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2D Flow Model of Kendal River Sedimentation Effect as Identification of Bandengan Village Flood Management

A. H. B. Kuncoro, T. Zhafira, H. Masvika

Abstract: ***Flooding is one of the hydrometeorological disasters that often occurs on the north coast of Central Java, such as in Bandengan Village. Kendal River sedimentation occurs, which causes flooding. A two-dimensional (2D) flow model is needed due to the influence of sedimentation in the Kendal River channel, especially around the Bandengan Village area. This modelling aims to prove that sedimentation of the Kendal River is one of the causes of flooding. Secondary data on land use and rainfall are used to calculate the design of flood discharge. Primary data collection in the form of sediment samples and river contours as the basis for making Digital Elevation Model (DEM) maps for hydraulics modelling using the HEC-RAS 2D application. The Universal Soil Loss Equation (USLE) Method was analysed to determine the erosion potential formed in the Kendall Watershed. The calculation of the design flood discharge is Q2 of 45.1 m³/s, Q5 of 62.8 m³/s, Q10 of 74.7 m³/s, and Q10 of 91.3 m³/s. Hydraulic analysis with three scenarios revealed that existing conditions caused flooding, conditions without sediment also caused flooding, and finally, river widening conditions showed no flooding. Erosion analysis shows that the erosion hazard class in the Kendal watershed is low, so there are two indications, namely the transportation of sediment from irrigation canals in the upper reaches of the Kendal watershed and sedimentation accumulated over the years due to the absence of sediment control in the Kendal River. This modelling concludes that sedimentation, small river cross-sections, and the erosion of the Kendal coastal area are the causes of flooding in the area. Handling the issue by widening the river and building sediment barriers in the upstream area can reduce sedimentation and flooding of the Kendal River around Bandengan Village.***

Keywords: ***2D Model, DEM, Flood, River, Sedimentation***

I. INTRODUCTION

Hydrometeorological disasters in Indonesia, especially on the North Coast of Central Java, are floods. Kendal Regency is a low-lying area on the north coast of the Java Sea and is often hit by floods. The flood phenomenon causes losses to flood-affected communities, both in the form of damage to environmental infrastructure, residential buildings, household furniture, and feelings of discomfort [1]. Flooding in Kendal District resulted in slum settlements, hundreds of hectares of ponds experiencing crop failure, and disruption to Pantura Road access due to frequent overflow of the Kendal River because one of the causes was high sedimentation in the river channel [2]. Changes in land use significantly affect the formation of sediments, as seen in the Central Capibaribe Estuary in Northeastern Brazil, where the mangrove environment produced fine sediments that were more dominant. When the environment changed to urban and sugarcane plantations, the amount of sand sediments increased. Finally, when urban expansion produced sand sediments that increasingly dominated [3]. The countryside around the Lower Khazir River in Northern Iraq is more affected by Flooding than the countryside far from the river's lower reaches [4]. The same problem also occurs in the Lower Kendal River due to flooding caused by several conditions, including high rainfall, changes in land use upstream, reduced river capacity due to sedimentation, tides, rising sea levels, and land subsidence. So, it is necessary to calculate the estimated amount of sediment formed due to land changes in the Kendal watershed. It is essential to carry out a 2D sedimentation model in the Kendal Hilir River channel to represent the original conditions that occur in the river. The last is the need to identify the handling of flooding and sedimentation problems in the Kendal River watershed.

II. LITERATURE REVIEW

The problem-solving approach in this study was carried out using 2D modelling in the estuary to see sediment flow speed and distribution as a reference in handling, planning estuary engineering and improving the optimization of estuary function [5]. The behavior of sediment transport in estuaries is influenced by hydro-oceanographic conditions such as river discharge, current speed, tides, and geographical conditions [6]. The formation of sediment transport based on the Universal Soil Loss Equation (USLE) method is based on soil erosion index due to rain intensity (EI), land erodibility index (K), slope length and slope index (LS), and due to vegetation cover and land processing index (CP) factors [7]. Sediment flow and transport are combined with changes in the river bed so that erosion and deposition processes are simulated simultaneously [8]. The application of 2D modelling to research the calculation of water flow rate and amount of sediment transported has proven effective [9].

