

VALIDATION OF FLOOD INUNDATION DISTRIBUTION IN THE BORO WATERSHED USING SENTINEL-1 IMAGERY AND 1D HEC-RAS SIMULATION AGAINST FIELD OBSERVATION DATA

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ABSTRACT

Flooding is a natural disaster that poses a serious problem in many regions of Indonesia, particularly in the Boro Watershed (DAS Boro), which experiences annual inundation in several urban villages. DAS Boro is a sub-watershed of the Bengawan Solo River, located in Jebres District, Surakarta City. Therefore, accurate flood management is necessary through disaster risk mitigation efforts. This study aims to identify flood inundation using Sentinel-1 satellite imagery visualization and hydraulic analysis through 1D modeling with HEC-RAS. The method applied is the HSS Snyder method with a two-year return period, calibrated using data from the Pepe Hilir Watershed. The analysis process began with site surveys and channel dimension measurements, along with field observations, including interviews with affected residents. Surveys were conducted at 19 points representing the inundated area. The area of DAS Boro was determined through data processing using QGIS 3.14.16, measuring 1.376 km², with a two-year flood discharge of 109.41 m³/s. The results show that flood visualization using Sentinel-1 achieved an accuracy (Recall) of 100% compared to data from BPBD and DPUPR Surakarta. Meanwhile, the HEC-RAS 1D model simulation reached only a 19.29% Recall rate, indicating that remote sensing approaches are more effective in identifying flood-affected areas

Keywords : *Flood, Boro Watershed, Snyder Method, Satellite Image Visualization, 1D HEC-RAS Modeling*

INTRODUCTION

Flooding is an annual problem experienced by almost all communities affected by inundation. One of the significant impacts of flood inundation is caused by high rainfall and river overflow. These inundations generally occur along riverbanks, with one of the main contributing factors being high population density. Therefore, information related to flood distribution data is highly needed to support decision-making by relevant agencies. The Boro Watershed is located in Jebres District, with its upstream area in Purwodiningratan Sub-district and its downstream area in Pucangsawit Sub-district. The Boro River also experiences flood inundation during the rainy season due to high rainfall and poor drainage systems. This flooding submerges road

access, causing traffic congestion, and the situation worsens when flooding occurs within residential areas due to heavy rain, leading to waterlogging. Based on the issues above, effective flood control measures are required..

Satellite imagery or remote sensing is the science and art of obtaining information about an object, area, or phenomenon through the analysis of data acquired without making direct contact with the object, area, or phenomenon under study (Adi Guna Prasetyo, Lisa Dwi Saryani, dan Romizah Elzahidah, 2025). On the other hand, hydraulic analysis using 1D HEC-RAS modeling also serves to simulate the flood distribution in the Boro Watershed area.

Research conducted by M. Yusuf, Putri Indah Sari Tarigan, Kartiko

Noviansah, Rizki Ridwana, Silmi Alfina Aliyan (2023), A study entitled “*Identification of Flood Inundation Using Sentinel-1 and Its Correlation with Flood Hazard in South Barito Regency*” was conducted. The objectives of this research were to identify flood inundation areas, determine the level of flood hazard, and analyze the correlation between flood inundation and flood hazard levels. The method used to identify the distribution of flood inundation was the Change Detection method, by observing changes in backscattering values from two Sentinel-1 images. The inundated areas in each sub-district are as follows: Dusun Hilir, with a total area of 139,347 ha and inundated area of 17,347 ha; Dusun Selatan, 125,472 ha with 3,793 ha inundated; Dusun Utara, 123,398 ha with 653 ha inundated; Gunung Bintang Awai, 122,004 ha with 147 ha inundated; Jenamas, 47,957 ha with 16,541 ha inundated; and Karau Kuala, 82,515 ha with 4,901 ha inundated. It can be concluded that Jenamas Sub-district experienced the most significant flood inundation, with 16,541 ha or about 34.5% of its total area. The widest distribution of flood hazard levels was found in Dusun Hilir Sub-district, with 62,060 ha or about 45% of its total area, followed by Jenamas Sub-district with 29,754 ha or about 62% of its total area. Gunung Bintang Awai Sub-district was identified as the safest, with a safe-class area of 31,857 ha or 26% of its total area, and a non-hazardous class area of 83,599 ha or 69% of its total area. The variability of the controlling parameters of flood hazard influences the variation in flood hazard levels.

