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The Capability of Sentinel 1 (SAR) for Flood Mapping: A Case Study in Serang Watershed, Kulonprogo Regency

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ABSTRACT
Floods are the most common natural disaster in Indonesia, with high intensity than any other natural disaster. A flood is a condition where an area is inundated due to an overflow of water that exceeds the water disposal capacity in a room, resulting in physical, social, and economic losses. The Serang watershed (DAS) belongs in the Priority I (critical) watershed condition, so it is necessary to determine flood-prone areas in future management. Sentinel 1 Remote Sensing Image (SAR) can record at any time, day or night, and in all weather conditions, making it suitable for flood analysis. This study aimed to determine the ability of Sentinel 1 Image (SAR) in determining the inundation flood area in Serang watershed, Kulonprogo Regency, Indonesia. The method used was the Otsu algorithm with threshold determination by measuring and evaluating the variance between classes of a threshold at a certain level calculated from the normalized histogram of the image. Floods in the Serang watershed, Kulonprogo Regency, mainly occur in agricultural areas. The ability of Sentinel images to obtain land surface data in all conditions can be used for flood analysis where passive sensor images cannot record it. In addition, the withdrawal of inundation areas on Sentinel 1 imagery using the Otsu algorithm can determine a threshold to separate inundated and unflooded areas with a confusion matrix of 77%.

INTRODUCTION

Floods are the most common natural disaster in Indonesia. Flood or flooding means a condition of partial or complete inundation of a place due to the overflow of water, which causes overcapacity of the water disposal in an area; As a result, it causes physical, social, and economic losses (Yunida et al., 2017; Qaiyim, 2018). The Indonesian National Agency for Disaster Management data in 2016 shows that hydro-meteorological disaster was responsible for the most frequent natural disaster, with 78% (11,648) of the total disaster that occurred from 2005 to 2015, while the remaining 22% (3,810) was a geological disaster. The Indonesian National Agency for Disaster Management noted that at least three thousand natural disasters occurred throughout 2021. The series of disasters was dominated by wet hydrometeorological events, such as floods, extreme weather, and landslides, which were exacerbated by the La Nina phenomenon. Flood is one of hydrometeorological disasters besides extreme waves, drought, forest wildfires, and extreme weather. According to BNPB's data in 2020, flood occurs 993 times annually in Indonesia, making it the most frequent natural disaster nationally, until December the seventh 2020.

Information regarding the flood vulnerability area is essential for flood management strategies. The vulnerability flood mapping represents the spatial distribution of areas with high flood vulnerability that must be appropriately administered to minimize the probability of flood risk. A flood risk management strategy, including control and reducing the impacts, has to be done by classifying the level of vulnerability which has an essential role in policy-making in dealing with disasters (Darmawan et al., 2017).

Flood susceptibility analysis requires an understanding of topographic conditions, land management, lithological components, soil, and the effect of rain on the catchment area (Erena & Worku, 2019). The catchment area is a watershed ecosystem. A Watershed is an ecosystem that plays an essential role in the hydrological cycle (Pambudi, 2019). Watershed as a unity of land region complex topographical barrier. The watershed has three significant parts: upstream, middle, and downstream. The upstream and downstream have biophysical linkages in the role of the hydrological cycle. The upstream primary function as a conservation area in a watershed ecosystem, while the middle is a cultivation area. The site with a wavy to flat topography directly conducted all activity in the upstream and middle parts, such as land use change (forest or vegetation to built-up land) (Maridi et al., 2015). Therefore, damage in the upstream area will directly affect the downstream region (Setyaningsih et al., 2019). The Directorate General of Water Resources data (2010) shows that (Progo-Opak-Serang River Area) most of the watersheds in the Progo-Opak-Serang River Area are included in Priority I (critical) watershed conditions.

Flood mitigation planning and management require land-use knowledge and flood-prone areas mapping to make decisions (Armenakis et al., 2017). Remote sensing images can present data accurately and in detail. Moreover, the data access is recorded periodically (the temporal resolution) to substantially contribute to various tasks, including flood zonation (Jahangir et al., 2019). The Sentinel-1A can register anytime, day or night, and under all weather conditions (not impeded by cloud cover) (Sghaier et al., 2018; Shen et al., 2019). The orbit has a 12-day repeat cycle for a single satellite and six days for a constellation of two satellites. Synthetic aperture radar (SAR) is mainly used for determining flood areas because it can produce high-resolution data in various weather conditions (Wakabayashi et al., 2019).

SAR data from Sentinel 1A can record all weather conditions, penetrate clouds, and provide an overview of the ground and surface water so that the distribution of inundation floods is close to the time of flooding (Rahman & Thakur, 2018; Uddin et al., 2019; Shahabi et al., 2020). SAR data has the potential for monitoring and mapping flood or water inundated areas (Khan et al., 2011; Amitrano et al., 2018). The SAR radiometric calibration determines imagery in which the pixel values of the radar backscatter of the scene or ground location. The pixel value conversion is performed as a SAR-normalized gamma nought format, which is a backscatter that provides the surface roughness and humidity of the scene. Sentinel-1 captures objects from the side; As a result, there are certain distortions. Geometric calibration of Sentinel images eliminates some errors due to topographic effects. SRTM DEM data can be used directly for Terrain Range-Doppler geometric calibration.