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*Correspondence Author(s)
A. H. B. Kuncoro*, Department of Civil Engineering, Universitas Semarang, Semarang, Indonesia. Email: ahmad@usm.ac.id, ORCID ID: 0000-0002-8429-8398.
T. Zhafira, Department of Civil Engineering, Universitas Semarang, Semarang, Indonesia. Email: thalita@usm.ac.id, ORCID ID: 0000-0002-3970-4924.
H. Masvika, Department of Civil Engineering, Universitas Semarang, Semarang, Indonesia. Email: hendramasvika@usm.ac.id, ORCID ID: 0000-0002-2345-772X.

However, 2D modelling requires calibration and validation so that the model can represent close to actual conditions [9,10,13,14]. As a step to determine handling to reduce the impact of Flooding, several actions can be taken, such as the role of local governments in increasing socialization of disaster response and early warning to residents who are at high and medium levels of danger and vulnerability [11]. The construction of a weir can reduce the rate of sediment transport in estuaries during the rainy season [12]. Control of land use change can reduce sediment input into river channels [3]. With all the methods described, a final goal is required in the form of a description of sedimentation behaviour or characteristics in the Kendal River channel, especially the downstream section, as a reference for decision-making in flood management in the Kendal District.

One-dimensional hydrodynamic models of HEC-RAS are used to simulate the Tigris River's flow patterns to understand the river's flow movements [13]. Sedimentary and hydraulic transport models were created using elevation and cross-section data in HEC-RAS [14]. 2D mathematical simulation on the Progo River around the Kamijoro Dam intake was carried out using the Nays2DH solver provided by iRIC software [15]. The MIKE 21 Sand Transport (ST) application was used to determine sediment movement along rivers in the Lower Var Valley, France [16]. The first-order second-moment method with numerical differentiation was applied to assess the uncertainty of the Lower Salzach River's 2D Hydro_FT-2D sediment transport model [17]. Experiment combining HEC-RAS 2D application as hydrodynamic analysis with WASP application as water quality analysis [18]. From several previous studies, it is evident that 2D flow modelling has not been affected by sedimentation; therefore, this study presents a novel approach to sedimentation analysis methods.

III. REVIEW CRITERIA

The location is in the Kendal watershed, specifically on the Kendal River around Bandengan Village, Kendal District, as shown in Figure 1. Design flood calculation using the Snyder synthetic unit hydrograph (SUH) method with parameters seen in Table 1. Then, the rain design based on the selected distribution frequency analysis is the Gumbel Distribution with P2 repeat rain of 113.1 mm, P5 of 141.5 mm, P10 of 160.3 mm, and P25 of 184.1 mm. Land-use data from the Kendall watershed, used as input for USLE method calculations, are presented in Figure 2 and Table 2.

Primary data in topographic surveys is used to complement DEM data as input for 2D flow modelling simulations using HEC-RAS. The topographic survey process of the channel and cross-section of the Kendal River can be seen in Figure 3. The DEM map used as a basis was obtained from the DEMNAS website with a resolution of 8.5 m, as seen in Figure 4.

The last data sought are sediment samples from several points in the river channel and outside the river channel, but within the Kendal watershed area, to determine whether erosion material indeed originates from the Kendal watershed area or from outside it. Sediment sample data collection, sediment sample testing, and sediment sampling test results can be seen in Figures 5 to 15.