Research conducted by Ria Dhanisa, Joko Sampurno, dan Radhitya Perdhana (2024), A study entitled “*Application of Sentinel-1 SAR Imagery for Flood Detection in Sandai Sub-district, Ketapang Regency, West Kalimantan*” was conducted. The imagery was processed using the Change Detection and

Thresholding (CDAT) method to produce a flood distribution map. Based on the results of the study, it can be concluded that the CDAT method applied to Sentinel-1 SAR data with a threshold value of 1.06 was able to generate a flood distribution map with an accuracy level of 0.67. This result indicates that the flood distribution map is fairly reliable in representing the actual flood distribution. According to the flood distribution map, the flood event that occurred on October 7–23, 2022, in Sandai Sub-district affected 11,300 people, inundated 5,400 buildings, and cut off access to 98 km of roads.

Research conducted by Muhlisin Alahudin, Nanag Saidul Rizal, dan Pujo Priyono (2024) A study entitled “*Flood Discharge Analysis at the D.I Wringin Weir Using the Nakayasu Unit Hydrograph, Snyder Unit Hydrograph, and HEC-HMS Methods*” was conducted. The design flood discharge calculation results for various return periods are as follows: Nakayasu Unit Hydrograph Method: 2-year return period: 68.57 m³/s; 5-year: 76.49 m³/s; 10-year: 83.18 m³/s; 25-year: 91.43 m³/s; 50-year: 97.89 m³/s; and 100-year: 104.61 m³/s. Snyder Unit Hydrograph Method: 2-year return period: 59.47 m³/s; 5-year: 66.82 m³/s; 10-year: 72.14 m³/s; 25-year: 79.30 m³/s; 50-year: 84.90 m³/s; and 100-year: 90.72 m³/s. HEC-HMS Model: 2-year return period: 15.00 m³/s; 5-year: 18.40 m³/s; 10-year: 21.20 m³/s; 25-year: 25.20 m³/s; 50-year: 28.50 m³/s; and 100-year: 32.20 m³/s.

Research conducted by Kezia, Mahmud Achmad, dan Fardiah, (2017) A study entitled “*Design Flood Hydrograph in the Tallo Watershed, Makassar, Using the HEC-HMS Hydrological Model*” was conducted. The objective of this research was to determine the design flood discharge for return periods of 2, 5, 20, and 50 years in the Tallo Watershed. The results were used to identify flood-prone areas and to inform the planning of

hydraulic structures such as bridges. The hydrological simulation employed the HEC-HMS software, with the SCS-CN method applied to derive the unit hydrograph. The rainfall station influence area was analyzed using the Isohyet method in ArcGIS. The peak discharge values for each return period were as follows: 2-year return period: 81.80 m³/s; 5-year return period: 115.30 m³/s; 20-year return period: 151.20 m³/s; and 50-year return period: 169.50 m³/s.

Research conducted by Rifai Munajad dan Slamet Suparyogi, (2019) A study entitled “*Rainfall-Runoff Analysis Using the HEC-HMS Model in the Wuryantoro Sub-Watershed, Wonogiri, Central Java*” was conducted. The method used to determine the Curve Number (CN) values was the SCS Curve Number method, while the flood hydrograph simulation was carried out using HEC-HMS software. The results showed that the physical characteristics of the Wuryantoro Sub-Watershed, based on

the composite CN value in 2010, were 69.53 under normal soil moisture conditions (AMC II). The flood hydrograph simulation using the HEC-HMS model for the Wuryantoro Sub-Watershed provided excellent results (objective function less than 10%), with a difference of 0.24% for peak discharge, 1.85% for outflow volume, and an identical peak time.

METHODS

Research Location

The Boro Watershed (DAS Boro) is a sub-watershed of the Bengawan Solo Watershed. The main river of the Boro Watershed is called the Boro River or Sonto River. The downstream area of the Boro River is located in Pucangsawit Sub-district, Jebres District, while the upstream area is situated in Purwodiningratan Sub-district. Figure 1 shows the map of the study area.

