JCE

Journal of Civil Engineering
ISSN 2086-1206 E-ISSN 2579-9029

Enhancing Flood Detection in Surabaya: A Comparative Study of VV and VH Polarizations with Sentinel-1 Data

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Submitted : 10 January 2025
Revised : 31 January 2025
Accepted : 18 February 2025

Abstract

Flood mapping is critical to strengthen urban resilience, particularly in Surabaya, where flooding is a major and recurring threat. Sentinel-1 satellite data offers significant advantages for flood model calibration due to its high-resolution imagery and frequent revisits. This study utilizes Google Earth Engine to process and analyse Sentinel-1 data for mapping flood extents using two different polarizations: VV and VH. The research compares the capabilities of these polarizations in detecting flood areas. The results show that VV polarization consistently identifies a larger flood area compared to VH polarization under similar processing conditions. However, the Kappa coefficient was used to assess classification accuracy, with VV achieving a Kappa of 0.8 and VH reaching a higher Kappa of 0.92, reflecting better classification performance. These findings suggest that while VV provides a broader flood detection, VH offers more reliable flood mapping, highlighting the trade-offs between sensitivity and accuracy in flood monitoring using Sentinel-1 satellite.

Keywords

Google earth engine, polarization, sentinel-1

INTRODUCTION

Strategy readiness in flood handling needs to be highlighted as an effort to strengthen urban resilience. In urban settings, flood mapping aids in planning and resource allocation. It allows city planners to identify vulnerable zones, optimize drainage systems, and implement flood-resilient designs in both public and private spaces. In recent years, significant investment has been made to reduce flood intensity and frequency by the local government of Surabaya [1] since the flood is a primary threat in Surabaya [2] exacerbated by climate change. Although Surabaya has implemented 13 regulations related to river and flood management, the responsibility for flood control is divided among seven different agencies, which makes cohesive efforts challenging. Some successes include waste reduction through composting, though a comprehensive city disaster plan is still absent. For this purpose, this paper explores flood map demonstration as a potential pathway for building resilience to sufficiently prepare for future flood events.

Modelling flood accurately includes the interplay of various factors such as topography, rainfall variability, and evolving land use patterns. The accuracy of flood models depends heavily on the availability of real-time data and proper calibration [3]. Historical flood event maps are crucial for assessing flood hazards, vulnerabilities, and risks, as they serve as the benchmark for calibrating hydrodynamic model parameters [4]. Concerning this situation, Sentinel-1can provide significant benefits in model calibration, especially for non-flash floods due to the high revisit time of the satellite. Researchers [5], [6], [7], [8] have already shown the ability to estimate inundation events using Sentinel-1. SAR imagery is not affected by weather thus it provides reliable way to detect flooded regions. Leveraging this capability, Google Earth Engine provides a scalable platform to process and analyze Sentinel-1 data for flood extent maps [9]. GEE's cloud-based environment offers immediate access to updated Sentinel-1 archives and allows for efficient implementation of preprocessing workflows, including speckle filtering, terrain correction, and backscatter analysis. This enables the timely detection of flood events, particularly crucial in tropical and densely populated regions where rapid response and resilience planning are vital. The availability of sentinel SAR instruments on the satellite platform covers global extension and, in some cases, the data presented without charge. Google Earth engine presents all data required to demonstrate a flood map. One of the key features of SAR data is its ability to capture different polarization modes, such as Vertical-Vertical (VV) and Vertical-Horizontal (VH) polarization. These polarization modes influence how radar signals interact with surface materials, affecting the accuracy of information extracted from SAR imagery.

VV polarization represents signals transmitted and received in the same vertical orientation, often providing strong backscatter in smooth surfaces like water bodies and urban areas. On the other hand, VH polarization involves cross-polarized signals, which are more sensitive to volume scattering from vegetation and complex surface structures. Understanding the comparative performance of VV and VH polarization is essential for optimizing SAR applications in various fields, including flood mapping, land cover classification, and urban resilience studies. This study aims to compare VV and VH polarization in terms of their effectiveness in detecting surface characteristics and environmental changes. By analysing the strengths and limitations of each polarization mode, we seek to provide insights into their suitability for specific applications, particularly in flood-prone urban areas.

