time [2]. The analysis of environmental damage that occurs is based on the type of land cover found in the coastal area, the land cover in the area affects the coastal ecosystem from land to tides.

Distribution and area of land cover affected by the tsunami on the coastal area

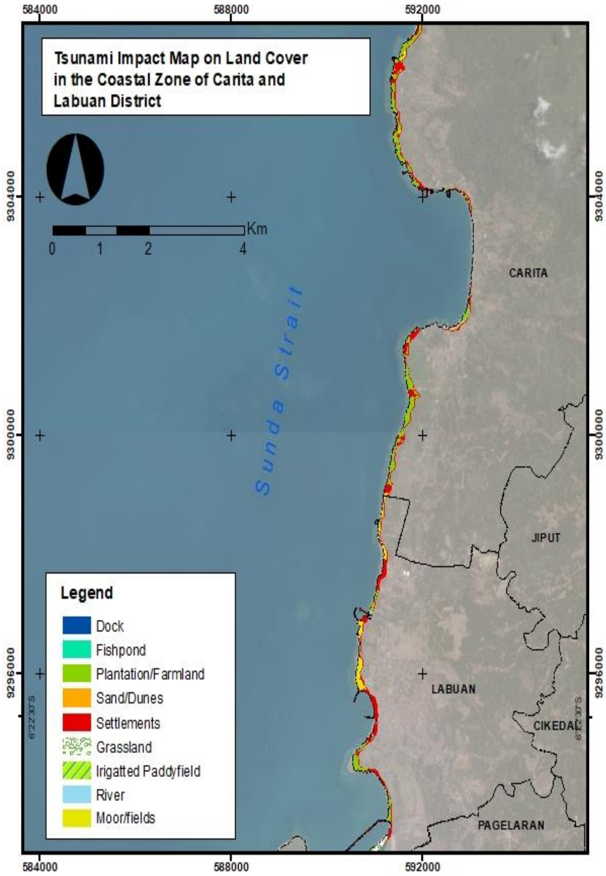

Figure 4 The Impact of the Tsunami on Land Cover in Carita and Labuan Districts

Based on the visual interpretation and on-screen digitization of the affected area using the Sentinel-2 multitemporal imagery before and after the tsunami, the results of the distribution of land cover in the coastal area of Pandeglang Regency were affected by the tsunami disaster in December 2018. From the study area, 5 (five) districts were most affected The results of data processing for the affected areas are shown in Fig. 4, where in general the Carita and Labuan areas have an impact of 159.4 Ha, based on Table 1, the dominant land cover damaged by the tsunami waves is plantation/farmland with an area of 76.07 Ha or 47.72% of the total area of the 2 sub-districts of this study, besides that the biggest impact was felt by the community and tourism actors because settlements covering an area of 40.98 Ha or 25.71% were affected by the tsunami, which caused a lot of material loss and human casualties.

Table 1 The land cover area of tsunami impact in the Carita and Labuan District

LAND COVER CLASS	**AREA (HA)**	**(%)**
Dock	8.78	5.51
Fishpond	0.02	0.01
Plantation/Farmland	76.07	47.72
Sand/Dunes	3.30	2.07
Settlements	40.98	25.71
Grassland	11.36	7.12
Irrigated Paddy Field	4.30	2.70
River	2.15	1.35
Moor/fields	12.44	7.81
Total	**159.40**	**100**

