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The Compatibility Study of Sentinel 1 Multitemporal Analysis For River-Flood Detection, Study Case: Bogowonto River

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Abstract

Flooding is a common natural disaster in Purworejo District, which can be caused by the overflowing of the Bogowonto River. The use of multitemporal analysis with Synthetic Aperture Radar (SAR) images, such as Sentinel-1, has the potential to aid in flood inundation detection for disaster mitigation in the area. However, there has not been any research examining the compatibility of flood inundation detection using multitemporal Sentinel-1 images with the flood susceptibility characteristics of the Bogowonto River. This study aims to evaluate this using a SWOT analysis. The results show that multitemporal analysis using Sentinel-1 images is not suitable for detecting flood inundation in the Bogowonto River due to difficulties in finding the right acquisition time at the time of the flood event. The duration of floods in the Bogowonto River is approximately 1-2 days, while the earliest reacquisition time for Sentinel-1 images for this study is 12 days. Additionally, Sentinel-1 images using band C have limitations in detecting floods under vegetation.

Keywords: River Floods, Multitemporal Analysis, Sentinel-1, Bogowonto River

1. Introduction

Based on Indonesia National Agency for Disaster Management's (BNPB's) data, 3,058 natural disasters occur in Indonesia in 2021 with 1,288 or 42.1% accidents came from flood. This fact makes flood becomes one of the most common natural disasters that year. River flood is a type of flooding that caused by overflowing water since river over capacity of water discharge (Benito & Hudson, 2010).

Some factors which causing river flood are extreme rainfall, land use change, slope, and climate change (Sudirman et al., 2014). Purworejo regency is one of the cities in Indonesia that has a high level of flood accidents, proven by 94 events in 2020 (BPS, 2022). The Bogowonto River is one of the major river which flows across Purworejo and is one of the major reasons of flooding in the city. Floods in Bogowonto river can happen since increasing of water discharge from the upstream of Bogowonto watershed, either from Mount Sumbing or Menoreh hills (Sudaryatno et al., 2020). A fast increase of water discharge can cause water to overflow from the river body because there is not enough time to transfer the water to the sea.

flood hazard mapping based on an in-depth study of physical and hydrological characteristics is an initial strategy for effective flood management (Dubey et al., 2021). The information of flood susceptibility level is urgently needed at the spatial planning level, so that mitigation actions can be appropriately carried out. It is written on the government rule (PP No.20, year 2021) about spatial management, which obligate each region to analyze flood hazard map for their spatial management planning.

Flood susceptibility study can be done in many different ways, is one of the examples is mapping the frequency of flood accidents in a region. Accurate information about distribution of flood inundation is an important aspect in mapping of the frequency of flood accidents so it should be studied more (Sipelgas et al., 2021). Satellite imagery is commonly used for inundation detection during floods because it is available on various specifications (Lin et al., 2016). Additionally, satellites always orbit the earth so it has good data continuity.