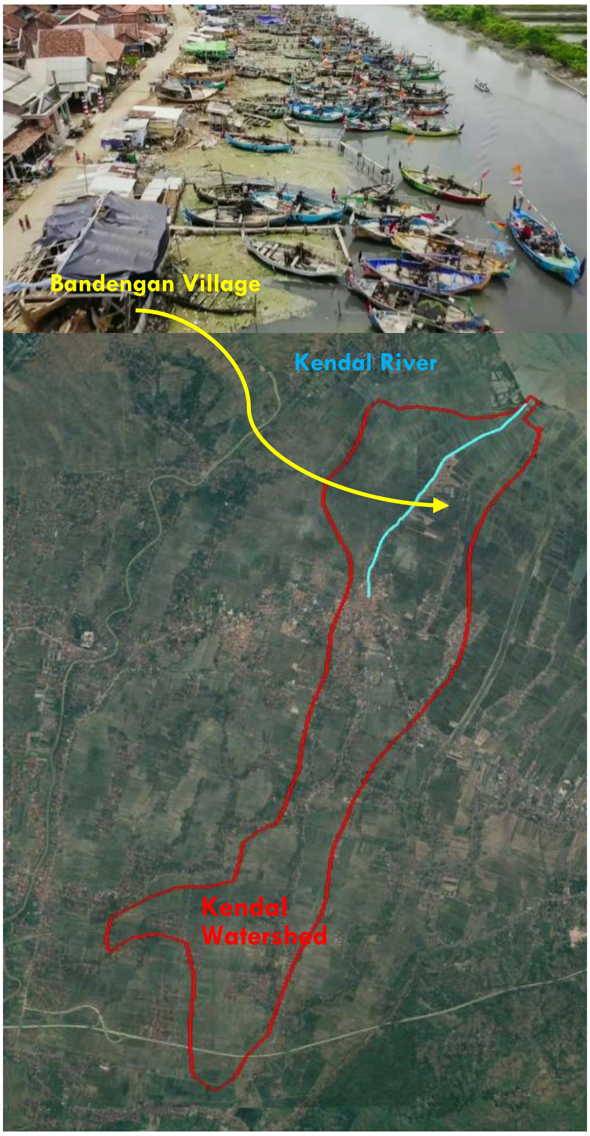

Fig. 1: Location Map of Study Area

Table I: Watershed Characteristic

No	Parameter	Symbol	Unit	Value
1	Watershed Area	A	km^2	26.02
2	Main River Length	L	km	15.17
3	Length to Watershed Centroid	Lc	km	6.96
4	Time Coefficient	Ct		1.10
5	Peak Discharge Coefficient	Cp		1.00
6	Recession Time	tr	hour	0.81
7	Estimated Peak Time	tp	hour	4.45
8	Duration of Effective Rainfall	te	hour	0.81
9	Peak Correction Time	tp'	hour	4.45
10	Peak Time	Tp	hour	4.85
11	Peak Discharge Per Unit Area	qp	m^3/s/mm/km^2	0.06
12	Peak Discharge	Qp	m^3/s/mm	1.50
13	Base Time	tb	hour	26
14	Rain Unit	R	mm	1.00
15	Curvature Coefficient of Hydrograph	λ	-	1.00
16	Hydrograph Coefficient	a	-	1.52

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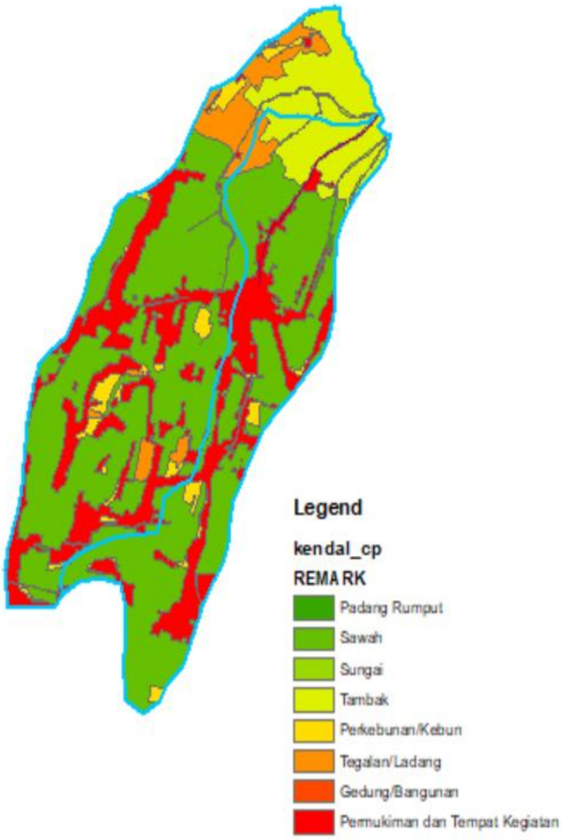

Fig. 2: Kendal Watershed Land Use

Table II: Land Use Data

Land use		Area (km^2)	Percentage of Total Area (%)
Padang Rumput	Natural Vegetation	0.156	0.6
Sawah	Agricultural Land	13.338	51.3
Sungai	Water Bodies	0.226	0.9
Tambak	Pond Area	1.700	6.5
Perkebunan/Kebun	Planting Land	0.590	2.3
Tegalan/Ladang	Open Scrub Land	0.475	1.8
Permukiman dan Tempat Kegiatan	Residential Area	9.533	36.6
Gedung/Bangunan	Building Up Land	0.001	0.0
Total		26.020	100.0

