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Spatial Analysis of Flood Inundation From Sentinel-1 Imagery Using Google Earth Engine (Case Study: Bengawan Jero Lamongan Regency)

Nafisatus Sania Irbah, Lalu Muhamad Jaelani*
Departemen Teknik Geomatika, FTSPK-ITS, Kampus ITS Sukolilo, Surabaya, 60111, Indonesia
*Corresponding author: lmjaelani@its.ac.id

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Abstract: Flooding is a natural disaster due to rivers that are no longer able to accommodate excessive rainwater so that water overflows and inundates the surrounding area. During the rainy season, many areas in Indonesia experience flooding, one of which is the Lamongan Regency. In early 2022, seasonal flooding occurred due to runoff from Bengawan Jero which caused many houses, agricultural land and access roads to be submerged in water. To improve disaster mitigation activities, it is necessary to identify flooding areas using remote sensing. The distribution area of flood inundation was identified using change detection and threshold methods. The change detection method is carried out by using ratio images from Sentinel-1 image data. The results of land cover in Lamongan Regency resulted in 9 land cover classes. Where is dominated by agricultural class land cover with an area of 1057.94 km^2 with a percentage of the total area of Lamongan Regency is 60.53%. While the smallest land cover area is the mangrove class covering an area of 101.237 km^2 with a percentage of the total area of 0.058%. Extraction of the inundation area was carried out with two different threshold values obtained from equations and statistical calculations. The flood inundation area generated on January 31, 2022, for the first threshold value is 54.932 km^2 with an overall accuracy of 97% with a kappa coefficient is 0.94. While the flood inundation area with the second threshold value is 90.330 km^2 with an overall accuracy of 94% and a kappa coefficient is 0.88.

Keywords : Change Detection; Flood Inundation; Google Earth Engine; Lamongan Regency; Threshold

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Introduction

The rapid pace of Indonesian development in various aspects has directly brought changes in human life and the surrounding environment. These changes can be in the form of changes in vegetation, changes in soil absorption of water, or river sedimentation so that it has the potential to increase river discharge which can lead to natural disasters such as floods (Heryana, 2020). Flooding is a natural disaster due to rivers that are no longer able to accommodate excessive rainwater so that water overflows and inundates the surrounding area. The causes of flooding can be divided into problems caused by population activities and natural conditions. Population activity factors affect the flood situation, such as the growth of cultivated areas in floodplain areas, hoarding of swampy areas or lakes, and narrowing of river flows due to settlements along river borders. While the influence of natural conditions in question includes high rainfall, overflow of river water, and river estuary dams due to high tides from the sea. (BNPB, 2010)

Flood disaster is a common thing in Indonesia, especially during the rainy season. One of them happened in Lamongan Regency. The district area covers 1755.929 km^2 or ± 3.78% of the total area of East Java Province which is located at 6º 51' 54" - 7º 23' 6" South and 112º 4' 41" - 112º 33 '12" East. The region has been separated by the Bengawan Solo River into two parts with a total length of about 65 km (BPS, 2021). At the start of 2022, seasonal flooding occurred due to runoff from the Bengawan Solo tributary area, known as the

Bengawan Jero which was unable to accommodate the water discharge due to the high intensity of rainfall. The impact of the flood was that many houses, agricultural land, and road access were submerged in water, especially in five sub-districts, namely Glagah, Kalitengah, Turi, Deket, and Karangbiangun sub-districts. (Saputro, 2021)

In this study, the distribution of flood inundation was mapped using remote sensing. Remote sensing is a science and art that is used to obtain information about an object, area, or phenomenon through analysis of data obtained with a tool without direct contact with the object, area, or phenomenon being studied (Lillesand et al., 2015). This study uses Sentinel-1 SAR satellite imagery as primary data. Synthetic Aperture Radar (SAR) which has the advantage of not being constrained by day or night, weather conditions, cloud cover, or fog that can eliminate important information from objects behind the closed area (Utomo, 2020). The SAR sensor is sensitive to dielectric properties(ESA, 2012). Water can be identified in SAR images easily because the water looks dark. After all, the smooth water surface cannot restore the SAR sensor (Moothedan et al., 2020). So that the radar satellite, Sentinel-1, can be used to map flood disasters.