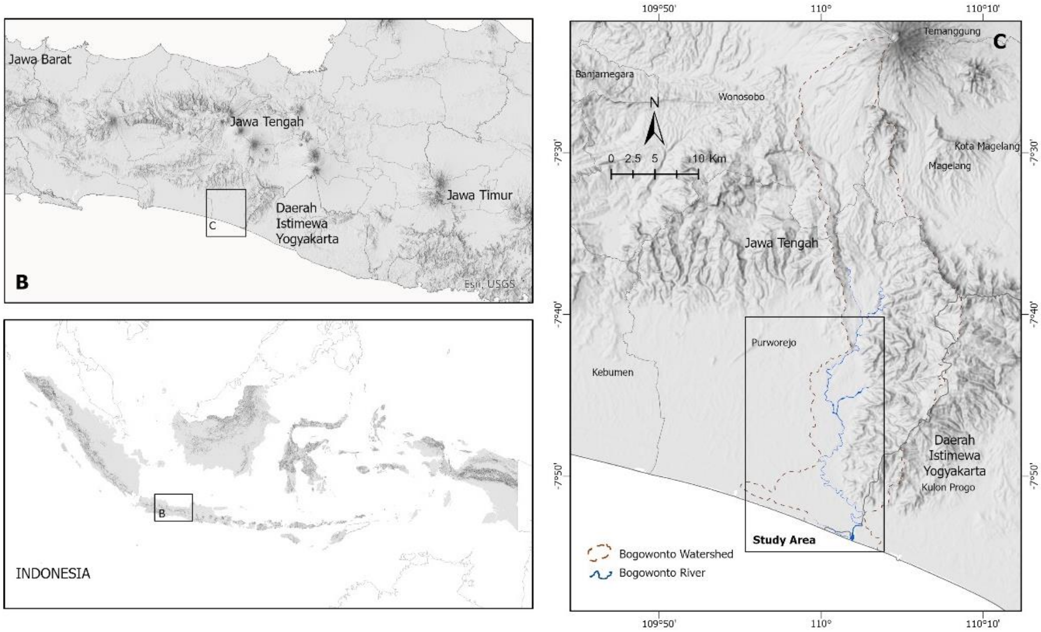


Fig. 1. Map of the study area

Remote sensing data have microwave from both active and passive sensors are very useful for flood mapping, active microwave Synthetic Aperture Radar (SAR) data have high spatial resolution (Vanama, et al., 2021). Sentinel 1 imagery is a type of satellite that use synthetic-aperture radar (SAR) so it can be used to detect flood coverage and monitoring of flood inundation even in large area (Sherpa & Shirzaei, 2022). The sentinel 1 monitoring function 1 is supported by a constellation of twin satellites with the same orbit, so that every location in the earth's surface can be recorded more frequently. Sentinel-1 satellite imageries have temporal resolution of 6 days in Indonesia. The advantage of using Sentinel imagery is can be used to map flood coverage along with its the total number of flood period (frequency level) it is because sentinel 1 records the same object in a relatively short time period (Sipelgas et al., 2021).

The using of radar waves in sentinel 1 has a high potential to be applied for flood zone detection in Indonesia, since because it can penetrate clouds which is a main problem for tropical country. The methodology of flood detection using satellite imagery continues to develop, from a simple method like visual interpretation, change detection, region growing algorithm, histogram thresholding, to supervised and unsupervised classification (Sherpa & Shirzaei, 2022). Many research often combine two or more method to get an effective way to detect flood inundation, like (Sipelgas et al., 2021) who use the combination of histogram thresholding and multitemporal change detection. This method can differentiate between flood inundation and other inundations better than single date imagery.This is also similar research to Binh and Son (2021) which compared Sentinel-1 SAR imagery data for monitoring water dynamics in lake Nui Coc (Vietnam).

Despite having many advantages, Sentinel-1 imagery also has drawbacks, one of which is the use of band C radar which has limitations in detecting floods in vegetated areas (Tsyganskaya et al., 2018). On the other hand, either research of multitemporal analysis for flood detection using sentinel 1 is rare or does not pay attention to flood characteristic of study area. Therefore, this research aims to do a compatibility analysis about advantages, drawbacks, and chances for river floods detection using multitemporal analysis of sentinel 1 imagery in Bogowonto river.

2. Methodology

This research was conducted on March-August 2022, focuses on the middle and lower area of the Bogowonto River (see Figure 1), because floods often occur in these areas. The historical data of river flood caused by the overflow of the Bogowonto River is taken into consideration in the selection of study area.

2.1 Data Collections

This study uses the GRD-Level data of Sentinel-1 imageries which are accessed through the Google Earth Engine (GEE) platform. The imageries used are recorded in IW swath mode and VV+VH polarization, because these imageries have the best spatial resolution and suitable polarization type for flood detection in open areas or under vegetation (Conde & De Mata Muñoz, 2019; Hlaváčová et al., 2021; Sipelgas et al., 2021). The timing of Sentinel-1 image is selected according to the date of the flood event, namely the image with the closest recording date before and after the flood.

This study also uses Sentinel-2 data for geomorphological analysis to determine the river flood characteristics in the Bogowonto watershed. The Sentinel-2 data was downloaded from GEE using the multitemporal mosaic method, therefore a single cloud-free image was obtained from combined imageries in the acquisition date which range from January 1, 2022 to June 2022. More details regarding the data used in this study can be seen in table 1.

Table 1. List of data source used in this study.