Fig. 3: Topographic Survey

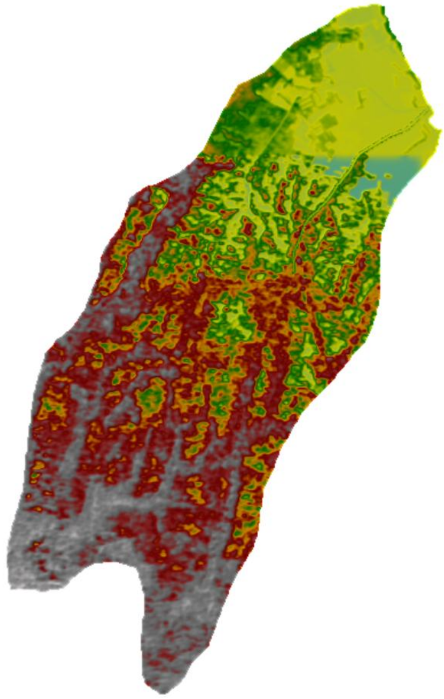

Fig. 4: DEM Data

Fig. 5: Sediment Sample

Fig. 6: Sediment Test

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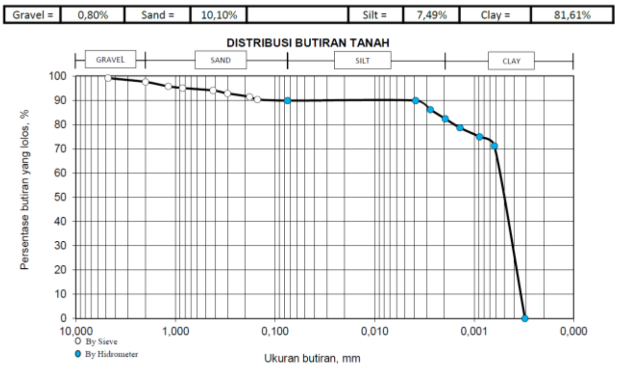