RESEARCH SIGNIFICANCE

This study aims to explore the effectiveness of different radar polarizations, specifically VV and VH, in urban flood assessment, with a focus on regions in Surabaya, East Java, that are frequently affected by flooding. By utilizing Sentinel-1 satellite data processed through Google Earth Engine (GEE), the research compares the flood detection capabilities of VV and VH polarizations.

METHODOLOGY

This study aims to evaluate flood extent maps using Google Earth Engine (GEE), a cloud-based geospatial analysis platform known for its computational power and extensive data repository. The research focuses on detecting flooded areas by analysing VV and VH radar polarizations from Sentinel-1 satellite imagery. Through the analysis of multi-temporal imagery, pre-flood and post-flood conditions will be compared to delineate the spatial extent and severity of flooding. The study examines the differences in flood detection between VV and VH polarizations, assessing their effectiveness in identifying inundated areas.

A. COLLECTION OF TECHNIQUE DATA

The primary data source for this analysis is Sentinel-1, a satellite mission launched by the European Space Agency (ESA). The data, accessed via the Synthetic Aperture Radar (SAR) sensor through Google Earth Engine (2024), is highly suited for flood extent mapping due to its ability to capture images under all weather conditions. Sentinel-1 operates in the C-band frequency and consists of two satellites, Sentinel-1A and Sentinel-1B, which provide high-resolution radar data with a revisit time of 6–12 days globally. The C-band imagery offers various polarization modes and resolutions, captured during both ascending and descending orbital passes. Sentinel-1 imagery utilizes four main SAR modes (Table 1 Sentinel-1 GRD Properties), each designed for configurations and observation purposes. The Instrument Mode refers to the specific acquisition mode of the Synthetic Aperture Radar (SAR) instrument.

Sentinel-1 imagery consists of three key components: VV (vertical transmit and vertical receive), VH (vertical transmit and horizontal receive), and the incidence angle. Studies have shown that VH polarization is particularly advantageous for flood mapping due to the low reflectance of water in the VH band, which simplifies the detection of flooded areas [10, 11]. Conversely, VV polarization often outperforms VH when single-polarization data is utilized. A comparative flood area analysis [12] indicated that VV polarization provides more accurate estimates of flood extent over submerged regions.

The choice between VV and VH polarization ultimately depends on the specific objectives and conditions of the analysis. This study evaluates flood extent maps using both VH and VV polarizations, providing a comparative perspective on their effectiveness for flood detection. Furthermore, historical inundation data is employed to establish local thresholds for flood detection.

Tabel 1. Sentinel-1 GRD Properties

Properties	Parameter
transmitterReceiverPolarisation	[‘VV’] [‘HH’] [‘VV’ ‘VH’] [‘HH’ ‘HV’]
instrumentMode	‘IW’ (Interferometric Wide Swath) ‘EW’ (Extra Wide Swath) ‘SM’ (Strip Map)
orbitProperties_pass	ASCENDING DESCENDING
resolution_meters	10, 25, or 40
resolution	‘M’ (medium) ‘H’ (high)