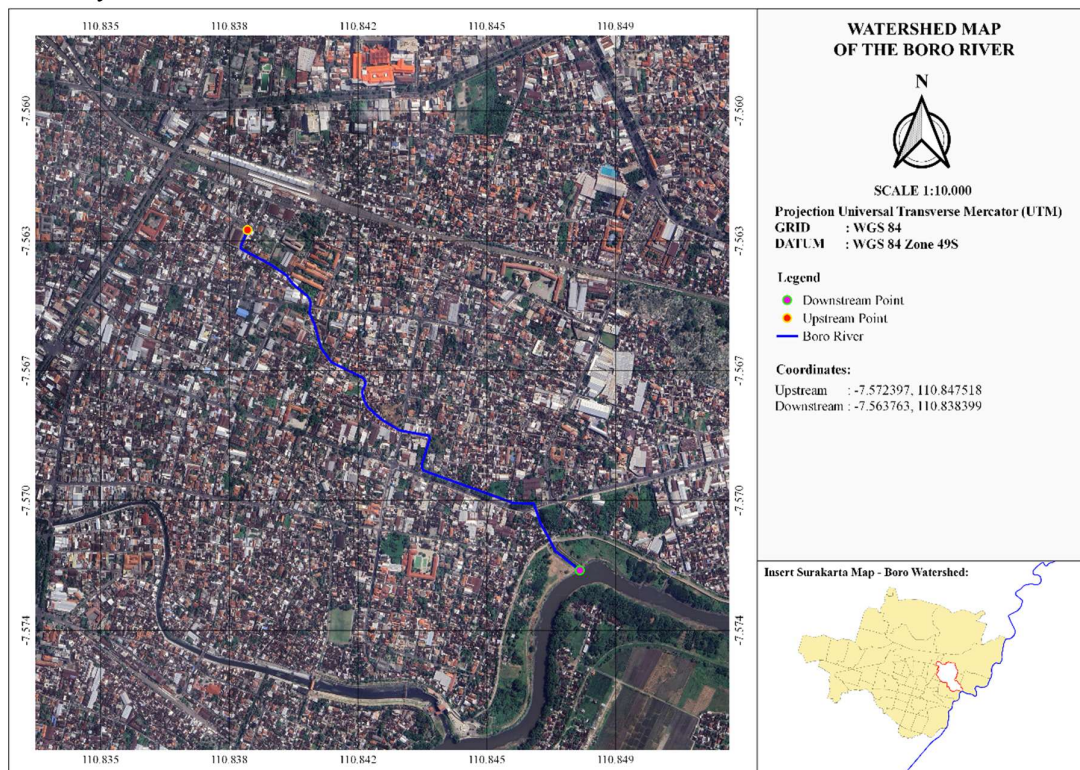


Figure 1 Boro Watershed

Data Collection

This study utilizes two types of data: primary and secondary data. Primary data were obtained from river cross-sectional surveys and interviews with communities affected by flooding in the study area. In addition, secondary data were used, including flood event records from the Surakarta DPUPR and BPBD, daily rainfall data from BBWS Bengawan Solo, land use data, RBI maps, and DEM data.

River Cross-Section

The acquisition of river cross-sectional dimensions in the Boro Watershed was carried out through direct surveys conducted at 17 points from upstream to downstream, with intervals of 100 meters per station.

Design Flood Discharge

The design flood discharge analysis was carried out using HEC-HMS software to determine the flow hydrograph with the Snyder method, following these steps:

1. Consistency test of rainfall data using the RAPS (Rescaled Adjusted Partial Sums) method.
2. Rainfall analysis using the Thiessen method.
3. Goodness-of-fit test of probability distribution using the Chi-Square and Kolmogorov-Smirnov methods.
4. Calculation of rainfall distribution for a 2-year return period.
5. Development of the design rainfall hydrograph using the ABM (Alternating Block Method).
6. Calculation of adequate rainfall.

7. Calibration of Snyder parameter determination.
8. Flow hydrograph analysis using HEC-HMS.

RESULT AND DISCUSSION

Accuracy Assessment of Sentinel-1 Satellite Imagery

In this study, the validation of Sentinel-1 satellite imagery was carried out using data from BPBD Surakarta for the years 2022, 2023, and 2024, as well as data from DPUPR Surakarta for the year 2022. A summary of flood events based on the BPBD and DPUPR Surakarta data is presented in Table 1.