The speckle filtering is needed for speckle noise reduction of Sentinel-1 SAR data. In addition, the speckle filtering process also makes the image interpretation process easier. Speckle Filtering can be used for the analysis of flooded and non-flooded areas. The speckle filtering applied in this study is the median filter with a 3x3 kernel size (the target kernel and the filter kernel have the same size). The centre pixel in the image is replaced by the median of pixel values in a moving window. In addition, this speckle filtering effectively improves the image data that suppresses unwanted noise in the image. Image extraction is used to convert the digital value into a backscatter sigma nought value, and then the calibration units are converted into decibels (dB).

The Otsu method is used to determine the optimal threshold for water and non-water classes and the area of inundation. Otsu is usually used to lower the threshold for optical data Optik (Du et al., 2016). However, several recent studies suggest that the Otsu method can also be applied to SAR data for water and non-water class separation (Clement et al., 2018; H. Cao et al., 2019).

The description of the land surface during flood conditions can be extracted using the SAR method with the result that the spatial distribution of flooded areas can be obtained. Floods can be divided into two types: inundation floods and runoff floods. This case study will discuss inundation flood analysis using SAR data. Inundation floods are a type of flood that is caused by the accumulation of flow in an area that causes soil could no longer absorb the standing water and become saturated. As a result, that water stagnates at that point or can overflow into streets and nearby properties (Miardini & Saragih, 2019). Flood is affected by the local topography or angle slope. The Topographic conditions significantly affect the distribution or places where the water accumulates. Water flows from a higher elevation to a lower one. Locations with lower elevations have a higher potential for flooding (C. Cao et al., 2016). The purpose of this research is to determine the ability of Sentinel-1 (SAR) to map the flood inundation area in the Serang watershed, Kulonprogo Regency.

RESEARCH METHODS

Data collected for the analysis is divided into two types which are primary data and secondary data. Primary data is obtained from satellite, or remote sensing images, especially Sentinel-1 were downloaded on the https://scihub.copernicus.eu page. The process of downloading satellite images considers the capture date of that satellite images so that the satellite images obtained have a capture date when the flood occurred, which was February 11, 2021, by *S1_ GRD/ S1A_ IW_ GRDH_ 1SDV_ 20210211T221748_ 20210211T221812_ 036548_ 044AD8_ 1DD6.* The secondary data is obtained from related institutions. Secondary data is an inventory of the distribution of flood locations in the Kulonprogo Regency on February 10, 2021, by the Agriculture and Food Service of the Kulonprogo Regency.

Table 1. Data and data acquisition sources

Data	Data Collected	
	Primary Data	Secondary Data
The flood occurred	Sentinel-1 (On February 11, 2021)	-
The distribution of flood locations in Kulonprogo Regency	-	by the Agriculture and Food Service of Kulonprogo Regency (on February 10, 2021)

Serang watershed is located in two Regencies: Kulonprogo Regency and Purworejo Regency. It extends between latitudes 7º 52′ 38.74″ and 7º 57′31.58″ South, and longitudes ±110º nine ′ 35.33″and 110º ten ″ 10.57″ East. The Serang watershed has an area of about 23940.31 Ha. Research focus area was conducted in Serang Watershed which is specially located in Kulonprogo Regency and covers about 23541.59 Ha of the total area of Serang watershed (figure 1).

The linear Discriminant Analysis (LDA) method is used to identify SAR data distribution areas. According to (Fisher, 1936) and (Otsu, 1979; Wakabayashi et al., 2019), to analyze the relationship between flood determination variables, a validation process can be applied from the modelling map by considering the results of historical flood data evaluation. Thus, the threshold value which will be selected is essential for mapping accurately the water area and not a body of water area. The polarization type selection from the output of image sharpening is used to determine the flood that occurred using the otsu algorithm.

The Otsu image threshold method is the most widely used approach for flood mapping (Li & Wang, 2015; Kordelas et al., 2018; H. Cao et al., 2019). It can be used to analyze the digital number value from the sigma nought conversion in decibel (dB) units so that the backscattering value of the surface area before and after the flood can be known; As a result, the flooded and non-flooded areas can be represented by this method. The thresholding method is used for separating two classes, foreground from background and assumes that the distribution of image pixel intensities follows a bi-modal histogram in the otsu algorithm. Otsu can classify water and open water objects on Sentinel 1 imagery with reasonable accuracy (Li & Wang, 2015; Tiwari et al., 2020; N & M, 2021). The Otsu method can automatically detect thresholds for separating water and non-water pixels without requiring user parameter dependence (reference point from the soil), unlike the supervised method (Tiwari et al., 2020). The results of the classification of flooded areas and not from the Otsu method was assessed its accuracy using confusion matrix method method (Congalton & Green, 2008). The accuracy test was carried out by comparing the results of the classification of inundated and non-inundated areas with field data. Otsu method show an overall accuracy more than 70% (H. Cao et al., 2019; Jennifer et al., 2020; N & M, 2021).