Data Type	heading2
Sentinel-1 Imagery	ESA Copernicus
Sentinel-2 Imagery	ESA Copernicus
Flood accidents data	Interview with Regional Agency for Disaster Management (BPBD) in year 2022
Flood Characteristics Data (Flood frequency, height, and duration)	Field Survey in year 2022

2.2 Multitemporal analysis of Sentinel 1 imagery

A speckle filtering process was applied to Sentinel-1 Level 1 GRD images to remove noises so that it will produce smooth images result (Conde et al, 2019). The filter-type used and the width of the window type are determined through visual interpretation of image subsets covering paddy fields, flood areas, water bodies, and rural areas (Conde et al, 2019). Flood area detection using Sentinel-1 satellite data is carried out by image differencing analysis followed by image thresholding. These processes are performed to determine the pixel values of river flood (illustration can be seen in figure 2). Image differencing and image thresholding analysis are change detection techniques for 2 multitemporal data that have been applied for many applications that used interval or ratio data categories (Mishra et al., 2017). Determination of the thresholding value of flood and non-flood area is based on a series of trials by looking at the histograms and visual appearance of the imageries. Li, et al (2018) change detection based on multi-temporal SAR imagery to monitor flood disasters that can distinguish between permanent water bodies and some water-like objects (floods).

2.3 Analysis of Flood susceptibility characteristic

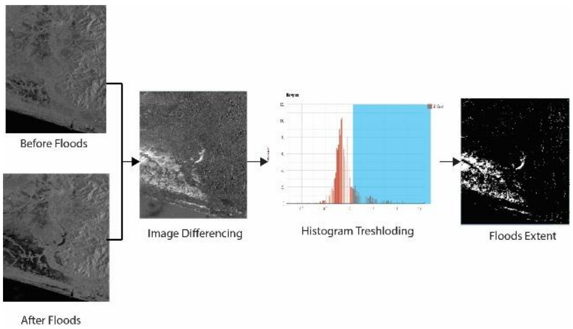


Fig. 2. Illustration of the river-flood detection method

Flood susceptibility analysis was conducted using the hydrogeomorphological method. This method involves identifying fluvial landforms and determining flood hazard parameters for each landform unit (Baldassarre et al., 2020). This study uses the landforms classifications developed by Marsoedi et al., (1997). Furthermore, a field survey was conducted to determine the flood susceptibility characteristics in the study area. Information taken during field surveys includes frequency, flood height, and flood duration. Field survey information are used to categorize landforms class into flood susceptibility levels (Benito & Hudson, 2010).

2.4 Map Matching analysis and SWOT

Map matching is an effective method for verifying and even calibrating the results of flood detection based on satellite imagery, this can be done by comparing the patterns and areas of satellite analysis with reference data that are considered to be correct (Mason et al., 2009). In this study, map matching was conducted through an overlapping process between the flood detection results from Sentinel-1 images and the flood susceptibility level maps produced from geomorphological analysis. Even though the geomorphological analysis has rough spatial scale, information of flood hazard characteristics can be used as an indicator to determine whether the flood detection results make sense.

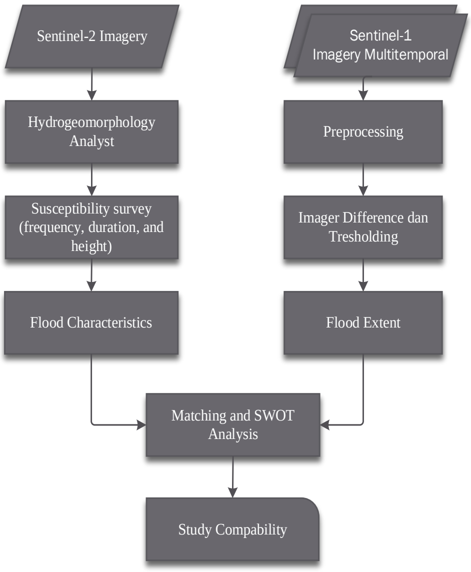


Fig. 3. Research workflow

3. Results and Discussion

3.1 River Flood Detection

River-Flood detection was conducted by analyzing Sentinel-1 imagery at two different dates (before and after the flood). Information about the date of the flood incident was obtained through interviews with the Regional Agency for Disaster Management (BPBD) of Purworejo Regency, and the selected flood events were major floods that occurred between 2017-2022. The following table shows lists of flood events along with the recording time of Sentinel-1 imagery which is used to identify the river flood.