B. TECHNIQUE ANALYSIS

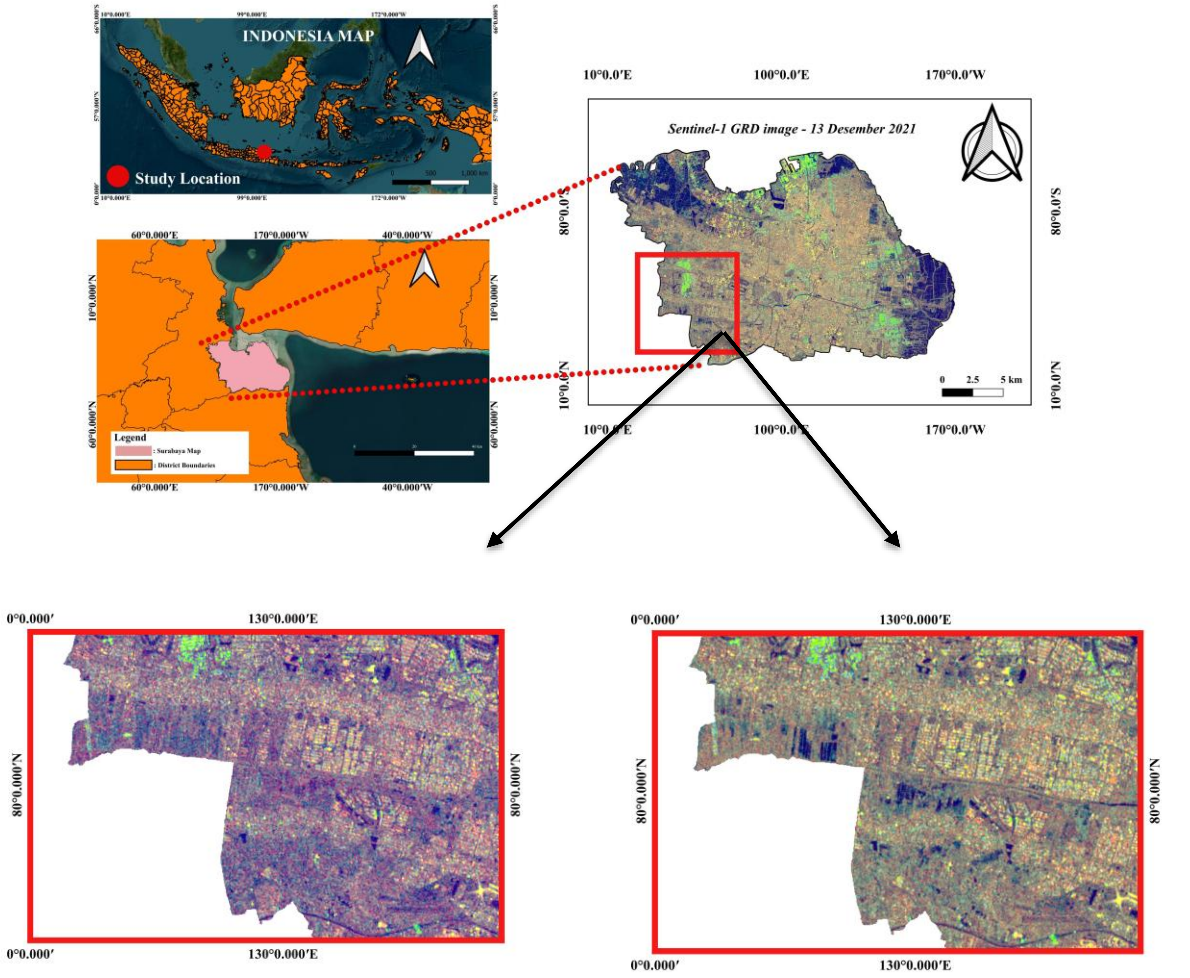
This study was conducted through literature reviews, data collection, analysis and demonstration, suggestions, and conclusions. The flood mapping was obtained using Google Earth Engine through java script language. The stages process is (1) SAR Sentinel-1 Data Preprocessing; (2) Change Detection; (3) Water Mask; (4) Mask Area of 5% Slope; (5) Remove Isolated Pixels; (6) Area Calculation.

RESULTS AND DISCUSSIONS

The pre-processing stage of this study was crucial for accurately defining pre-flood and post-flood conditions using satellite imagery. A time frame was selected based on Surabaya's flood data recap to capture significant water-level fluctuations, ensuring the imagery corresponded to relevant flood events. The chosen dates for the analysis were August 9–16, 2021, representing the dry season as pre-flood conditions, and December 13–22, 2021, representing the post-flood conditions. The *instrumentMode* property was set to IW (Interferometric Wide Swath), which is commonly used for land applications.

This analysis evaluates the performance of VV and VH polarizations to determine their effectiveness in flood mapping. The comparison aims to identify which polarization provides more accurate and reliable delineation of flooded areas, especially in regions with diverse surface textures and vegetation cover. To ensure consistent change detection, images from the same pass direction were selected to maintain uniform viewing angles and minimize discrepancies caused by variations in sensor perspective. The selection between ascending or descending pass directions was a critical consideration when working with Sentinel-1 data. This decision determines the satellite’s trajectory during data acquisition, directly influencing the quality and consistency of the analysis results. Additionally, selecting an appropriate resolution was essential for obtaining accurate and reliable outcomes.