Table 1 Summary of Flood Events

No	Sources	Date	Name of the Urban Village
1	BPBD Surakarta	08/05/2022	Jebres
2	BPBD Surakarta	11/02/2023	Jebres
3	BPBD Surakarta	11/02/2023	Purwodiningratan
4	BPBD Surakarta	16/02/2023	Jagalan
5	BPBD Surakarta	18/02/2023	Pucangsawit
6	BPBD Surakarta	25/02/2024	Jagalan
7	BPBD Surakarta	25/02/2024	Sewu


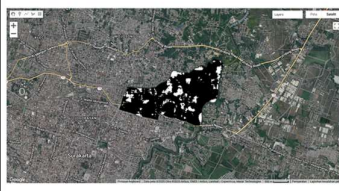

From the seven datasets analyzed, all of them indicated the occurrence of flooding, which was validated through field interview data. The recall calculation results of flood detection using Sentinel-1 satellite imagery against the validated flood events are as follows:

$$Recall = \frac{TP}{TP + FN} \times 100\%$$

$$Recall = \frac{7}{7} \times 100\% = 100\%$$

The validation summary can be seen in Table 2.

Table 2 Visualization Results of Sentinel-1 Satellite Imagery Compared with Field Data

No	Name of the Urban Village	Flood Data Sources	Flood Event Date	Citra Satellite Visualization	Interview Results
1	Jebres	BPBD Surakarta	08/05/2022		Occurred Due to High Rainfall Intensity
2	Jebres	BPBD Surakarta	11/02/2023		Occurred Due to High Rainfall Intensity
3	Purwodiningratan	BPBD Surakarta	11/02/2023		Occurred Due to High Rainfall Intensity

Rain Consistency Test

The consistency test was carried out based on the determination of the rainfall station, where the entire Boro Watershed area falls within the Pabelan rainfall station, using rainfall data from 2003 to 2024.

Average Rainfall Thiessen Method

The calculation was performed using the Thiessen method, which is used to determine the average annual rainfall, with the summary of results presented in Table 3.

Table 3 Maximum Rainfall

No	Year	P (max)
1	2003	85
2	2004	104
3	2005	89
4	2006	92
5	2007	133
6	2008	126
7	2009	142
8	2010	103

No	Year	P (max)
9	2011	114
10	2012	99
11	2013	76
12	2014	123
13	2015	166
14	2016	138
15	2017	118
16	2018	69
17	2019	116
18	2020	113
19	2021	167
20	2022	104
21	2023	82
22	2024	111

Distribution Fit Test

The testing was carried out using two methods, Chi-Square and Kolmogorov-Smirnov. The results are presented in Tables 4 and 5.

Table 4 Smirnov Kolmogorov Fit Test

Kolmogorov Smirnov Distribution Test	D max	Test Result
Normal	0.067	Accepted
Log Normal	0.050	Accepted
Gumbel	0.074	Accepted
Log pearson III	0.051	Accepted

Based on the goodness-of-fit test above, the calculation used the Log-Normal distribution in determining the 2-year return period.

Table 5 Chi Kuadrat Fit Test

Chi Square Distribution Test	χ^2	Test Result
Normal	0.727	Accepted
Log Normal	1.182	Accepted
Gumbel	2.091	Accepted
Log pearson III	1.182	Accepted

Rain Recurrence Period

The calculation was carried out using the Log-Normal distribution method, with the results and steps presented in Table 6.

Table 6 Rain Recurrence Period

No.	Year	R (mm)	Ln R	Ln R - Ln R Average	$[\text{Ln R} - \text{Ln R Average}]^2$
1	2003	85	4.44	-0.252	0.064
2	2004	104	4.64	-0.051	0.003
3	2005	89	4.49	-0.206	0.043
4	2006	92	4.52	-0.173	0.030
5	2007	133	4.89	0.195	0.038
6	2008	126	4.84	0.141	0.020
7	2009	142	4.96	0.261	0.068
8	2010	103	4.63	-0.060	0.004
9	2011	114	4.74	0.041	0.002
10	2012	99	4.60	-0.100	0.010
11	2013	76	4.33	-0.364	0.133
12	2014	123	4.81	0.117	0.014
13	2015	166	5.11	0.417	0.174
14	2016	138	4.93	0.232	0.054
15	2017	118	4.77	0.076	0.006
16	2018	69	4.23	-0.461	0.213
17	2019	116	4.75	0.058	0.003
18	2020	113	4.73	0.032	0.001
19	2021	167	5.12	0.423	0.179
20	2022	104	4.64	-0.051	0.003
21	2023	82	4.41	-0.288	0.083
22	2024	111	4.71	0.014	0.000
Amount (Σ)			103.29	AMOUNT	1.142
Average			4.70		
Standart deviation			0.23		
A lot of data (n)			22		