This research was conducted for spatial analysis of the distribution of flood inundation in the Lamongan Regency. Flood mapping uses the change detection method, which is comparing two images (before and after) to identify changes in waterlogging (Kasanah, 2020). The result obtained is the extracted flood distribution map which is expected to be a reference for the Regional Government in flood disaster mitigation activities.

Data and Method

1. Location Study Area

The location used as a case study in this research is Lamongan Regency which is geographically located at coordinates between 6º 51' 54” - 7º 23' 6” S and 112º 4' 44” - 112º 33' 13” E displayed in Figure 1. As for the border areas, to the north the Java Sea stretches, to the east it is bordered by Gresik Regency, to the south by Mojokerto Regency and Jombang Regency, and to the west by Tuban Regency and Bojonegoro Regency. (BPS, 2021)

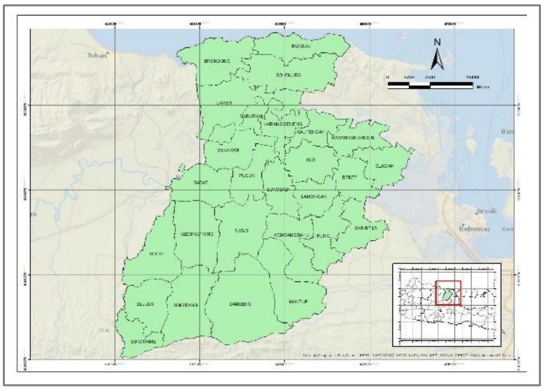

Figure 1. Location study area

2. Data and Tools

The data used in this study include the Sentinel-1 SAR Satellite Imagery obtained from the Google Earth Engine platform with 2 different recording times, for before the flood dataset from October 1, 2021, to October 10, 2021, and for the dataset when the flood occurred starting from January 31, 2022, to February 13, 2022. JRC Global Surface Water Mapping Layers version 1.3 data was used for masking permanent water bodies from flood inundation in the study area (Pekel et al., 2016). As well as WWF HydroSHEDS Void-Filled DEM data, 3 ArcSeconds required for masking slope(Lehner et al., 2008). This study also uses district administrative boundary vector data obtained from the Geospatial Information Agency or Badan Informasi Geospasial (BIG) and ESA World Cover data obtained from the GEE dataset to determine the topography in Lamongan Regency. In addition, for validation, use flood event data from the Regional Disaster Management Agency or Badan Penanggulangan Bencana Daerah (BPBD) of Lamongan Regency. The softwares used in this research are Google Earth Engine, ArcMap 10.8, ENVI 5.3, and Microsoft Office 365.

3. Methods

The processing stage can be seen in Figure 2. The first processing carried out was pre-processing the Sentinel-1 satellite image which consists of four steps. The first step is applying orbit file to update the metadata orbit status vector. The second is remove the thermal in order to normalize the backscattered signal. The next step is radiometric calibration normalizes the value in the image into a backscatter value so as to produce a sigma naught (dB) value as a good separator between water bodies and ground level. The last step is terrain correction to adjust the coordinates. The Sentinel-1 image data that has been pre-processed only uses amplitude not phase (Alawiyah & Harintaka, 2021). To find the availability of data, the data must be filtered by the type of instrument mode, polarization, pass direction and spatial resolution (Fajrin et al., 2019). After that, the image is clipped by Lamongan boundaries then processed with Lee Filter script to remove the noise. (Ngurawan, 2021).