The homogenous data was clipped to the area of interest to focus the analysis on the specific region of concern. This structured and methodical approach ensures that the analysis accurately captures the spatial extent of flooding, providing actionable insights into its impacts. A key preprocessing method in this study was speckle filtering, which offers significant benefits such as noise reduction, feature preservation, and enhanced analysis quality. Speckle noise, a common issue in synthetic aperture radar (SAR) imagery, can obscure important details and negatively affect tasks like classification, segmentation, and change detection. The primary objective of speckle filtering is to minimize noise while preserving critical details such as edges, textures, and boundaries. By improving image clarity, speckle filter significantly enhances the accuracy of flood detection. For this study, the Lee Refined filter was employed, a widely recognized method that effectively reduces speckle noise while maintaining edge integrity and preserving essential image features [13]. This technique played a vital role in preparing high-quality data for subsequent flood extent analysis. The visualization of the preprocessing results of Sentinel-1 data for pre-flood and post-flood detection is presented in Figure 1. Potential Flood Colour Pseudo in RGB. The figure highlights the differences in reflectance properties, which signify changes between the two periods. A change detection process was performed to identify areas impacted by flooding. This process involved generating a difference image by subtracting the backscatter values of the pre-flood image from those of the post-flood image. The resulting difference image highlights changes in surface water reflectance, effectively delineating flooded regions. Generally, higher backscatter values result in brighter object visualization in the image, whereas lower backscatter values produce darker visualizations. In Sentinel-1 imagery, bright objects are typically non-water features, while water bodies appear dark due to their high absorption of radar waves, which reduces the amount of backscatter received by satellite sensors. This high absorption is influenced by water's high dielectric constant, approximately 80, compared to non-water objects with dielectric constants ranging from 3 to 8 [14]. A higher dielectric constant means that radar signals are less likely to be reflected, resulting in lower backscatter values. The historical inundated area data provides a reference to areas that have been previously flooded, which helps in

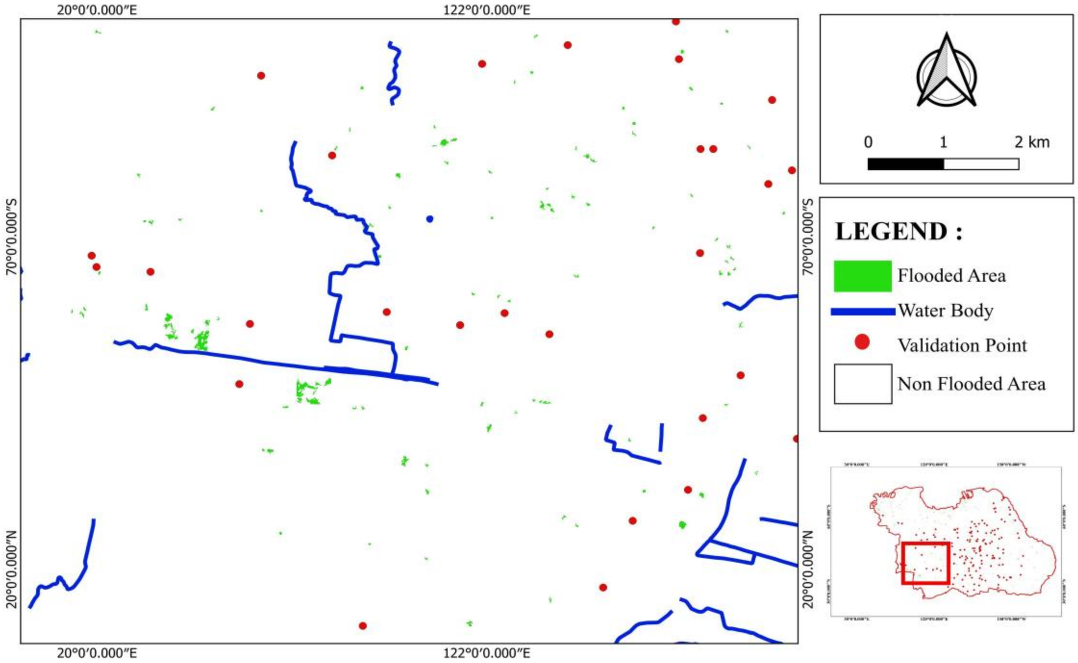


Before Period – *Sentinel 1 GRD Image – 9 August 2021* **After Period** – *Sentinel 1 GRD Image – 13 Desember 2021*