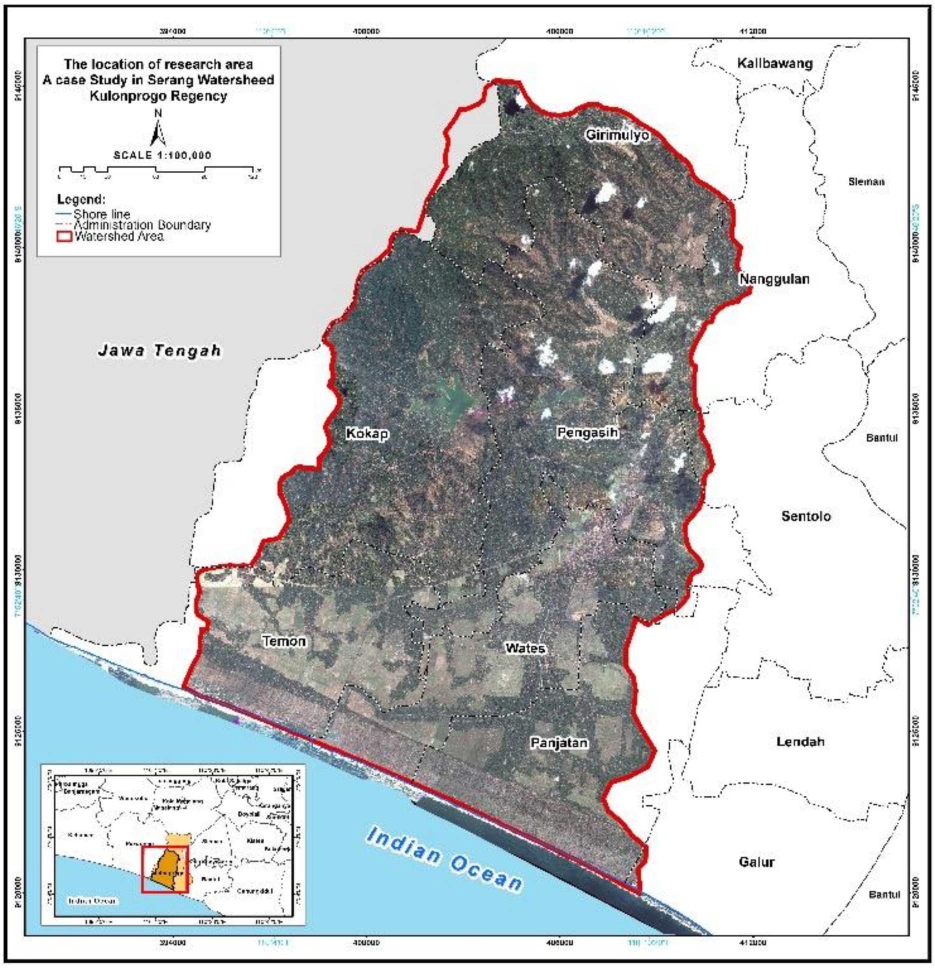


Figure 1. The location of the research area

RESULTS AND DISCUSSION

Collecting data of the actual flood areas can be obtained in two methods: visiting the location /site surveys or applying the remote sensing method using images of satellites. The second method can represent the distribution of current flooding. In this study, the satellite images were selected by captured date in accordance with when the flood disaster occurred. The suitable type of satellite image is Sentinel 1. Sentinel 1 imagery can record any time using an active sensor, so it will not be constrained by cloud cover during the rainy season when floods often occur. The distribution of flood locations can be seen in Figure 2.