The rainfall distribution calculation for a 2-year return period is as follows :

$$T = 2 \text{ Years}$$

$$\text{Probabilitas (\%)} = 50$$

$$K(\text{Frequency}) = 0$$

$$Sd_{\text{Log P.K}} = 0.23 * 0.00 = 0.00$$

$$\text{Ln } P_{\text{rancangan}} = 4.70 + 0.00 = 4.70$$

$$P_{\text{rancangan}} = 10^{4.70} = 109.41$$

Based on the calculation, the 2-year return period design discharge is 109.41 m³/s

Design Rain Hyetograph (ABM)

The calculated return period rainfall was converted into hourly rainfall by adjusting it to the location in Surakarta City (Fauziyah et al., 2013). The calculation results are presented in Table 7.

Table 7 Design Rain Hyetograph

Td (hours)	Δt (hours)	It (mm/hours)	ItTd (mm)	Δp (mm)	pt (%)	Hyetograph	
						(%)	(mm)
1	0-1	37.93	37.93	37.93	63.00%	11.49%	12.57
2	1-2	23.89	47.79	9.86	16.37%	63.00%	68.92
3	2-3	18.24	54.71	6.92	11.49%	16.37%	17.92
4	3-4	15.05	60.21	5.51	9.14%	9.14%	10.00
		Amount	60.21	100.00%	100.00%		109.41

Effective Rain

The calculation of adequate rainfall requires the CN value, which is determined from land cover data and soil type data processed using QGIS 3.14.16

Figure 3 Land Cover Map of Pepe Hilir Watershed

software. These data serve to complement the calculation requirements. After the analysis was carried out, the results are shown in Figures 2 and 3.

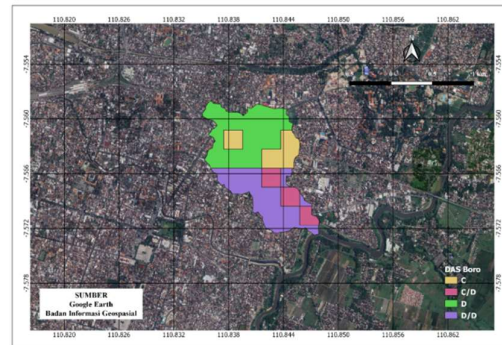
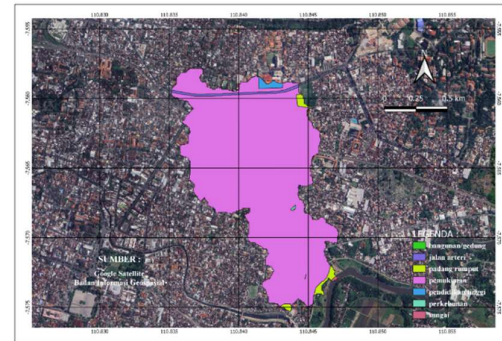


Figure 2 Soil Type Map of Lower Pepe Watershed

Based on the analysis shown in Figures 2 and 3, a CN value of 84.1123 was obtained, as detailed in Table 8.

Table 8 CN value calculation

Land Cover		Land Classification		Area Km ²	%	Area Km ²	CN x Area	CN Average
Badan Informasi Geospasial (BIG)	CN	Soil Type	CN					
Estate	Farmed Land	D	91	0.0008	0.06%	0.0008	0.0706	84.1123
Grassland	Healthy Meadow	D	80	0.0193	1.40%	0.0193	1.5409	
Arterial Road	Pavement with Drainage	D	98	0.0162	1.17%	0.0162	1.5833	
Building/Structure	Settlement	D	84	0.0002	0.02%	0.0002	0.0175	
Higher Education				0.0101	0.73%	0.0101	0.8452	
Settlement and Activity Area				1.3296	96.62%	1.3296	111.6834	
Amount				1.3760	100.00%	1.3760	115.7409	

Based on the analysis in determining the CN value, the requirements for

calculating adequate rainfall have been fulfilled, with the calculation results presented in Table 9.