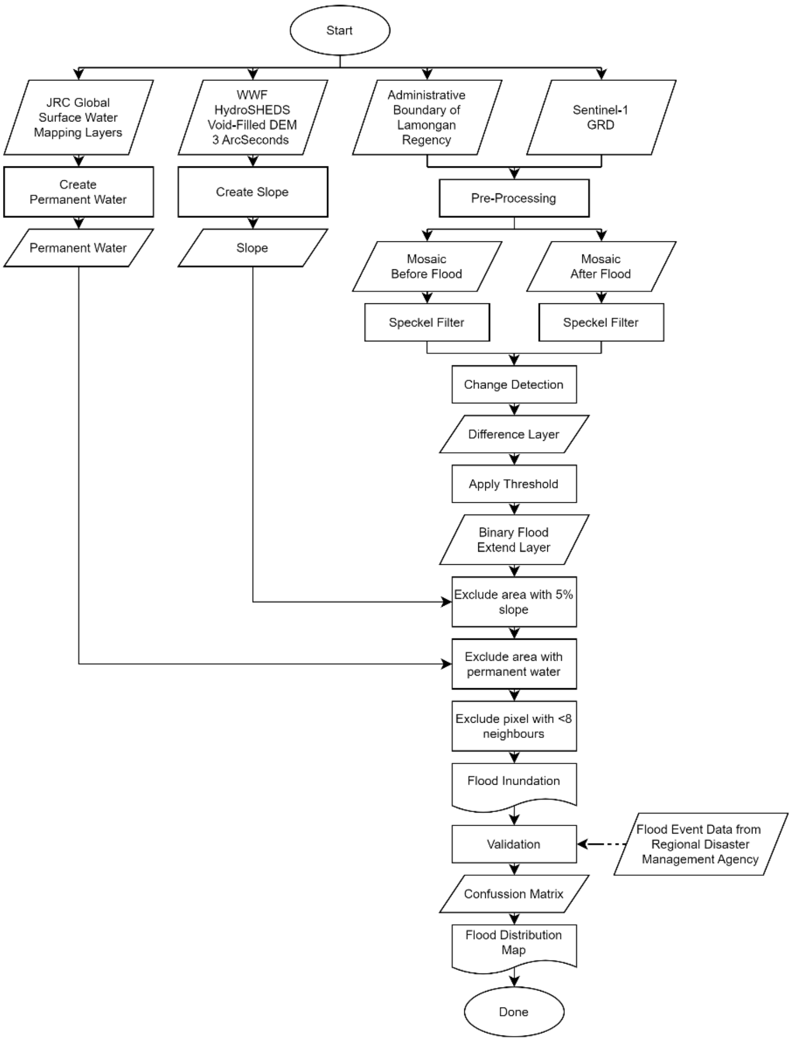

Figure 2. Flowchart of Data Processing

The threshold determination in this study is done by two methods. In the first method, the layers separated into water and non-water bodies using JRC Water Surface Global Mapping then extract the pixel value from POI to obtain the mean (μ) and standard deviation (σ) values from each object. The optimum threshold can be generated from equation 1 (Vanama et al., 2021) :

$$Optimum\ Threshold = \mu_{water} + \sigma_{water} \quad (1)$$

where:

$$\mu_{water} = \frac{1}{N}\sum_{i=1}^{N} WaterPOI_i \quad (2)$$

$$\sigma_{water} = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}|WaterPOI_i - \mu_{water}|^2} \quad (3)$$

The non-water pixel value is also used in determining the optimum threshold. Pixel values between the threshold for water bodies and non-water bodies are identified as flooded areas (Vanama et al., 2021).

While the second method is to calculate the median value using equation 4 and then look at the visual results of the value on the change detection (Pramana, 2014).

$$T = \frac{\max + min}{2} \quad (4)$$

From that equation, the first threshold is 1.15 to 1.5 and the second threshold is 1.1.

In the next stage, the image will be separated from the permanent water data processing Global Surface Water Mapping. Then remove pixels with a slope of more than 5%. The DEM data is then processed to determine the level of slope to produce a slope image. Then the process of excluding pixels with less than 8 neighbors is to eliminate pixels that are connected to less than eight adjacent pixels to reduce noise from the visualization of flood distribution (Fajrin et al., 2019).

Validation is carried out after getting the results of the distribution and inundation of floods using flood event data from the Regional Disaster Management Agency of Lamongan as well as local news and articles. The calculation of the confusion matrix is carried out to determine the level of accuracy of processing success with actual flood events. Then, a comparison analysis of the results was carried out visually and quantitatively from the threshold used.

Results and Discussion

1. Change Detection

The principle of change detection is to detect changes in the backscattering from two data series Sentinel-1 imagery, namely before the flood on October 10, 2021, which is shown in Figure 3, and after the flood on January 31, 2022, which is shown in Figure 4. The image shows the color range from white to black with the black value getting smaller. Where the darker the color of an area, the more water in that area.