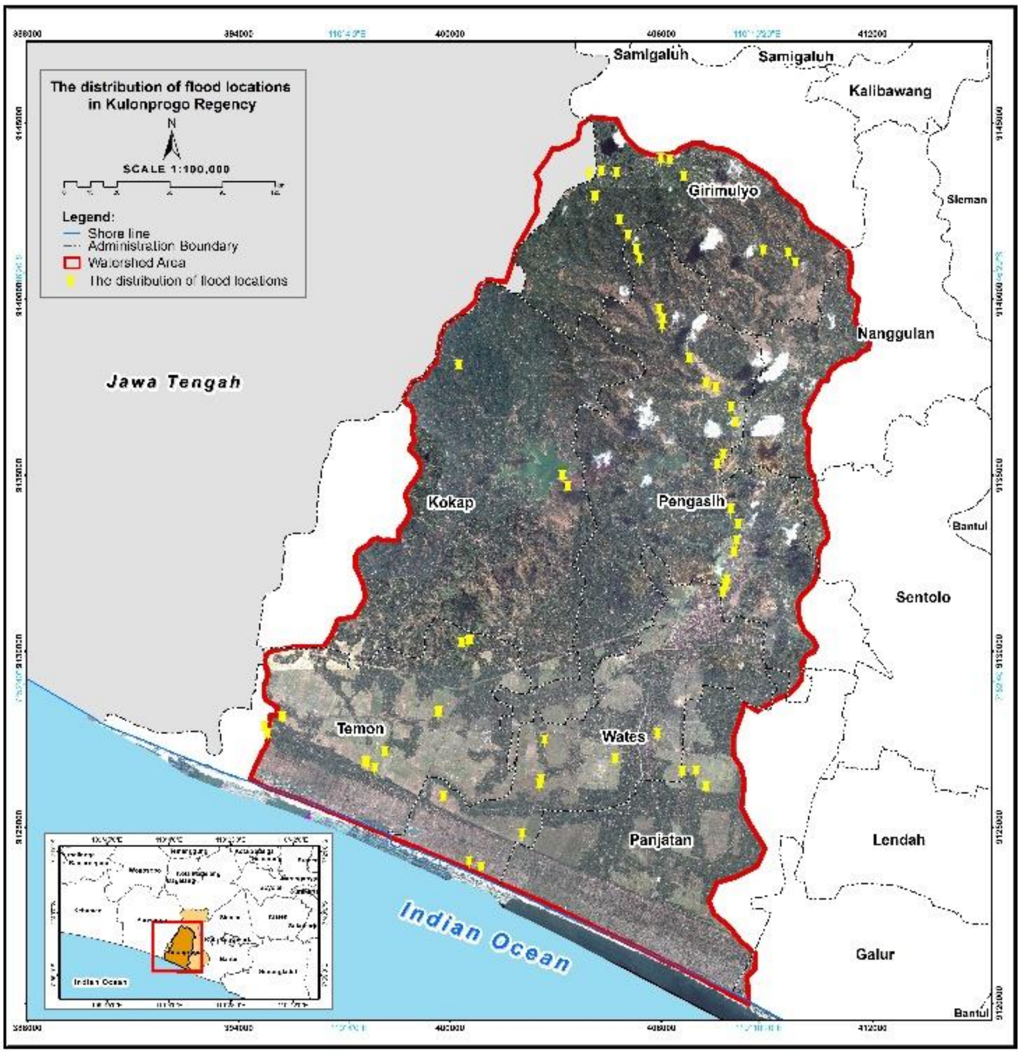


Figure 2. Distribution of flood location

The Sentinel image used in this study is Ground Range Detected (GRD) Mode, level-1 C-Band, while the polarization data chosen is the VV polarization, using images captured on February 11, 2021. The applied polarization type refers to (Wakabayashi, Gautam Dadhich). Sentinel GRDH is a data type projected onto an ellipsoid model so that the pixel value represents the magnitude of the amplitude value on the earth's surface. Therefore, there is no phase difference in the pixel values in the image (ESA, 2012). Preprocessing data includes apply orbit file, GRD border noise removal, thermal noise removal, radiometric calibration, terrain correction (orthorectification), and conversion of backscattering values (σ°) to decibels (dB). In addition, the analysis of inundated areas in the Serang watershed used speckle filtering with a median filter 3x3 kernel size (Anusha & Bharathi, 2020). Furthermore, the conversion of the gamma nought value was also carried out to eliminate unwanted noise in the image. As a result, the appearance of the inundated area looks clearer, as can be seen in Figure 3.

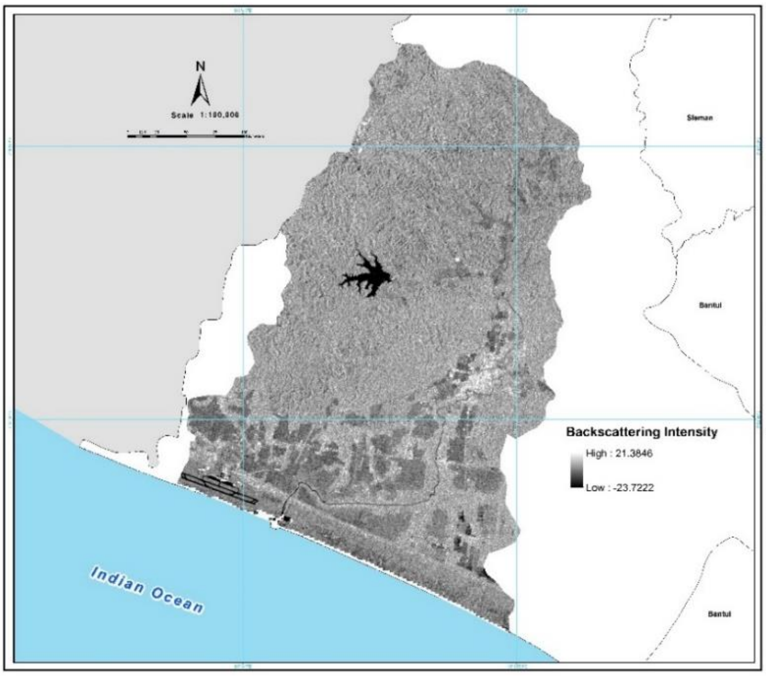


Figure 3. Backscattering intensity

The backscattering intensity that can be seen from the gamma nought value describes the type of surface object in the study area. The interaction between radiation and the internal property of the captured object produces surface backscattering, volume backscattering, double backscattering reflections, and specular scattering (Wang, 2010; Arief et al., 2017) (Figure 4).