Table 9 Effective Rain

t	P	Σ P	Ia	ΣPeff	Peff
1	12.57	12.57	9.60	0.17	0.17
2	68.92	81.49	9.60	43.12	42.95
3	17.92	99.41	9.60	58.54	15.42
4	10.00	109.41	9.60	67.41	8.87
S	109.41			S	67.41

Snyder Parameters

Calibration is a method of aligning the model output values with the actual values through parameter adjustment. This study utilized flow calculation data obtained using a current meter, along with daily rainfall data from the Pepe Hilir Watershed. The calibration of the Boro Watershed was considered comparable to that of the Pepe Hilir Watershed, as both are sub-watersheds of the Bengawan Solo. The calibration in this study used the following main reference coefficients:

Ct coefficient : 1.36

Cp coefficient : 0.69

Flow Hydrograph Analysis

Flood discharge analysis was carried out using the HEC-HMS 4.11 software, with the output in the form of a flow hydrograph generated for the Boro River. The data required in this analysis include the calculation of adequate rainfall and Snyder parameters with a 2-year return period. The results obtained can be seen in Figure 4 and 5.

Date	Time	Precip (MM)	Loss (MM)	Excess (MM)	Direct Flow (M3/S)	Baseflow (M3/S)	Total Flow (M3/S)
21Feb2024	00:00				0.0	0.0	0.0
21Feb2024	01:00	0.17	0.00	0.17	0.0	0.0	0.0
21Feb2024	02:00	42.95	0.43	42.52	5.3	0.0	5.3
21Feb2024	03:00	15.42	0.07	15.35	10.0	0.0	10.0
21Feb2024	04:00	8.87	0.03	8.84	6.9	0.0	6.9
21Feb2024	05:00	0.00	0.00	0.00	2.7	0.0	2.7
21Feb2024	06:00	0.00	0.00	0.00	0.6	0.0	0.6
21Feb2024	07:00	0.00	0.00	0.00	0.0	0.0	0.0
21Feb2024	08:00	0.00	0.00	0.00	0.0	0.0	0.0
21Feb2024	09:00	0.00	0.00	0.00	0.0	0.0	0.0
21Feb2024	10:00	0.00	0.00	0.00	0.0	0.0	0.0
21Feb2024	11:00	0.00	0.00	0.00	0.0	0.0	0.0
21Feb2024	12:00	0.00	0.00	0.00	0.0	0.0	0.0
21Feb2024	13:00	0.00	0.00	0.00	0.0	0.0	0.0
21Feb2024	14:00	0.00	0.00	0.00	0.0	0.0	0.0
21Feb2024	15:00	0.00	0.00	0.00	0.0	0.0	0.0
21Feb2024	16:00	0.00	0.00	0.00	0.0	0.0	0.0
21Feb2024	17:00	0.00	0.00	0.00	0.0	0.0	0.0
21Feb2024	18:00	0.00	0.00	0.00	0.0	0.0	0.0
21Feb2024	19:00	0.00	0.00	0.00	0.0	0.0	0.0
21Feb2024	20:00	0.00	0.00	0.00	0.0	0.0	0.0
21Feb2024	21:00	0.00	0.00	0.00	0.0	0.0	0.0
21Feb2024	22:00	0.00	0.00	0.00	0.0	0.0	0.0
21Feb2024	23:00	0.00	0.00	0.00	0.0	0.0	0.0
22Feb2024	00:00	0.00	0.00	0.00	0.0	0.0	0.0