After processing with ENVI 5.3, the average change detection Ratio Image (RI) value of the image was 1.497. This value indicates a change in the location because the value of RI is 1. The ratio value will be greater than 1 or less than 1 depending on changes in the two images. The RI results can be seen in Figure 5, black pixels indicate that the location has a high-value ratio and indicates a high change and vice versa. In addition, calculations are also carried out on the Google Earth Engine by displaying a histogram as shown in Figure 6. The difference value with the highest number of pixels is 0.914 with a pixel count of 29294 pixels. While the difference value which has the least number of pixels is 0.762 with the number of pixels as many as 29 pixels.

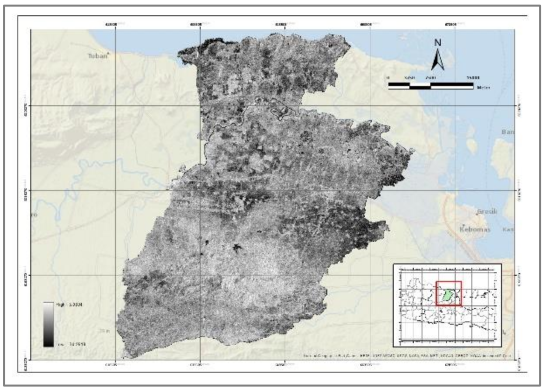

Figure 3. Imagery Before Flooding in October 2021

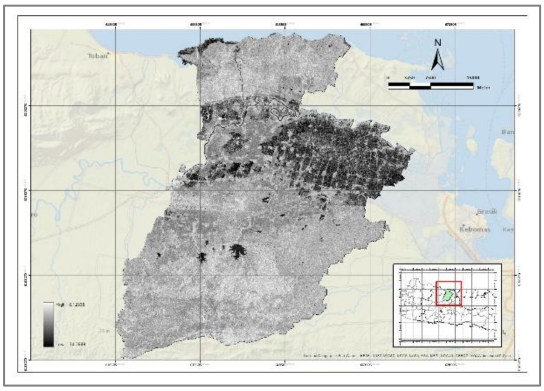

Figure 4. Imagery After Flooding in January 2022

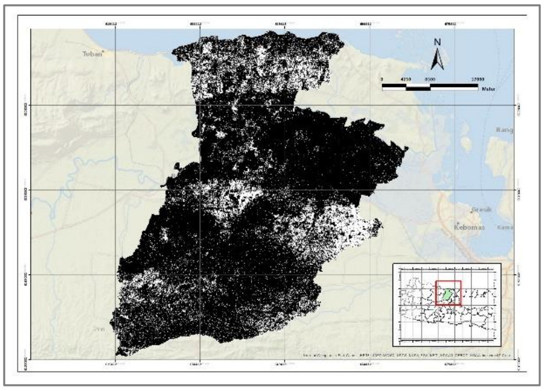

Figure 5. The result of Change Detection Ratio Image

2. Thresholding

After obtaining the RI index, the determination of the optimum threshold value is carried out. This optimum threshold is used to identify flooded and non-flooded areas obtained from two methods. The first method is done by separating water and non-water bodies first. Then pasted the image from the change detection Ratio Image to create a fishnet in the area and extract the value to get the pixel value. Based on the values that have been obtained and performing statistical calculations according to equations (2) and (3), the results are shown in Table 1. Based on the calculation results, the optimum threshold for water bodies is 1.5 and for non-water bodies is 1.15 which it shows the flood range at 1.15 to 1.54. While the pixel values that are outside the range are indicated as non-flood areas.

Table 1. The results of the extract value RI

Area	Stdv	Mean	Optimum Threshold
Waterbody	0.25	1.29	1.54
Non-Waterbody	0.20	0.96	1.15

The second method to determine the threshold is used the histogram of sum in Figure 6 which shows the pixel value and its frequency from change detection image. This method is carried out with the median value and trial and error to obtain a threshold value of 1.1. So that it can be classified if the difference value is less than the specified threshold value, it is included in the flood area. Meanwhile, if the difference value is more than the predetermined threshold value, it is included in the non-flood area. The result of the thresholding form of a binary layer shows a value of 1 for all pixels that are at the threshold value (binary layer) is a layer that only has two values of gray level (grey level) 0 or 1. A value of 1 indicates a flood class, while a value of 0 indicates a non-flooded class.