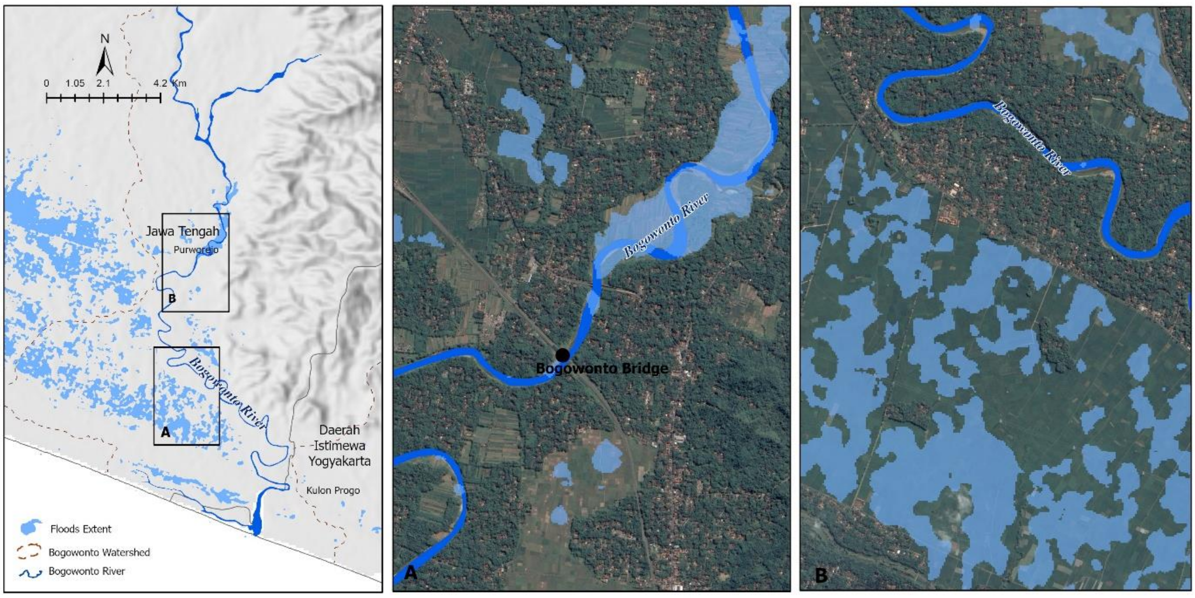


Fig. 4. River flood detection at March 14, 2022

Table 2. List of Flood Estimation Date and Sentinel-1 recording date.

Flood Estimation Date	Sentinel-1 recording date (Before floods)	Sentinel-1 recording date (After flood)
March 14-16 2022	March 3 2022	March 14 2022
Nov 30 – Dec 1 2021	November 24 2021	December 5 2021
March 17-19 2019	March 16 2019	March 27 2019
November 28-30 2017	November 12 2017	December 5 2017

From the table 2, it can be seen that it is very difficult to find Sentinel-1 images that record the flood events in the same dates with the flood accidents, therefore only the flooding events on March 2022 coincided with Sentinel-1 recording the Bogowonto River. The 6-day temporal resolution on Sentinel-1 imagery cannot be used for river flood detection analysis because it has a different satellite orbit (Descending/Ascending). In fact, the satellite orbit for river flood detection must be the same for all the images before and after the flood (Conde & De Mata Muñoz, 2019; Hlaváčová et al., 2021; Sipelgas et al., 2021). Thus, the closest possible time span for Sentinel-1 imagery to be used for analysis is 12 days.

On March 14, 2022, the distribution of river flood was well detected in the floodplain area on the north of the Bogowonto River bridge (Figure 2A). That area is agricultural land for annual crops like corn and vegetables. In addition, river flood was also well detected in paddy fields on the alluvial plains around the meander (Figure 2B). The results of this detection have been verified in the field through historical data and interviews with local communities. However, flood was almost undetectable in the area which was covered by tree canopy, even though the location is a river terrace area which is always flooded according to the results of the field survey. This is probably caused by the limitation of C band radar to penetrate through vegetation objects (Ferro-Famil & Pottier, 2016).