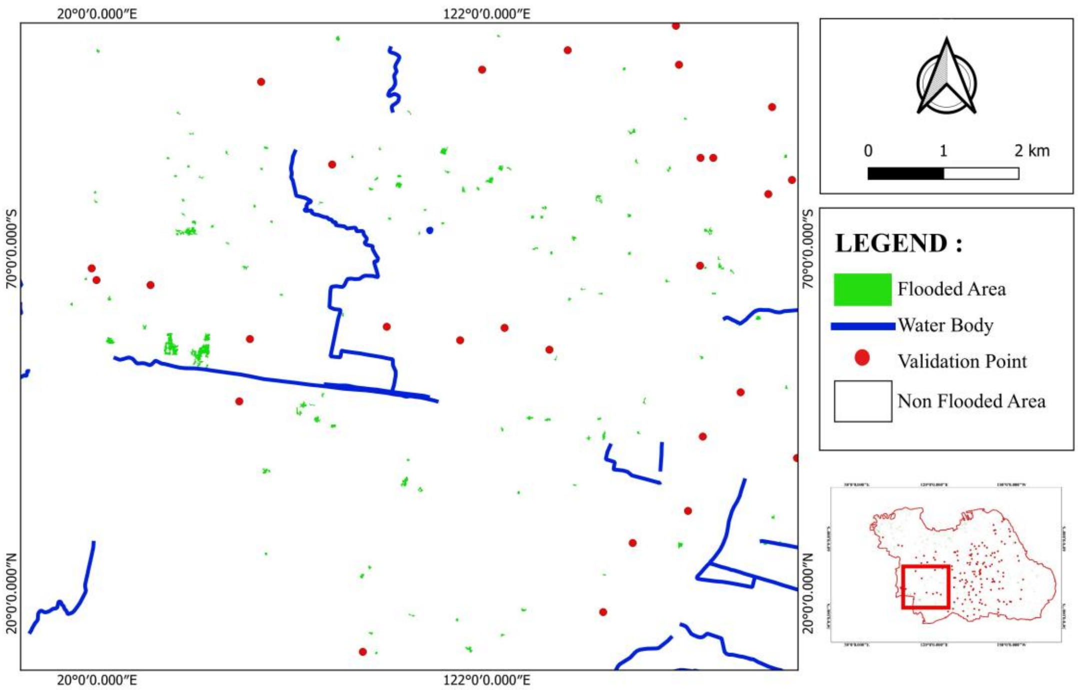
Figure 1. Potential Flood Colour Pseudo in RGB.

determining a reliable threshold for distinguishing flooded from non-flooded areas in the imagery. By comparing the reflectance values or pixel intensities from satellite imagery to the known flooded regions in the historical data, the author can define a threshold value that best separates the flooded areas from the non-flooded areas.

Flood mapping process through Google Earth Engine (GEE) involves water masking to accurately distinguish temporary inundation from permanent water bodies and other land cover types. One particularly effective dataset is the JRC Global Surface Water (GSW), which provides detailed insights into water dynamics over time. Among its valuable features is the seasonality band, which indicates



(a) Flood Inundation Distribution Map Using VH Polarization



(b) Flood Inundation Distribution Map Using VV Polarization
Figure 2. Flood Distribution Map