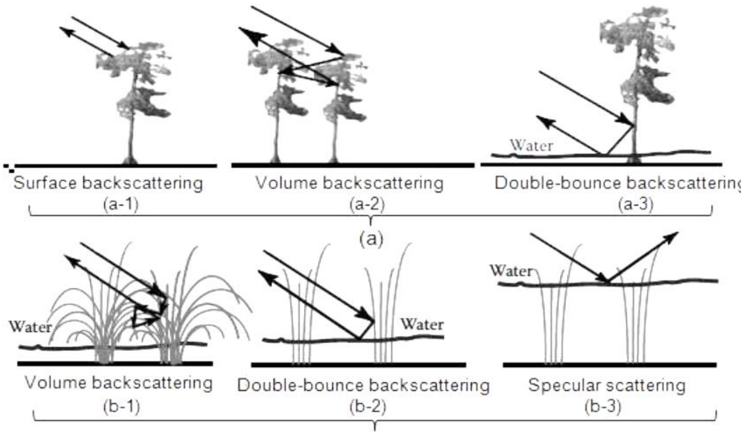
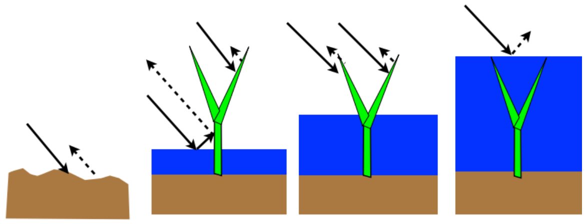


Figure 4. Backscattering in interaction with surface roughness (Wang, 2010) in (Arief et al., 2017)

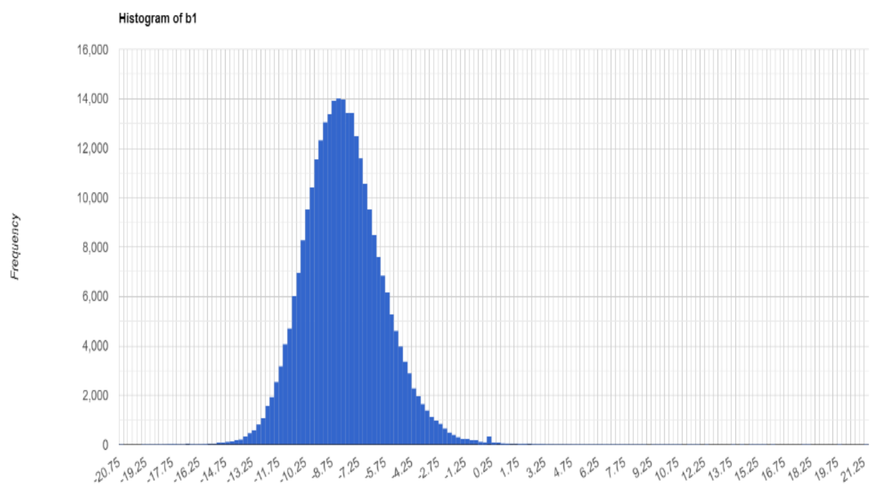
Backscattering analysis on the image was used to specify the main component of flooding. Inundation areas or bodies of water tended to show low backscattering intensity values. This was due to the signal moving away from the sensor to have a darker colour. However, some areas also had common backscattering intensity values and a dark colour but were not bodies of water. The areas were agricultural land, especially rice fields. The Serang watershed area in Kulonprogo Regency has a comprehensive agricultural land cover. In this case, (Wakabayashi et al., 2019) stated that the phases of rice growth will have different values of backscattering which are closely related to the water objects on its surface, which will affect the lightness or darkness of a colour.



Paddy status	Before planting	Irrigation	Increase water level	Completely flood
Dominant scattering	Surface scattering from the ground	Volume scattering+ Double bounce	Volume scattering	Specular scattering
Change of backscattring		increase	decrease	decrease

Figure 5. Backscattering in interaction paddy field (Wakabayashi et al., 2019)

The drawing of the inundated and unflooded area boundaries not only consideration of the value shown directly on the images but also requires a unique algorithm to choose the matching threshold value. In this case (Li & Wang, 2015; Kordelas et al., 2018; H. Cao et al., 2019; Tiwari et al., 2020; N & M, 2021) used the Otsu Algorithm for the decided threshold value. The Otsu algorithm can give the optimal threshold between water and non-water classes to show the inundated flood areas. In addition, to provide the optimal classification, it was necessary to apply a masking process to avoid distortion while classifying the flood inundation areas, such as areas with slopes >5% and bodies of water. When the river's carrying capacity cannot accommodate the existing flow, the flow will overflow and inundate the area around theriver (Bachri et al., 2020). Floods in the Serang watershed, Kulonprogo Regency, mainly occur in agricultural areas. Land use is one of the parameters that affect the amount of surface runoff (Saputra et al., 2020). The downstream watershed has a slight slope resulting in large amounts of rainwater being absorbed into the ground (Astuti et al., 2017). Areas with flat slopes have slow runoff flows and turn into inundation (Asrul & Simanungkalit, 2013). On the other hand, agricultural areas also have low backscattering values. Therefore, to provide good accuracy of the Flood Map, it was necessary to mask agricultural regions. Mapping of inundated flooded areas was using median sharpened images. In addition, the Otsu algorithm performs an iteration in determining the threshold value. It can be shown in graphs to classify the data into unflooded and inundated areas. It can be interpreted from the charts below that the extent of the site in images had a backscatter value of -23,72 -21,38. So, it can be determined the threshold value is -8,94 to separate unflooded and inundated areas.