3.2 Flood Susceptibility characteristic of Bogowonto River

This study identified flood-prone landforms in the Bogowonto watershed using the classification of Marsoedi et al (1997). The results of the hydrogeomorphological analysis show that two of the water sources of the Bogowonto River come from upstream area of Mount Sumbing and Menoreh old vulcanic mountains. These water sources were in high slope area and have relatively close distance to the river, so that a lot of rainwater accumulate as surface runoff that enter the Bogowonto River. The approach used is hydrogeomorphology which focuses on the identification and in-depth observation of the landform originating from fluvial processes (Baldassarre et al., 2020). However, the flood potential of marine landform in the south part of study area is also investigated. Additionally, Landforms that are not included as fluvial or marine are considered to be not prone to river flooding (the volcanic landform of Mount Sumbing and Menoreh Mountains).

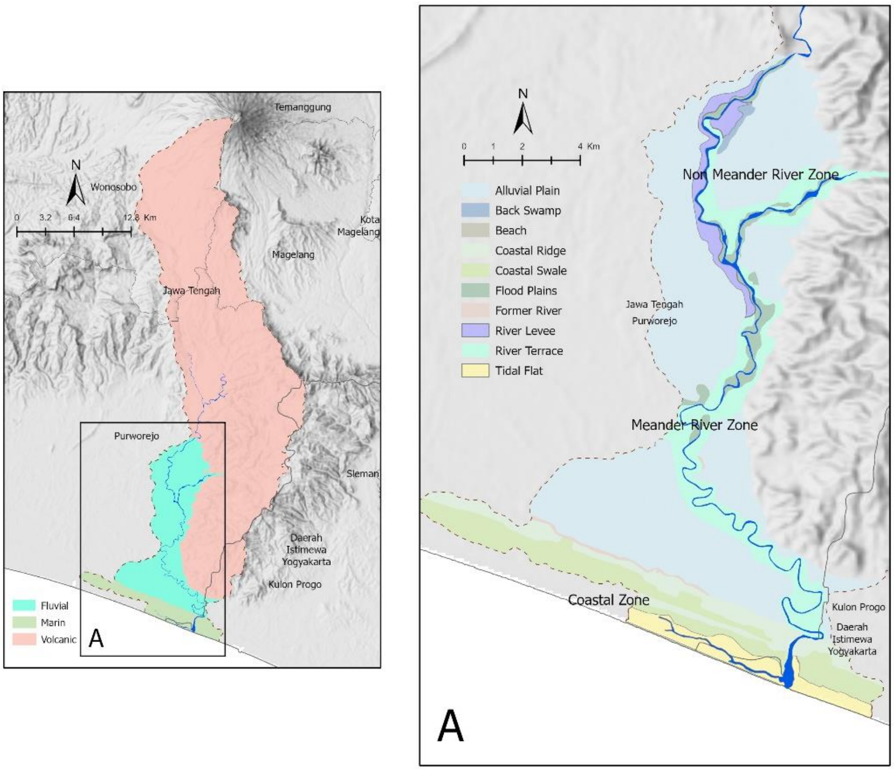


Fig. 5. The Result of Geomorphological Analysis of Fluvial Dan Marine Landform In Bogowonto Watershed

The results of the geomorphological analysis show that the fluvial landform can be divided into 2 main categories: the first is the fluvial landform which is influenced by meandering rivers, and the second is the fluvial landform which is influenced by non-meandering rivers. Meanwhile, the downstream area of the Bogowonto River is dominated by marine landforms, there are coastal ridges and coastal basins. Furthermore, these landform classes are identified by conducting a field survey to determine the characteristics of the river flood susceptibility, which includes information on flood frequency, height, and duration. Information of the level of river flood susceptibility is obtained by collecting historical data of flooding events such as trash, traces of inundation, and flood footprints, as well as interviews with the people around the flood-affected areas.