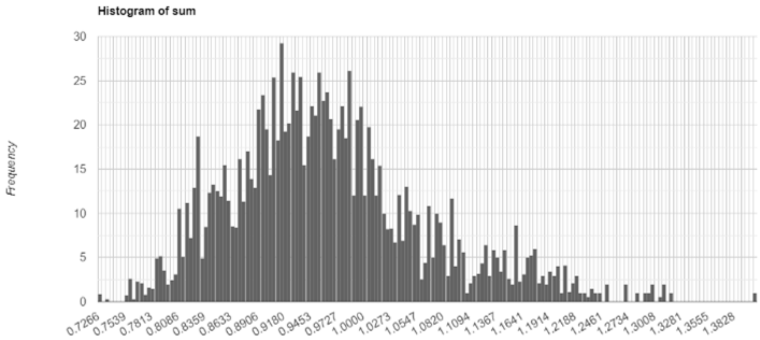

Figure 6. Histogram of Change Detection

3. Distribution and Are of Flood Inundation in each District

To detect the distribution and extent of flood inundation areas on January 31, 2022, it is necessary to mask permanent water bodies, slopes, and pixel neighbors. From the processing that has been done, two different results are obtained based on the method of determining the threshold. The research area or the area of Lamongan Regency consists of 1755.929 km^2. The results of the flood inundation areas in Figures 7 and 8 are shown in red.

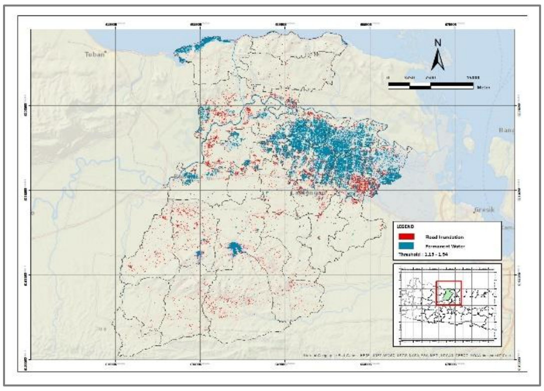
Figure 7. Flood Inundation Distribution with the 1st Threshold

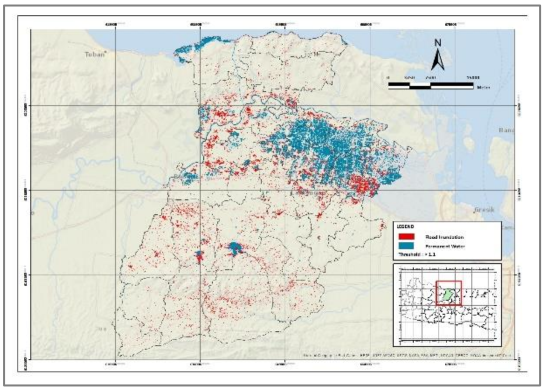
Figure 8. Flood Inundation Distribution with the 2nd Threshold

In the flood inundation distribution area of the 1st threshold value, statistical calculations are used from the range of values pixels of water bodies and non-water bodies to get the pixel range which is a flood area between 1.15 to 1.54. Flood inundation covers all sub-districts in Lamongan Regency with a total flood inundation area of 54.932 km^2.

Table 2. A comparison of the total area between thresholds

Metode	Threshold	Flood (km^2)	Non-Flood (km^2)
Separation of objects	1.15 – 1.5	54.932	1700.997
Median value	1.1	90.330	1665.599

As for the results of the flood inundation distribution area from the second threshold from the change detection seen from the histogram graph, the value of 1.1 is obtained. This means that areas with a change detection value of less than 1.1 are identified as flood inundation areas, while areas with a change detection value of more than 1.1 are identified as non-flood areas. The results of flood inundation distributions are shown in Figure 8. Similar to the previous results, the flood inundation covers throughout Lamongan Regency with a total area of 90.330 km^2. A comparison of the total area of flood and non-flood areas between the two thresholds is presented in Table 2. Where the percentage of flood inundation distribution area to the total area of Lamongan Regency for the 1st threshold value is 3.07% while the percentage for the 2nd threshold value is 5.09%.

A calculation of the distribution of floods based on sub-districts is carried out to find out which areas have the highest and lowest percentages affected by floods. The results of the distribution of flood inundation in each sub-district can be seen in Table 3. The highest percentage of flood-affected areas to the area of their sub-districts based on the first threshold is found in Laren District, with a flooded area is 5.829 km^2, and based on the second threshold also found in Laren District, with a flooded area is 9.411 km^2. Meanwhile, the smallest percentage of areas affected by floods based on the first threshold is found in Sukorame District, with a flooded area is 0.189 km^2, and based on the second threshold in Sukorame District with a flooded area is 0.470 km^2.