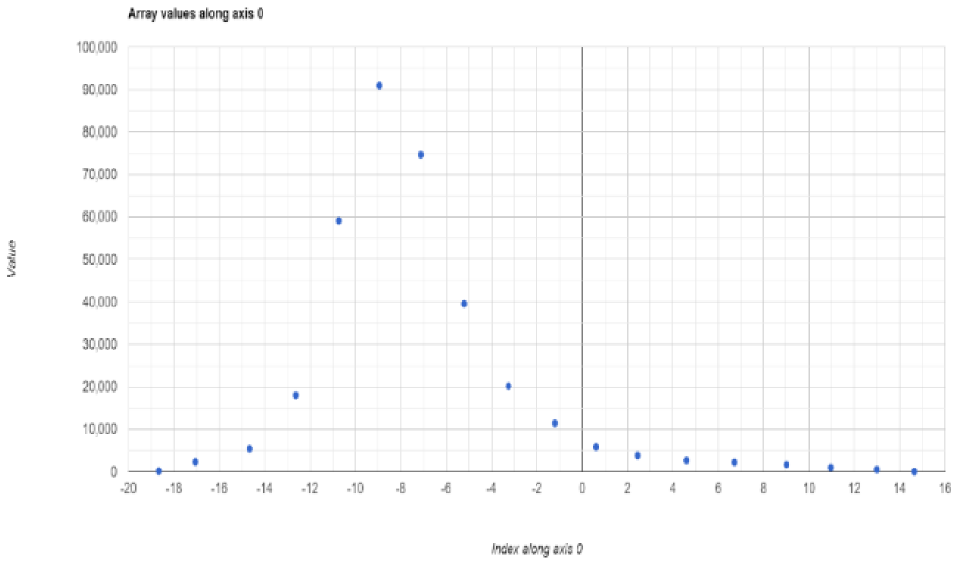


Figure 6. Histogram of median filter imagery

Figure 7. Map showing unflooded areas ad inundated area

Mapping of inundated flooded areas was using median sharpened images. In addition, the Otsu algorithm performs an iteration in determining the threshold value. This algorithm uses all the threshold values to separate the optimal water and non-water class thresholds to figure the inundated area. The accuracy test used data from flood locations by the Agriculture and Food Service of Kulonprogo Regency for the flood incident on February 10, 2021. The test results from the sample points have a total accuracy of about 77% (Table 2). The accuracy test value is the most widely used to test the accuracy of an interpretation or a classification result (Simarmata et al., 2022).

Table 2. Confusion matrix for accuracy assessment of flood

Field Survey	Sentinel 1A February 11, 2021		Total	User Accuracy (%)	Error Commission (%)
	Flood	Non-Flood			
Flood	60	22	82	73%	27%
Non-Flood	5	32	37	86%	14%
Total	65	54	119	77%	

CONCLUSION

To sum up, Sentinel imagery's ability to obtain land surface data in all conditions could be used for flood events because passive sensor images cannot record it. In addition, there were various algorithms for drawing regions in optimizing Sentinel 1 imagery with the Otsu algorithm. It could determine the threshold for separating inundated and unflooded areas with a confusion matrix of 77%. Flood mapping with a straightforward automation process without specific hardware can obtain inundation information quickly with good results. Therefore, to get improved outcomes from this method, it is necessary to conduct the best trial of the polarization used, the number of sample tests, or combine other methods to sharpen the bimodal separation to obtain the best threshold.

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REFERENCE LIST

Amitrano, D., Di Martino, G., Iodice, A., Riccio, D., & Ruello, G. (2018). Unsupervised Rapid Flood Mapping Using Sentinel-1 GRD SAR Images. *IEEE Transactions on Geoscience and Remote Sensing*, *56*(6), 3290–3299. https://doi.org/10.1109/TGRS.2018.2797536

Anusha, N., & Bharathi, B. (2020). Flood detection and flood mapping using multi-temporal synthetic aperture radar and optical data. *Egyptian Journal of Remote Sensing and Space Science*, *23*(2), 207–219. https://doi.org/10.1016/j.ejrs.2019.01.001

Arief, M., Anggraini, N., Adawiah, S. W., Hartuti, M., & Suwargana, N. (2017). Aplikasi Data Satelit Radar Sentinel-1A Guna Deteksi Hutan Mangrove Studi Kasus : Segara Anakan , Kabupaten Cilacap. *Seminar Nasional Penginderaan Jauh Ke-4 Tahun 2017*, *1982*, 277–289.

Armenakis, C., Du, E. X., Natesan, S., Persad, R. A., & Zhang, Y. (2017). Flood risk assessment in urban areas based on spatial analytics and social factors. *Geosciences (Switzerland)*, *7*(4), 1–15. https://doi.org/10.3390/geosciences7040123

Asrul, & Simanungkalit, N. M. (2013). Penyebaran Daerah Rawan Banjir di Kelurahan Anggrung Kecamatan Medan Polonia Kota Medan. *Jurnal Geografi*, *5*(1), 157–168.