Fig. 7: Downstream River Sediment

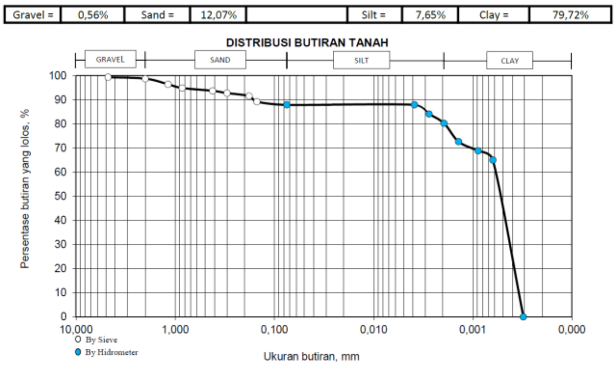

Fig. 8: Middle River Sediment

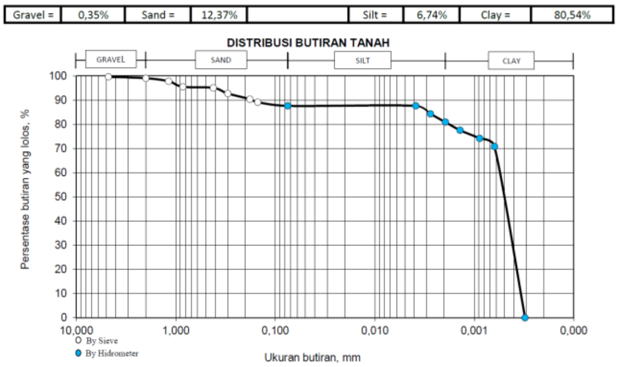

Fig. 9: Highland River Sediment

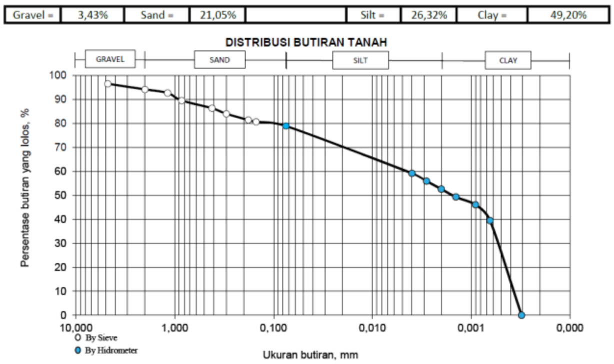

Fig. 10: Left Site Downstream River Sediment

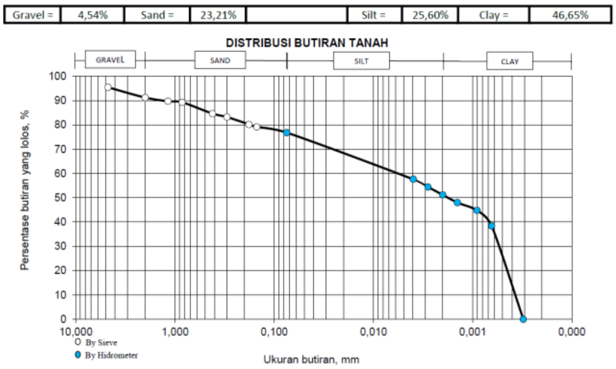

Fig. 11: Right Site Downstream River Sediment

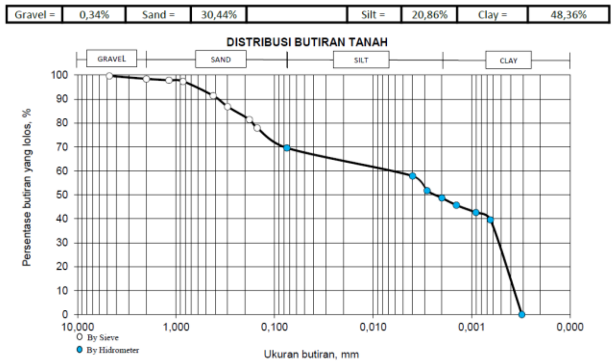

Fig. 12: Left Site Middle River Sediment

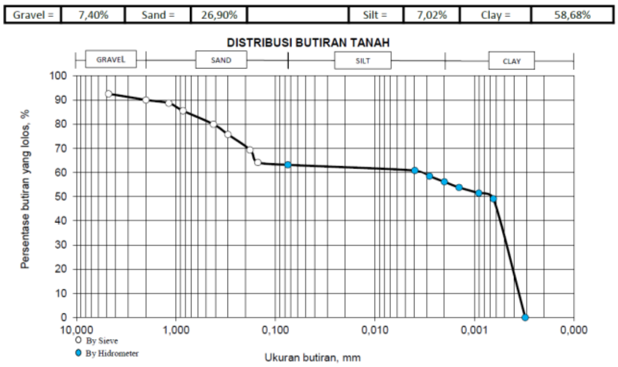

Fig. 13: Right Site Middle River Sediment

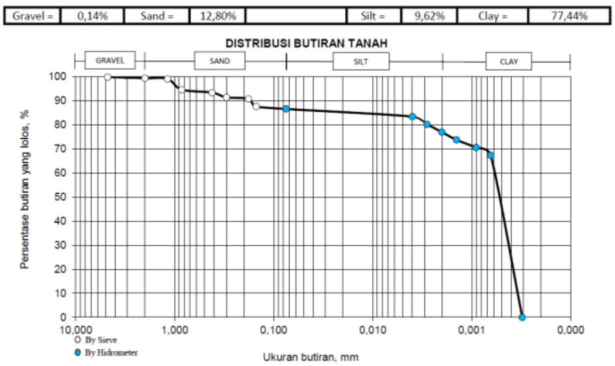

Fig. 14: Left Site Highland River Sediment

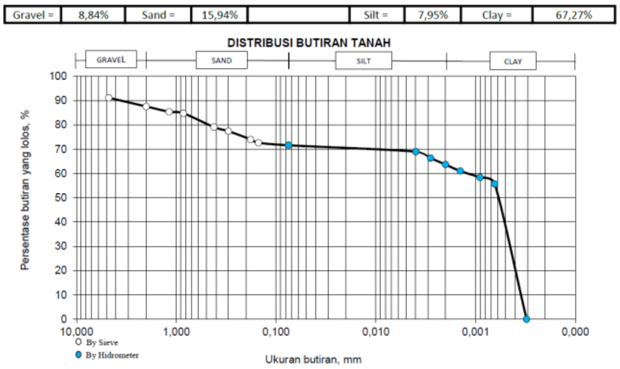

Fig. 15: Right Site Highland River Sediment

IV. METHODOLOGY

The initial calculation involves a hydrological analysis to determine the revival discharge resulting from the recurrence of rain. Then, the discharge is calculated based on Snyder's HSS, with a rain duration of 24 hours. Results from the hydrological analysis are used as input in flow modelling using HEC-RAS 2D.