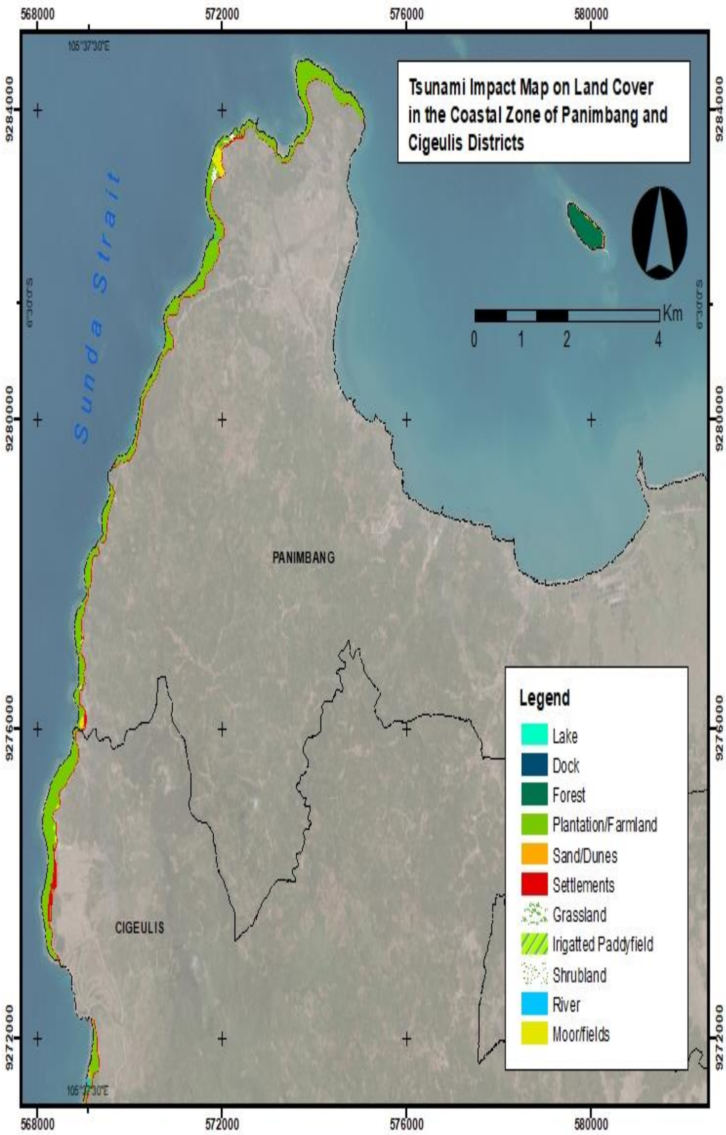

Figure 5 The Impact of the Tsunami on Land Cover in Panimbang and Cigeulis Districts

In the study area, the parts of Panimbang and Cigeulis districts have a larger coastal area compared to other parts of the study area, from the analysis of the pre and post-tsunami images, the total area affected in this area is 313.11 Ha (Table 2), which is spread over more many in the western part of Panimbang as in Fig. 5, especially at the upper end of the Panimbang District which has many resorts and villas as tourist attractions which were Swept away faster because it was close to the location of the Mount Anak Krakatau landslide. The area of land cover that is dominantly affected is plantation/farmland 224.76 Ha or 71.78% of the total area of the affected area, the coastal area with a low slope making this area dominated by this land cover. Sand/dunes around the coast is 18.19 Ha or 5.81% affected by the tsunami waves, while for Settlements it has a percentage of 2.33% of the affected area in Panimbang Cigeulis District with an area of 7.29 Ha.

Table 2 The land cover area of tsunami impact in the Panimbang and Cigeulis District

LAND COVER CLASS	AREA (HA)	(%)
Lake	0.34	0.11
Dock	0.03	0.01
Forest	22.73	7.26
Plantation/Farmland	224.76	71.78
Sand/Dunes	18.19	5.81

Settlements	7.29	2.33
Grassland	1.06	0.34
Irrigated Paddy Field	3.43	1.10
Shrubland	1.61	0.51
River	2.95	0.94
Moor/fields	30.73	9.81
Total	**313.11**	**100**