Astuti, A. J. D., Nurwihastuti, D. W., & Triastuti, R. (2017). Analisis Koefisien Aliran Permukaan dengan Menggunakan Metode Bransby-Williams di Sub Daerah Aliran Sungai Babura Provinsi Sumatera Utara. *Jurnal Geografi*, *9*(2), 158–165.

Bachri, S., Aldianto, Y. E., Sumarmi, U, K. S. B., & F, M. N. (2020). Flood Modelling of Badeng River Using Hec-Ras in Singojuruh Sub- District, Banyuwangi Regency, East Java, Indonesia. *Jurnal Geografi*, *13*(1), 76–87. https://doi.org/10.24114/jg.v

Cao, C., Xu, P., Wang, Y., Chen, J., Zheng, L., & Niu, C. (2016). Flash flood hazard susceptibility mapping using frequency ratio and statistical index methods in coalmine subsidence areas. *Sustainability (Switzerland)*, *8*(9). https://doi.org/10.3390/su8090948

Cao, H., Zhang, H., Wang, C., & Zhang, B. (2019). Operational flood detection using Sentinel-1 SAR data over large areas.

Water (Switzerland), *11*(4), 1–21. https://doi.org/10.3390/w11040786

Clement, M. A., Kilsby, C. G., & Moore, P. (2018). Multi-temporal synthetic aperture radar flood mapping using change detection. *Journal of Flood Risk Management*, *11*(2), 152–168. https://doi.org/10.1111/jfr3.12303

Congalton, R., & Green, K. (2008). *Assessing the Accuracy of Remotely Sensed Data: Principles and Practices (Second Edition)*.

Darmawan, K., Hani'ah, & Suprayogi, A. (2017). Analisis Tingkat Kerawanan Banjir di Kabupaten Sampang Menggunakan Metode Overlay dengan Scoring Berbasis Sistem Informasi Geografis. *Jurnal Geodesi Undip*, *6*, 31–40.

Du, Y., Zhang, Y., Ling, F., Wang, Q., Li, W., & Li, X. (2016). Water bodies' mapping from Sentinel-2 imagery with Modified Normalized Difference Water Index at 10-m spatial resolution produced by sharpening the swir band. *Remote Sensing*, *8*(4). https://doi.org/10.3390/rs8040354

Erena, S. H., & Worku, H. (2019). Urban flood vulnerability assessments: the case of Dire Dawa city, Ethiopia. *Natural Hazards*, *97*(2), 495–516. https://doi.org/10.1007/s11069-019-03654-9

ESA. (2012). Sentinel 1- ESA's radar observatory mission for GMES operational services. In *ESA Special Publication* (Vol. 1, Issue 1322). https://sentinel.esa.int/documents/247904/349449/S1_SP-1322_1.pdf

Jacinth Jennifer, J., Saravanan, S., & Abijith, D. (2020). Integration of SAR and multi-spectral imagery in flood inundation mapping–a case study on Kerala floods 2018. *ISH Journal of Hydraulic Engineering*, *00*(00), 1–11. https://doi.org/10.1080/09715010.2020.1791265

Jahangir, M. H., Mousavi Reineh, S. M., & Abolghasemi, M. (2019). Spatial predication of flood zonation mapping in Kan River Basin, Iran, using artificial neural network algorithm. *Weather and Climate Extremes*, *25*(July), 100215. https://doi.org/10.1016/j.wace.2019.100215

Khan, S. I., Hong, Y., Wang, J., Yilmaz, K. K., Gourley, J. J., Adler, R. F., Brakenridge, G. R., Policelli, F., Habib, S., & Irwin, D. (2011). Satellite remote sensing and hydrologic modeling for flood inundation mapping in lake victoria basin: Implications for hydrologic prediction in ungauged basins. *IEEE Transactions on Geoscience and Remote Sensing*, *49*(1 PART 1), 85–95. https://doi.org/10.1109/TGRS.2010.2057513

Kordelas, G. A., Manakos, I., Aragonés, D., Díaz-Delgado, R., & Bustamante, J. (2018). Fast and automatic data-driven thresholding for inundation mapping with Sentinel-2 data. *Remote Sensing*, *10*(6), 1–23. https://doi.org/10.3390/rs10060910

Li, J., & Wang, S. (2015). An automatic method for mapping inland surface waterbodies with Radarsat-2 imagery. *International Journal of Remote Sensing*, *36*(5), 1367–1384. https://doi.org/10.1080/01431161.2015.1009653

Maridi, Saputra, A., & Agustina, P. (2015). Kajian Potensi Vegetasi dalam Konservasi Air dan Tanah di Daerah Aliran Sungai (DAS): Studi Kasus di 3 Sub DAS Bengawan Solo (Keduang, Dengkeng, dan Samin). *Prosiding Seminar Nasional Konservasi Dan Pemafaatan Sumber Daya Alam*, 65–68.