Hydraulic analysis aims to determine the cross-sectional capacity of the Kendal River around Bandengan Village. The cross-section of the channel comes from the results of topographic surveys in the Kendal River channel. Channel cross-sectional results are converted into DEM data and combined with DEMNAS data for input in HEC-RAS 2D applications. Hydraulics simulation is carried out with three criteria: the cross-section of the existing river, the cross-section of the river without sediment, and the cross-section of the river with widening, especially for widening carried out several times until the river's cross-sectional capacity can accommodate flood discharge designed for Q25 years.

Erosion prediction using the USLE method was carried out to determine the Erosion Hazard Level in the Kendal Watershed Area. The results of sediment and soil tests in grain gradation indicate where the most significant contributor to sedimentation in the Kendal River channel comes from.

Finally, discussion and conclusions related to the analysis results were drawn in statements about whether sedimentation is one of the causes of Flooding. Then, what needs to be done for flood management in Bandengan Village? Briefly, this modelling flow is illustrated in Figure 16.

V. RESULT AND DISCUSSION

Hydrological analysis using Snyder's HSS yielded a flooded hydrograph, as shown in Figure 17. From this graph, by multiplying the 24-hour duration of ABM distributed rain during the 24-hour recurrence, as shown in the example of P25 years in Figure 18, a peak discharge will be formed, considered a flood discharge in the Kendal River—the results of a design flood discharge calculation yield data that are presented in Table 3.

Hydraulics analysis is in the form of 2D flow modelling using the HEC-RAS application. The first thing to do is to process DEM data into terrain on the RAS Mapper menu—data geometry with grooves, cha, tunnel cross-sections, and watershed boundaries. Then, input the discharge to indicate the flood you want to simulate. The flow simulation results are presented in Figures 19 to 21.