Based on the results of the hydrogeomorphological analysis, the study area can be qualitatively categorized into 3 levels of flood susceptibility. Areas with high level of susceptibility are dominated by meander-influenced fluvial landforms, like meander floodplains, former meander rivers, and meander river terraces. Nevertheless, floodplains in rivers that are not influenced by meanders are also categorized at a high level of susceptibility if they have flood frequency of 1-3 times/year, flood heights between 1-3 meters, and a maximum inundation period of 2 days. More details regarding the characteristics of flood susceptibility level can be seen in table 3.

Table 3. River flood level and its characteristics in Bogowonto Watershed

Landform class	Flood Frequency, Height, and Duration	Susceptibility Level
Meander Floodplain, non-Meander Floodplain, backswamp, former meander-river, meander river terraces	**Frequency** :1-3/year **Height** : 1-3 m **Duration** : 1-2 days Note: if a big flood occurs, the duration can be more than 3 days in the area of former meander-river	High
Mender-river alluvial plain, terrace of non-meander river, sandy tidal flats	**Frequency** :1-2/year **Height** : 1 m **Duration** : 1-2 days	Medium
Non-meander alluvial plain, coastal ridges, coastal basins	**Frequency** : 1/year in area with basin micro-relief **Height** : < 1 m **Duration** : < 1 day	Low

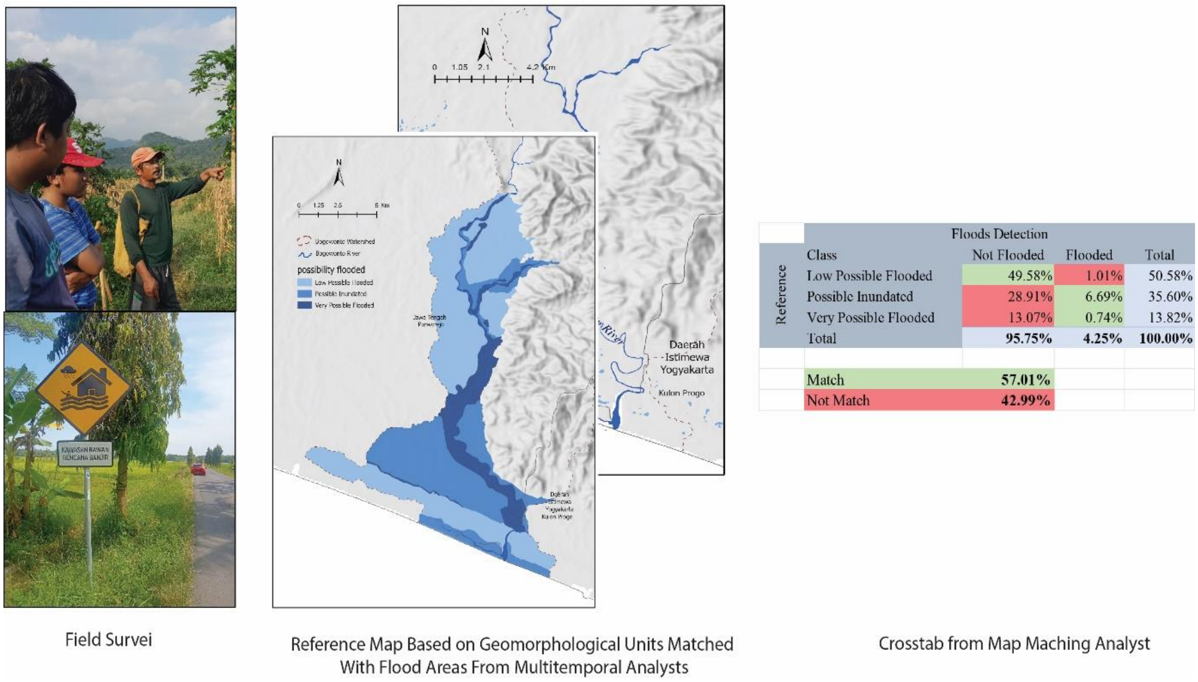
3.3 The Compatibility of River Flood Detection In Bogowonto Watershed

Map matching method is used to see the match between the area of detected river-flood and data that represents field condition. The reference map used is the result of flood susceptibility survey using geomorphological analysis unit, because it is very difficult to draw the river flood area that occurred in the past. Field surveys were conducted by collecting historical data of flooding events like traces of inundation, trash, and flood footprints and also interview the local community to find out the March 2022 river-flood areas. Furthermore, the survey results were matched with geomorphological units in the study area.