Miardini, A., & Saragih, G. S. (2019). Penentuan Prioritas Penanganan Banjir Genangan Berdasarkan Tingkat Kerawanan Menggunakan Topographic Wetness Index Studi Kasus di Das Solo. *Jurnal Ilmu Lingkungan*, *17*(1), 113. https://doi.org/10.14710/jil.17.1.113-119

N, T., & M, N. (2021). *ALOS-2 and Sentinel-1 Backscattering Coefficients for Water and Flood Detection in Nakhon Phanom Province, Northeastern Thailand*. *17*(3), 39–48.

Qaiyim, A. (2018). Analisis Dampak Sosial Ekonomi Di Kabupaten Pamekasan (Studi Kasus Banjir, Longsor dan Kekeringan di Pamekasan 2007). *Journal of Management and Accounting*, *1*(2), 153–

168. https://media.neliti.com/media/publications/266500-analisis-dampak-sosial-ekonomi-pasca-ben-30a35ded.pdf

Rahman, M. R., & Thakur, P. K. (2018). Detecting, mapping and analyzing of flood water propagation using synthetic aperture radar (SAR) satellite data and GIS: A case study from the Kendrapara District of Orissa State of India. *Egyptian Journal of Remote Sensing and Space Science*, *21*, S37–S41. https://doi.org/10.1016/j.ejrs.2017.10.002

Saputra, A. K., Santoso, D. H., & Ade Yudono, A. R. (2020). Zonasi Tingkat Kerawanan Banjir Pada Ruas Bekas Sungai di Kabupaten Sukoharjo. *Jurnal Geografi*, *12*(01), 255. https://doi.org/10.24114/jg.v12i01.14390

Setyaningsih, W., Sriyono, S., & Benardi, A. (2019). Kajian Kerusakan Lahan Di Daerah Aliran Sungai (Das) Kreo Akibat Pembangunan Pemukiman Di Sekitar Waduk Jatibarang Kota Semarang. *Media Komunikasi Geografi*, *19*(2), 177. https://doi.org/10.23887/mkg.v19i2.16027

Setyo Pambudi, A. (2019). Watershed Management in Indonesia: A Regulation, Institution, and Policy Review. *Jurnal Perencanaan Pembangunan: The Indonesian Journal of Development Planning*, *3*(2), 185–202. https://doi.org/10.36574/jpp.v3i2.74

Sghaier, M. O., Hammami, I., Foucher, S., & Lepage, R. (2018). Flood extent mapping from time-series SAR images based on texture analysis and data fusion. *Remote Sensing*, *10*(2), 1–30. https://doi.org/10.3390/rs10020237

Shahabi, H., Shirzadi, A., Ghaderi, K., Omidvar, E., Al-Ansari, N., Clague, J. J., Geertsema, M., Khosravi, K., Amini, A., Bahrami, S., Rahmati, O., Habibi, K., Mohammadi, A., Nguyen, H., Melesse, A. M., Ahmad, B. Bin, & Ahmad, A. (2020). Flood detection and susceptibility mapping using Sentinel-1 remote sensing data and a machine learning approach: Hybrid intelligence of bagging ensemble based on K-Nearest Neighbor classifier. *Remote Sensing*, *12*(2). https://doi.org/10.3390/rs12020266

Shen, X., Wang, D., Mao, K., Anagnostou, E., & Hong, Y. (2019). Inundation extent mapping by synthetic aperture radar: A review. *Remote Sensing*, *11*(7), 1–17. https://doi.org/10.3390/RS11070879

Simarmata, N., Nadzir, Z. A., & Agustina, L. K. (2022). Application of Spot6/7 Satellite Imagery for Rice Field Mapping Based on Transformative Vegetation Indices. *Jurnal Geografi*, *14*(1), 69. https://doi.org/10.24114/jg.v14i1.29036

Tiwari, V., Kumar, V., Matin, M. A., Thapa, A., Ellenburg, W. L., Gupta, N., & Thapa, S. (2020). Flood inundation mapping-Kerala 2018; Harnessing the power of SAR, automatic threshold detection method and Google Earth Engine. *PLoS ONE*, *15*(8 August), 1–17. https://doi.org/10.1371/journal.pone.0237324

Uddin, K., Matin, M. A., & Meyer, F. J. (2019). Operational flood mapping using multi-temporal Sentinel-1 SAR images: A case study from Bangladesh. *Remote Sensing*, *11*(13). https://doi.org/10.3390/rs11131581

Wakabayashi, H., Motohashi, K., Kitagami, T., Tjahjono, B., Dewayani, S., Hidayat, D., & Hongo, C. (2019). Flooded area extraction of rice paddy field in Indonesia using sentinel-1 SAR data. *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences - ISPRS Archives*, *42*(3/W7), 73–76. https://doi.org/10.5194/isprs-archives-XLII-3-W7-73-2019

Yunida, R., Kumalawati, R., & Arisanty, D. (2017). Dampak Bencana Banjir Terhadap Kondisi Sosial Ekonomi Masyarakat Di Kecamatan Batu Benawa Kabupaten Hulu Sungai Tengah, Kalimantan Selatan. *Jurnal Pendidikan Geografi*, *4*(4), 42–52.