Table 2. Polarization parameter scenarios

Polarization	Scenario			Inundated Area (km2)
	Water Mask	*Masking Area Slope of 5%*	*Isolated Pixel Removing*	
VV	√	√	√	1.91
VH	√	√	√	1.03
Total Area of Surabaya Region				329.8

the number of months per year that a specific location is covered by water. Seasonality values range from 0, representing no water presence, to 12, representing year-round water presence. By leveraging seasonality data, researchers can create a permanent water mask to exclude areas that are consistently covered by water, such as lakes, rivers, and reservoirs. This process incorporates slope-based masking to enhance flood mapping accuracy by excluding areas with slopes greater than 5%, as flatter regions are more likely to retain water and contribute to flood-prone zones. The 5% slope threshold is a practical criterion for identifying regions where water accumulation is probable. This method ensures the analysis is concentrated on areas with the highest potential for flooding. Furthermore, isolated pixel removal is required to eliminate noise and small, scattered water pixels that are unlikely to represent actual inundation. This process involves applying a filtering technique, such as a majority filter or morphological operations, to smooth the classified water layer and remove single or small clusters of pixels that do not form part of larger water bodies. In this analysis, scenarios are developed to apply specific polarizations parameter that align the identified inundated areas with historical flood data. Each scenario's performance highlights how different polarization choices can influence the accuracy of flood extent mapping, flood distribution using VV and VH polarization could be seen in the Figure 2. Flood Distribution Map.

As shown in the Table 1. Polarization parameter scenarios. The results indicate that there is a notable difference in flood detection between VV and VH polarization. VV polarization identified a larger inundated area (1.91 km²) compared to VH polarization (1.03 km²). From this analysis, the spread of flooding is measured using a confusion matrix with historical data. The confusion matrix is used to compare the flood mapping results generated from the model with the flood data recorded historically. In this study, the objective is to assess the accuracy of flood detection using remote sensing data by evaluating the performance of different polarizations in classifying flooded and non-flooded areas. A validation dataset of 150 points was used, consisting of 75 flooded points and 75 non-flooded points. The goal is to measure the classification accuracy through the Kappa coefficient, which evaluates the agreement between the predicted and observed classifications while accounting for the possibility of random chance. VV polarization typically detecting larger flooded areas compared to VH. The analysis of flood detection results using VH and VV polarizations reveals notable differences in their classification performance. As shown in the Table 2. Confusion Matrix for Flood Distribution, for VH Polarization, the User Accuracy for flooded areas is high at 0.92, indicating that 92% of the flooded areas were correctly identified, while non-flooded areas were classified perfectly with a User Accuracy of 1.00. The Kappa value for VH is 0.92, this indicates that VH polarization strikes a balance in identifying both flooded and non-flooded areas, with fewer misclassifications compared to VV. On the other hand, VV Polarization shows a lower User Accuracy of 0.80 for flooded areas, meaning it correctly identifies only 80% of the flooded regions, while it still achieves perfect classification for non-flooded areas. The Kappa value for VV is 0.8, indicating moderate agreement but lower performance than VH. This suggests that VV may be overestimating the extent of the flooded areas, leading to a higher number of False Positives. In conclusion, while VV Polarization is more sensitive in detecting flooded areas, it tends to misclassify more regions as flooded, resulting in a lower Kappa. VH Polarization, with its higher Kappa value, offers more balanced and reliable classification.

CONCLUSIONS

The result analysis of flood detection using VV and VH polarizations reveals distinct differences in performance. VV Polarization consistently detects more flooded areas compared to VH, resulting in a Kappa of 0.92, this indicates moderate agreement between observed and

Table 3. Confusion Matrix for Flood Distribution

Polarization	Class Value (Validation)	Flooded	Non-flooded	Total	User Accuracy	Kappa
VH	**Flooded**	69	6	75	0.92	
	Non-flooded	0	75	75	1	
	Total	69	81	150		
	P. Accuracy	0.92	1			
	Kappa					0.92
VV	**Flooded**	60	15	75	0.8	
	Non-flooded	0	75	75	1	
	Total	60	90	150		
	P. Accuracy	0.8	1			
	Kappa					0.8

expected classifications, with VV tending to overestimate flooded regions, which may lead to an increase in False Positives. In contrast, VH Polarization shows a Kappa of 0.8, indicating moderate-to-good agreement and a better balance between detecting both flooded and non-flooded areas. This suggests that VH polarization is more accurate leading to a higher Kappa value. While VV provides more sensitivity in detecting flooded regions, it may produce more misclassifications. Therefore, VH offers a more balanced classification, with fewer errors.

ACKNOWLEDGMENTS

The authors would like to express their gratitude to the Institut Teknologi Sepuluh Nopember for providing access to the laboratory, which enabled the authors to conduct this research.

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