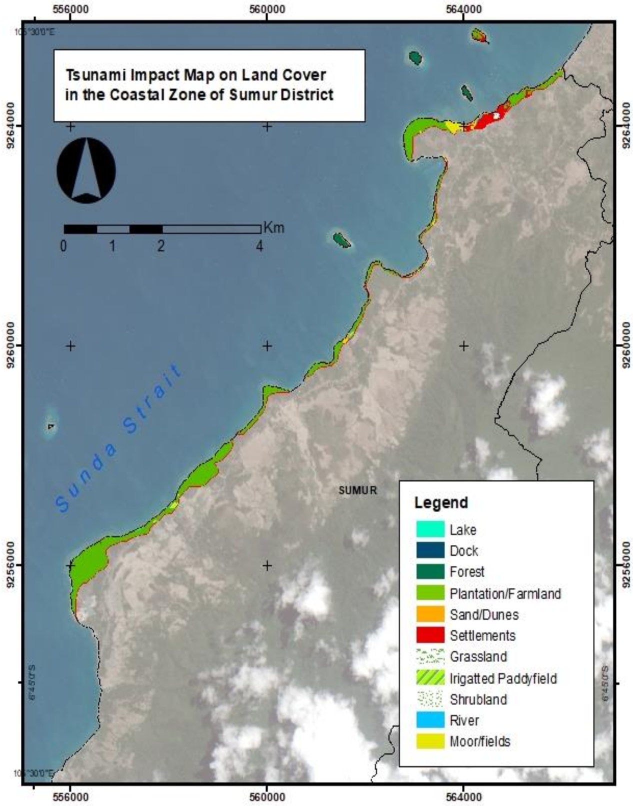

Figure 6 The Impact of the Tsunami on Land Cover in Sumur Districts

In the Sumur District area, the distribution of land cover impacts is attached in Fig. 6, where it can be seen visually that the dominant affected land cover affected is plantation/farmland, based on Table 3, plantation/farmland has an area of 169.20 Ha 78.53% of the area. total land cover affected by Tsunami in Sumur District. Settlements in Sumur District are centered in the northern part of the area with a red symbol, which is the center of residents' settlements and adjacent to tourist sites, where the area of impact on this land cover is 15.09 Ha or 7% of the impact on the coastal area of Sumur District.

Table 3 The land cover area of tsunami impact in the Sumur District

LAND COVER CLASS	AREA (HA)	(%)
Lake	0.28	0.13
Dock	0.05	0.02
Forest	9.96	4.62
Plantation/Farmland	169.20	78.53
Sand/Dunes	7.68	3.56
Settlements	15.09	7.00
Irrigated Paddy Field	2.91	1.35
Shrubland	1.20	0.56
River	1.19	0.55
Moor/field	7.91	3.67

Total	**215.46**	**100**

Most of the land cover affected by the tsunami in the coastal area of Pandeglang Regency is plantation/farmland which is generally found in coastal areas and is used by humans who live around the area. The most affected settlements according to Fig. 4 and Fig. 5 are tourist areas and settlements of residents who predominantly work as fishermen and fish traders. The impact on settlements was felt on the communities in the Carita and Sumur areas, where as a result of the tsunami the tourist area was deserted and their economy was disrupted. As for the impact on the pond environment in the Panimbang and Sumur area, residents who work in pond cultivation are hampered and have to restore the pond land first, which results in considerable economic losses, as well as fishermen who are affected by damaged boats and cannot go to sea for work as usual. Based on the results of checking the field points on the interpretation results as a test of the accuracy of the data from the classification results of land cover using the configuration matrix method, the resulting average accuracy value is 91% of a total of 32 sample points scattered in the study area from Carita to Sumur District, field accuracy is also supported by the results of interviews as shown in Fig. 7 with the affected surrounding communities to find out the extent of the impact after the 2018 tsunami and how the cover changes due to the impact of the tsunami around the study area.