Based on the results of field surveys and interviews with local communities, researchers divide the probability level of being inundated during river-flood in March 2022 into 3 classes (can be seen in Figure 6). Based on the results of the map matching analysis, it can be seen that the match rate between the flood detection using Sentinel-1 imageries with the reference map is 57%. This percentage shows the quality of river-flood detection data relative to the field data. The biggest discrepancy is found around the river terraces of the Bogowonto River, with 'possible inundated' class in reference map but detected as not flooded in river-flood detection map. Confirmation from local communities show that the area was indeed inundated during the 2022 floods, but the water had receded in less than 24 hours, besides that the area was also covered by dense vegetation so that Sentinel-1 was unable to detect the flood.

SWOT analysis results can be seen in table 3. This study shows that sentinel 1 imagery has an advantage in penetrating cloud, so that can be use in any season. River-flood detection is also seen well in paddy fields and annual crops around the floodplains of the Bogowonto river, provided that these areas are not covered with dense vegetation. However, there are some limitations in using sentinel 1 imageries for river-flood detection in Bogowonto river. First, revisit time that can be used is 12 days, because the polarization of imagery should be the same between before and after flood. This is a problem because in Bogowonto watershed the duration of flood is relatively quick. Second, sentinel-1 C band radar has limitation in flood detection over dense vegetation area, even though Bogowonto river terraces which have high level of susceptibility are dominated by dense vegetation and settlement.

Multitemporal analysis of SAR data is possible to map Bogowonto's river-flood despite some drawbacks like the inability to map a flood which has short-duration, due to lack of temporal resolution, therefore more rapid revisit time is needed to get better river-flood detection. This problem may be solved by adding more satellites in one orbit for future SAR missions. Meanwhile, the potency of incompatibility of this analysis can increase if society does something to overcome flood susceptibility, for instance in Bogowonto river, many sluice and irrigation channels were built to speed up drainage. This scenario may shorten the flood duration, therefore satellite imagery in hourly timescale is needed to identify the flood accurately.



	Class	Floods Detection Not Flooded	Flooded	Total
Reference	Low Possible Flooded	49.58%	1.01%	50.58%
	Possible Inundated	28.91%	6.69%	35.60%
	Very Possible Flooded	13.07%	0.74%	13.82%
	Total	**95.75%**	**4.25%**	**100.00%**
	Match	**57.01%**		
	Not Match	**42.99%**		

Fig. 6. The illustration of analysis process of map matching to verify the results of flood-river detection

Table 4. SWOT Analysis for the study of Compatibility of River Flood Detection using Sentinel 1 Multitemporal Imageries

Strong	Weakness
• Has cloud penetration ability therefore it is compatible for any season • Good for flood detection in alluvial plain which is dominated by paddy field and flood plain which is dominated by seasonal crop	• It is difficult to obtain the right recording time • Has limitation in detecting river-flood in the river terrace of Bogowonto river which is dominated by dense vegetation and settlement
Opportunity	**Threat**
• It is possible to be applied in Bogowonto Watershed if the Satellite developer add more satellite to the orbit for increasing the temporal resolution of the satellite • More suitable if it is applied in an area with long flood duration, such as tidal flood	• Many sluices and drainage channels have been built around Bogowonto river, therefore flood will vastly recede. Hence, satellite imagery with hourly timescale is needed to record the flood at the right time

4. Conclusion

To sum up, the utilization of multitemporal analysis of sentinel-1 imagery is not suitable for river flood detection in Bogowonto river. This is because the shortest revisit time for river-flood detection is 12 days, which does not correspond to the relatively fast duration of river-flood in Bogowonto river. Moreover, the using of C band in sentinel-1 imagery has limitation in terms of penetrating areas covered by settlement or dense vegeation. The verification results of flood inundation identification from the analysis of multi-temporal Sentinel-1 images also indicate a matching level of only 57% when compared to flood susceptibility analysis based on geomorphological analysis and field surveys.

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