Figure 4 Results of Flow Hydrograph for 2-Year Return Period

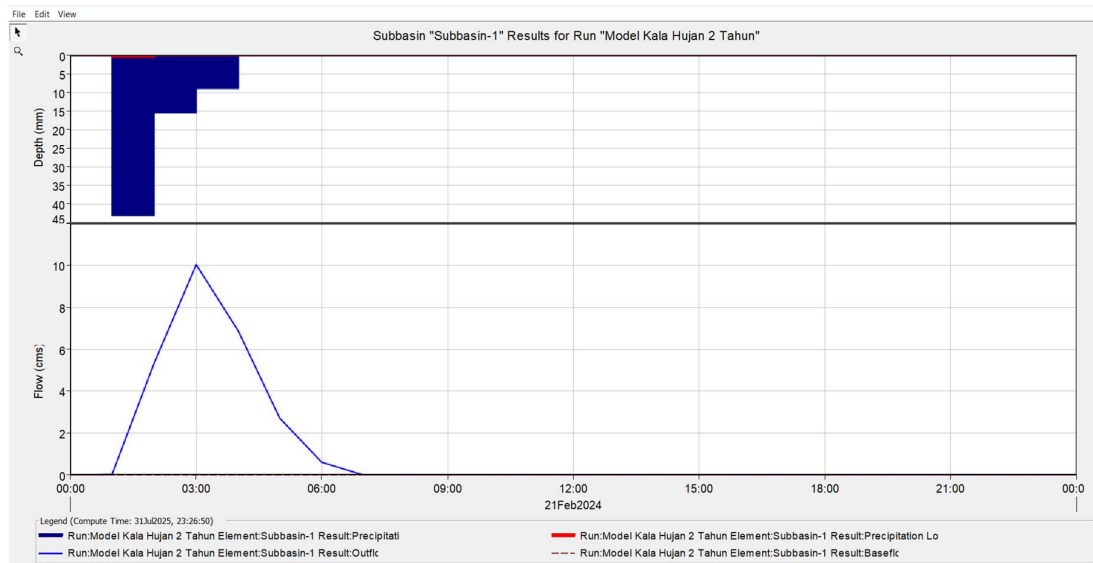


Figure 5 2-Year Return Period Hydrograph

Accuracy Level of the 1D HEC-RAS Model

The initial stage in starting the modeling process using HEC-RAS is to

determine the river cross-sectional dimensions, which serve as input data for the cross-sections. The results are presented in Table 10.

Table 10 Stream Cross-Section Dimensions

STA	Base Width (m)	Maximum Depth (m)	Surface Width (m)	Base Elevation (m)	Setback Area (m)	
					Left	Right
0	5.3	6.73	7.50	81.00	10.00	10.00
100	5.3	6.26	7.50	81.81	10.00	10.00
200	5.3	5.8	7.50	82.63	0.50	4.30
300	5.3	5.8	7.50	83.44	0.80	3.65
400	5.3	3.5	7.50	84.25	0.50	5.40
500	5.3	3.5	7.50	85.06	3.50	4.50
600	5.3	3.5	7.50	85.88	-	4.50
700	5.3	3.5	7.50	86.69	1.50	2.30
800	4	2.3	7.50	87.50	4.50	2.50
900	4	2	5.60	88.31	4.50	2.50
1000	4	1.6	5.60	89.13	-	-
1100	4	1.5	5.60	89.94	-	-
1200	4	1.4	5.60	90.75	-	-
1300	2.4	2.2	4.00	91.56	1.40	2.80
1400	2.4	1.2	4.00	92.38	-	1.20
1500	2.4	1	4.00	93.19	1.00	1.50
1600	2.4	1.7	4.00	94.00	3.20	5.00

Next, the river cross-section dimension data are entered into the cross-section input, followed by the flow hydrograph that has been analyzed using HEC-HMS. The model is then executed (running) to begin the simulation process. The results of the 1D model run can be observed in Figures 6, 7, and 8.

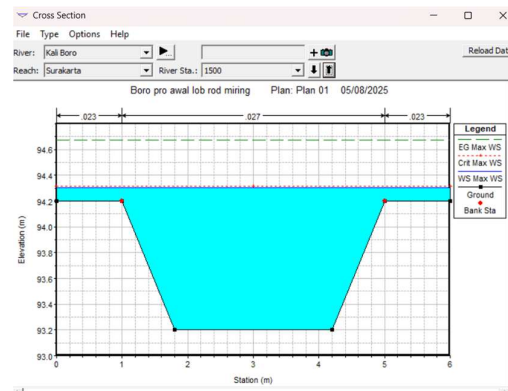


Figure 7 STA 14+00

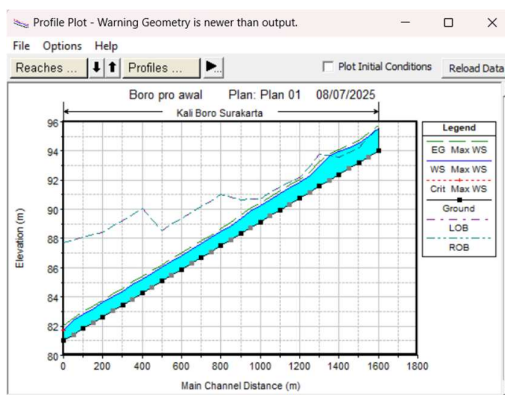


Figure 6 Profiles Plot

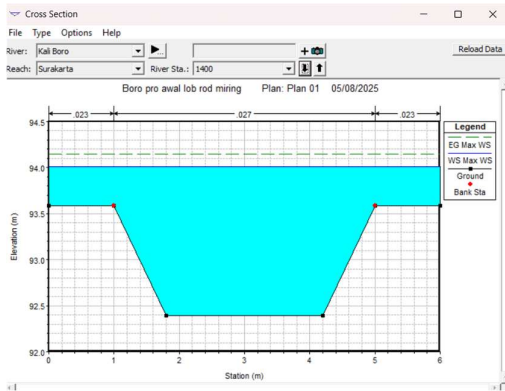


Figure 8 STA 15+00

Based on the modeling carried out in HEC-RAS, only 1 out of 7 flood events was detected. Therefore, the Recall value against the field observation data is calculated as follows:

$$Recall = \frac{TP}{TP + FN} \times 100\%$$

$$Recall = \frac{1}{7} \times 100\% = 14,29\%$$

The recap of flood events can be seen in Table 11

Table 11 Flood Event Visualization Results

No	Name of the Urban Village	Flood Data Sources	Flood Event Date	HEC-RAS Modeling	Description	Interview Results
1	Jebres	BPBD Surakarta	08/05/2022		No Flood Occurred	Occurred Due to High Rainfall Intensity
2	Jebres	BPBD Surakarta	11/02/2023		No Flood Occurred	Occurred Due to High Rainfall Intensity
3	Purwodiningratan	BPBD Surakarta	11/02/2023		No Flood Occurred	Occurred Due to High Rainfall Intensity

Comparison of Flood Event Representations

Based on the analysis results, Sentinel-1 satellite imagery demonstrates a higher level of accuracy, with a recall

value of 100%, compared to the HEC-RAS software, which achieved only 14.29%. The comparison of flood event representations can be seen in Table 12.

Table 12 Accuracy Level Comparison

No	Sources	Name of the Urban Village	Date	Data Availability		
				Institution	Citra Satellite Sentinel-1	HEC-RAS 1D
1	BPBD Surakarta 2022	Jebres	8 Mey 2022	✓	✓	X
2	BPBD Surakarta 2023	Jebres	11/02/2023	✓	✓	X
3	BPBD Surakarta 2023	Purwodiningratan	11/02/2023	✓	✓	✓
4	BPBD Surakarta 2023	Jagalan	16/02/2023	✓	✓	X
5	BPBD Surakarta 2023	Pucangsawit	18/02/2023	✓	✓	X
6	BPBD Surakarta 2024	Jagalan	25/02/2024	✓	✓	X
7	BPBD Surakarta 2024	Sewu	25/02/2024	✓	✓	X
Recall					100%	14,29%

This indicates that Sentinel-1 satellite imagery is capable of capturing flood events caused by both river overflow and poor drainage conditions. The

comparative diagram can be seen in Figure 9.

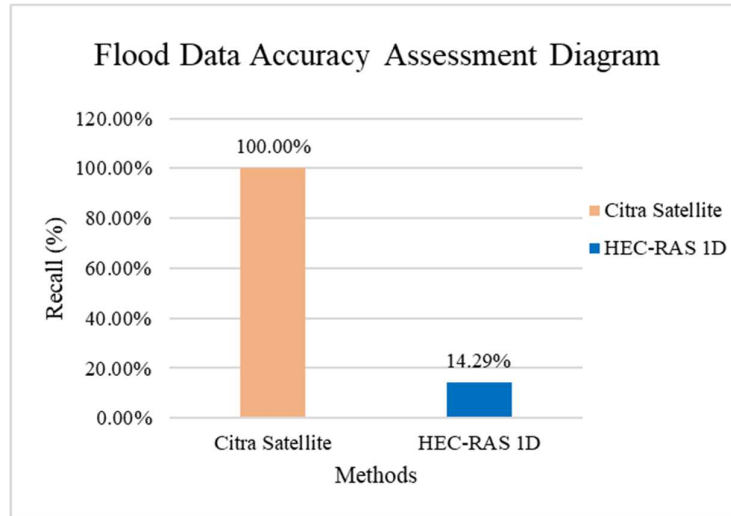


Figure 9 Flood Data Accuracy Assessment Diagram

CONCLUSION

Sentinel-1 imagery is a method capable of effectively representing flood events based on field observation data, specifically through flood event visualization. The accuracy level of flood event detection using Sentinel-1 satellite imagery, when compared to data from BPBD Surakarta and DPUPR Surakarta, achieved a recall value of 100%. A 2-year return period was used as the design flood discharge for the Boro watershed. The analysis was conducted using the HEC-HMS software, resulting in an output discharge of 109.41 m³/s. The accuracy level of the 1D HEC-RAS simulation, when compared to data from BPBD Surakarta and DPUPR Surakarta, yielded a recall value of only 14.29%.

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