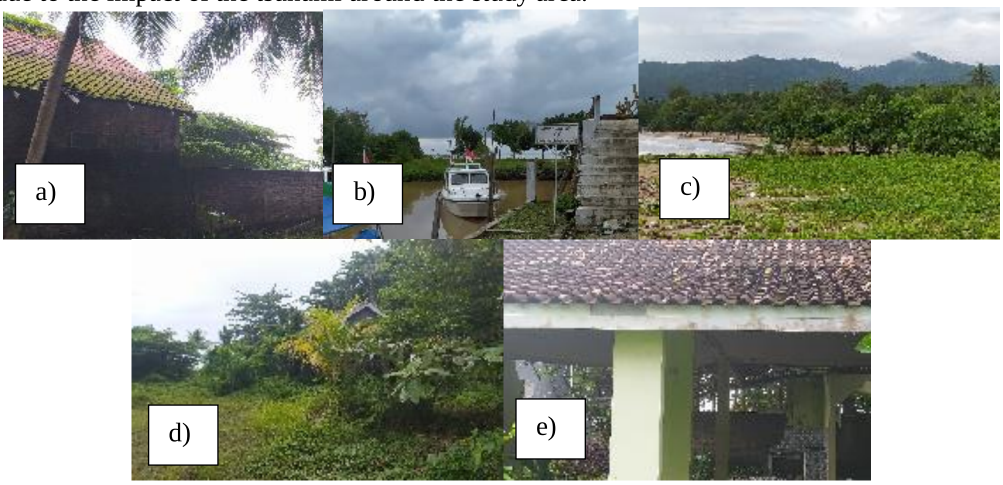

Figure 7 Activities from field checks for land cover a) Hotels affected b) Broken bridges by the tsunamic) Dominant land use in coastal areas d) Plantation/farmland land cover, and e) Post-tsunami damage

Recommendations in disaster mitigation for the coastal area of Pandeglang Regency : The results of the impact assessment prove that most of the land cover affected by the tsunami is plantation/farmland areas which have >70% of the total area affected in Pandeglang Regency. In addition, environmental settlements have a large area because many settlements are found directly in coastal areas, coupled with the proliferation of hotels and resorts that have received permits to develop in areas adjacent to the shoreline. Based on Presidential Regulations No. 51 of 2016, Provincial and Regency/City Governments that have coastal boundaries are required to determine their coastal boundaries in a Regional Regulation concerning Regional Spatial Planning (RTRW). This coastal boundary determination is carried out to protect and safeguard: a) Preservation of ecosystem functions and all resources in coastal areas and small islands; b) The life of people in coastal areas and small areas from the threat of natural disasters; c) Allocation of space for public access through the coast; and d) Allocation of space for water and sewage channels [10]. As a result of the disaster, coastal areas that do not monitor space allocation and ecosystem sustainability will have greater vulnerability when abrasion waves or tsunamis occur, such as a large number of lands uses as settlements in vulnerable locations (coastal). This should be carried out an assessment to be able to reduce disaster risk in coastal areas, with the existence of regional spatial arrangements regulated by the government with reference to the direction of disaster mitigation, it will be one of the non-structural aspects of mitigation. Settlements located in disaster-prone areas should have preparedness by being given socialization regarding the level of risk and efforts to increase capacity, which with this program the residential environment has resistance to tsunami disasters. Tsunami disaster mitigation is not only social and physical but also requires land adjustment, with the existence of the

RTRW in Pandeglang Regency, it is necessary to make a green belt, which can withstand waves from the sea to the land, such as planting mangroves which is more environmentally friendly and relatively cheap.

Several locations around Labuan and Anyer Beach which are close to Carita District already have an early warning system as a warning. When there is a seismic activity that has the potential for a tsunami, however, like the December 2018 tsunami case the device does not function effectively, because the tsunami did not occur due to plate crushing and seismic. However, due to landslides from Mount Anak Krakatau activity material, it is necessary to have a system that can directly reduce the potential damage caused by the tsunami, namely the construction of a wave break zone in sloping coastal locations and many are affected by settlements and community activities, so that from sea waves can automatically decrease periodically until it reaches the settlement.

IV. CONCLUSION

The results of the analysis of land cover affected by the tsunami using remote sensing imagery of Sentinel-2 have advantages with fast temporal and spatial 10-20 meters, especially with multispectral fusion with 832 composites to analyze changes in cover affected by the tsunami. The distribution of land cover is mostly dominated by plantation/farmland around the coast of Panimbang and Sumur Districts, which reaches >70% of the total area affected. The area of the affected settlements is mostly located in Carita and Labuan Districts because the centers of settlements and tourism are in these locations, besides that, settlements in the northern region of Sumur District and resorts/hotels in the western end of Panimbang district are the center of tourist locations. Other land covers that were affected but not significantly included; forest, paddy field, dock, and moor/fields. Tsunami disaster mitigation can be carried out by referring to land cover and affected areas by re-adjusting land use that has been regulated in the spatial planning of Pandeglang Regency, the number of settlements and tourism actors in prone locations must be given disaster-related knowledge to increase community capacity in dealing with disasters. Non-structural mitigation can be carried out naturally, such as making greenbelt in coastal areas and utilizing mangrove plants, and by building a wave break zone as a barrier when a tsunami occurs in a vulnerable location.

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