Table 3. A comparison of the total area of each district between thresholds

No	District	Threshold 1 (km^2)	Threshold 2 (km^2)
1	Babat	1.349	2.237
2	Bluluk	0.303	0.683
3	Brondong	0.505	1.068
4	Deket	5.727	7.992
5	Glagah	3.182	4.685
6	Kalitengah	1.369	2.006
7	Karangbinangun	1.283	2.035
8	Karanggeneng	1.600	2.395
9	Kedungpring	3.928	6.892
10	Kembangbahu	0.672	1.288
11	Lamongan	2.805	4.215
12	Laren	5.829	9.411
13	Maduran	1.876	3.025
14	Mantup	1.934	3.727
15	Modo	2.006	3.509
16	Ngimbang	1.527	3.041
17	Paciran	0.375	0.849
18	Pucuk	2.072	3.166
19	Sambeng	3.072	5.849
20	Sarirejo	0.804	1.289
21	Sekaran	2.991	4.628
22	Solokuro	0.632	1.426
23	Sugio	2.025	4.573
24	Sukodadi	1.438	2.401
25	Sukorame	0.189	0.470
26	Tikung	0.451	0.861
27	Turi	3.658	5.277

4. Distribution and Are of Flood Inundation in each Land Cover

Based on the results of ESA World Cover data export from the Google Earth Engine dataset, 9 classes of land cover in Lamongan Regency were generated from 11 existing classification classes. The class cover includes trees, shrubland, grassland, cropland, built-up, barren/sparse vegetation, open water, herbaceous wetland, and mangroves (Zanaga et al., 2022). Where the cover classes that are not found in Lamongan Regency are snow and ice, moss, and lichen. A display of land cover results can be seen in Figure 9.

From the visualization, Lamongan Regency is dominated by agricultural land cover classes. While the class that has the smallest area is the mangrove land cover class in the northern part of Lamongan Regency which is the border of land and sea. To find out the area in km^2 of each land cover class, calculations were carried out using ArcGIS to obtain the area results in Table 4. Similar to the visualization results, Lamongan Regency is dominated by agricultural class land cover with an area of 1057.947 km^2 with a percentage of the total area of the Lamongan Regency up to 60.53%. The smallest land cover area is the mangrove class covering an area of 1.012 km^2 with a percentage of the total area of 0.058%.

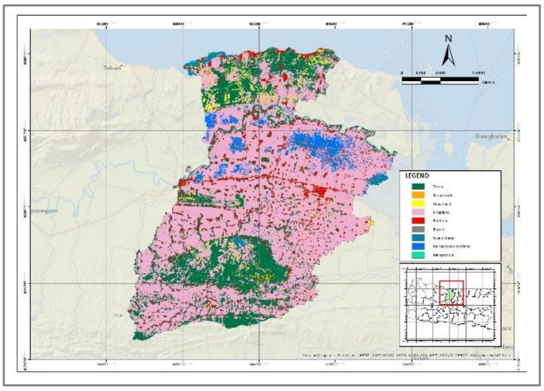

Figure 9. Land Cover Map based on ESA World Cover

Table 4. Area of each land cover class and flood inundation from ESA World Cover

No	Class	Total Area (km^2)	Threshold 1 (km^2)	Threshold 2 (km^2)
1.	Threes	407.982	4.854	10.333
2.	Shrubland	7.251	0.080	0.185
3.	Grassland	48.331	0.769	1.502
4.	Cropland	1057.947	41.490	64.250
5.	Built-up	104.264	2.013	4.362
6.	Barren/sparse vegetation	17.648	0.361	0.708
7.	Open water	36.657	0.547	1.329
8.	Herbaceous wetland	66.724	3.474	5.736
9.	Mangroves	1.012	0.010	0.035

In addition to calculating the area of each land cover class, the area of flood inundation for each land cover class is also calculated in Table 4. This is a calculation to find out whether the distribution of the flood will affect people's lives. The flood inundation area for the 1st and 2nd threshold values has differences. The largest percentage of flood inundation to the land cover class area based on the first threshold is Wetland class with 5.21%, or 3.474 km^2 and based on the second threshold is Wetland class with 8.60% or 5.736 km^2 of total area. While the smallest percentage results based on the first threshold were obtained at the mangrove class land cover with 1.03% or 0.010 km^2 and based on the second threshold in the Threes cover class with 2.53% or 10.333 km^2 of total area.

Flood inundation with the highest percentage at both thresholds is in the wetland class. Wetlands in Lamongan Regency itself are widely used for the aquaculture sector, which is one of the main livelihoods of the community. Although the pond is indeed a place to hold water, the impact of the flood causes the fish seeds that have been stocked to disappear and mix with other ponds and even come out into the river. That way floods have a significant impact on people's lives, especially the economic sector. The results of the calculation of the affected area can be used as planning for disaster mitigation activities to determine the distribution of floods that have a major impact on the community.

5. Accuracy Test

Validation of the identification results of flood inundation distribution was carried out using flood event data from the Regional Disaster Management Agency of Lamongan, news and articles as well as image interpretation, and then creating flood and non-flood sample points by digitizing on Google Earth Engine. The sample points used for calculating the confusion matrix are 200 points consisting of 100 flood points and 100 non-flood points for both thresholds. From this sample, it can be calculated the overall accuracy and kappa coefficient contained in Table 5 and Table 6. Accuracy is determined empirically by selecting a sample at each pixel of a thematic map determined from reference data (collected from field surveys). The reference data is actual object information, while the pixels selected to assess accuracy are called pixel tests. (Richards & Richards, 2022)

Table 5. Confusion Matrix Threshold 1

Class	Flood	Non-Flood	Total
Flood	95	5	100
Non-Flood	1	99	100
Total	96	104	200
User's Accuracy	95%	99%	
Producer Accuracy	99%	95%	
Overall Accuracy			97%
Kappa Coefficient			0.94

Table 6. Confusion Matrix Threshold 2

Class	Flood	Non-Flood	Total
Flood	96	4	100
Non-Flood	8	92	100
Total	104	96	200
User's Accuracy	96%	92%	
Producer Accuracy	92%	96%	
Overall Accuracy			94%
Kappa Coefficient			0.88

The overall accuracy value is determined by adding up the correct number of pixels and dividing it by the total number of pixels. Overall accuracy is the accuracy that compares the total number of areas that are processed correctly to the total number of observation areas (Congalton & Green, 2019). While the kappa coefficient is the accuracy or precision produced by processing results with reference data by indicating the major diagonal and agreement changes (Guo & Manatunga, 2009). The results of the confusion matrix calculation between Sentinel-1 Image processing using GEE with validation data at the first threshold resulted in an overall accuracy value of 97% with a kappa coefficient is 0.94. While the overall accuracy results for the second threshold is 94% with a kappa coefficient is 0.88. This shows that the threshold with the first method produces better flood identification.

Conclusions

Sentinel-1 satellite imagery can be used to identify flood inundation that occurred in Lamongan Regency on January 31, 2022. The method used is change detection and thresholding. To determine the threshold value for flood and non-flood areas, threshold two methods. The first method with a threshold in the range of 1.15 to 1.5 and a threshold is 1.1. The flood inundation area generated for the first threshold value is 54.932 km^2 with a percentage based on the sub-district area, the largest flood inundation is in Laren District covering an area of 5.829 km^2, and the smallest percentage is in Sukorame District covering an area of 0.188 km^2. Meanwhile, based on land cover, the largest percentage of flood inundation is in the Wetland class with 5.21% km^2 or 3.474 km^2, and the smallest percentage in the mangrove class with 1.03% or 0.010 km^2.

The flood inundation area using the second threshold method is 90.330 km^2. Based on the sub-district area, the largest percentage of flood inundation is in Laren District covering an area of 9.410 km^2 and the smallest percentage is in Sukorame District covering an area of 0.070 km^2. Meanwhile, based on land cover, the largest percentage of flood inundation is in the Wetland class with 8.60% of the total area or 5.736 km^2, and the smallest percentage in the tree cover class with 2.53% or 10.333 km^2 of the total area. After testing the accuracy, it is found that the threshold that is more suitable to be used is the first method, with a value range of 1.15 to 1.5 which has an overall accuracy of 97% with a kappa coefficient is 0.94.

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