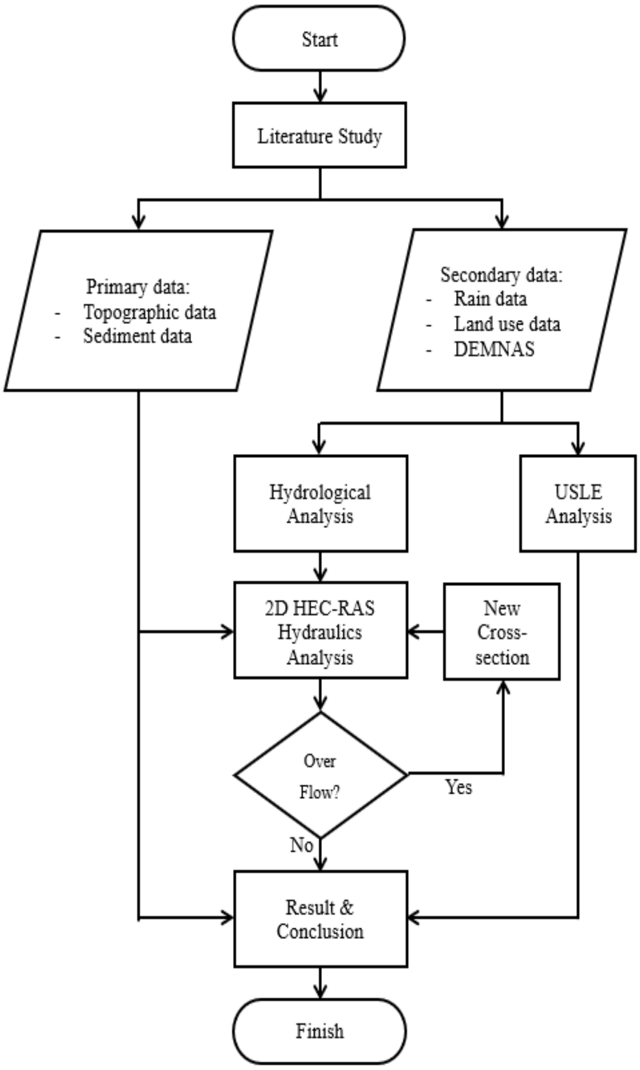

Fig. 16: Flowchart

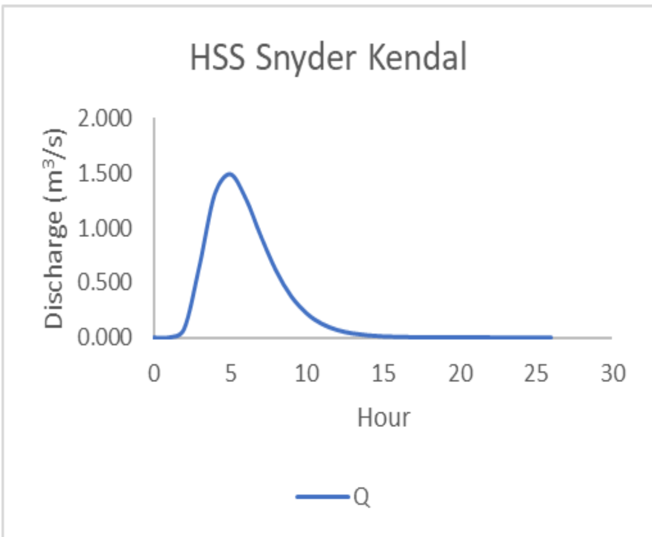

Fig. 17: Flood Hydrograph

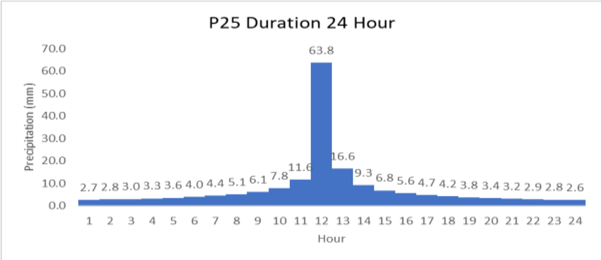

Fig. 18: Precipitation ABM Distribution

Table III: Annual Flood Discharge Planning

WS	Q2	Q5	Q10	Q25
Kendal	45.1	62.8	74.7	91.3

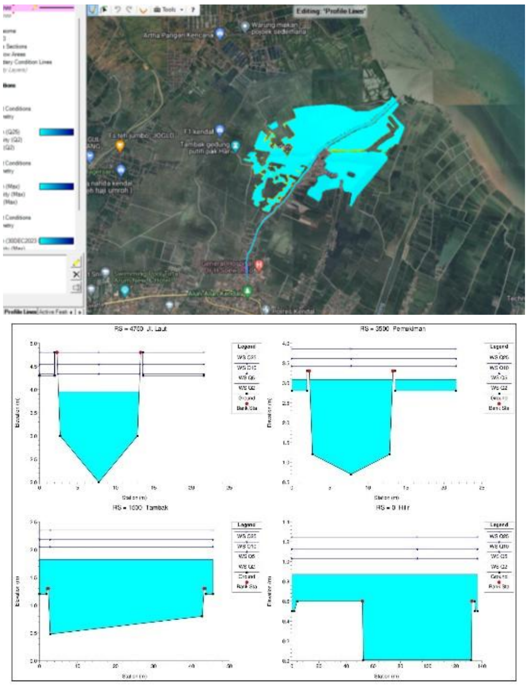

Fig. 19: Modelling of Existing Conditions

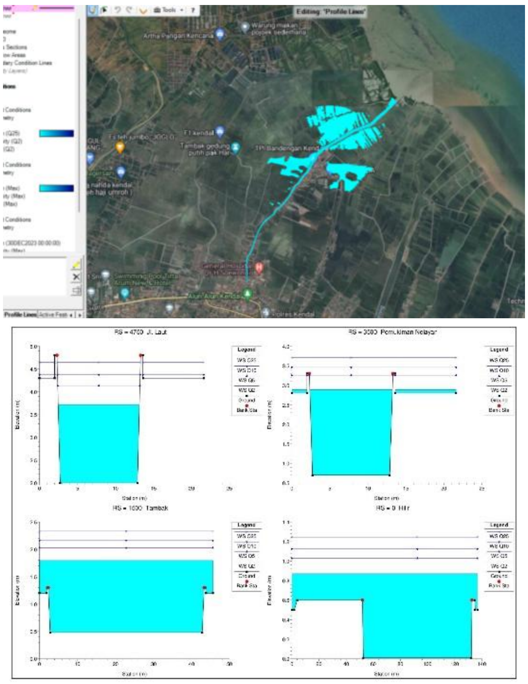

Fig. 20: Modelling of Conditions Without Sediment

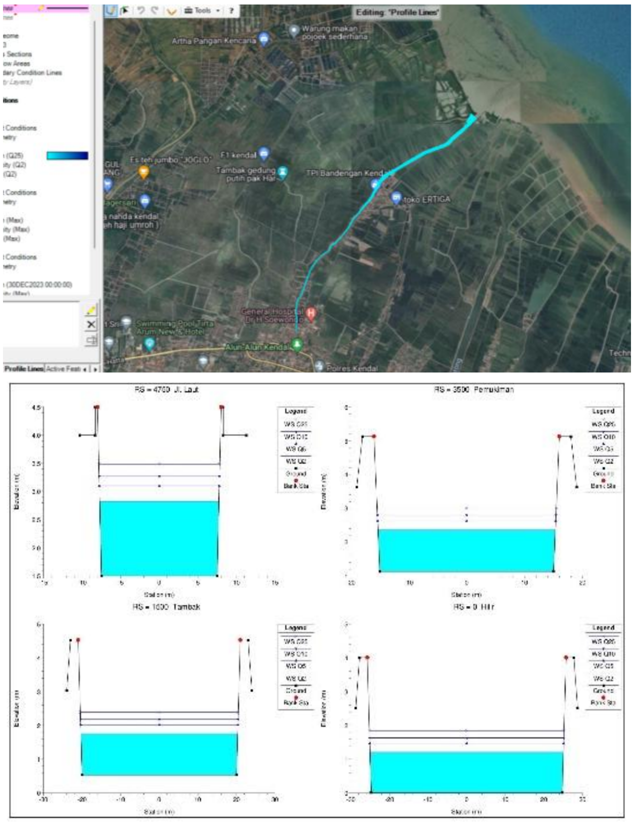

Fig. 21: Modelling of River Cross-Sectional Widening Conditions

From the simulation results with the cross-section of the existing river, it can be seen in Figure 19 that there is still flood overflow in each design flood discharge. The results of the second simulation with sediment dredging in the river channel, as shown in Figure 20, show a decrease in the height of the flood overflow. Figure 21 presents a simulation experiment in which the cross-section of the river is widened or expanded. The results show that the new cross-section can accommodate flood discharge designed for all potential flood events.

Based on the results of erosion calculations using the USLE method, it is evident that Kendall watershed farmers have a low risk of erosion hazard, as shown in Table 4. When viewed from reality, sedimentation may result from accumulated years of erosion and sediment that has never been handled. In addition, the test results of sediment and soil samples show that the average river channel soil type is, on average, 60% clay.

When viewed from the soil type in the region, the closest to the similarity of soil types is on the right and left of the upstream area of the Kendal watershed. The upstream condition of the Kendal watershed is a rice field with technical irrigation, which has a high probability of sediment transportation, so the sediment transportation is deposited partly in rice fields and partly into the Kendal River channel. The construction of buildings such as groundsills or sediment retainers in the upper reaches of the Kendal River is expected to reduce sediment supply from the Upper Kendal Watershed Area, which is the leading supplier of sediment transportation into the Kendal River channel.

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Table IV: USLE Analysis Result

No.	Watershed	Area (km^2)	Factor				Annual Soil Erosion (T/Ha/Y)	Erosion Hazard Class	Erosion Hazard Level	Erosi (T/Y)	Sediment Delivery Ratio	Sediment Yield (T/Y)
			R	K	LS	CP						
1	Kendal	26.02	134.27	0.47	1.40	0.41	36.72	II	Low	343.36	0.43	16.21

VI. CONCLUSION

From the modelling results, it can be concluded that sedimentation in the Kendal River channel, especially in the Bandengan Village Area, is one of the causes of Flooding; the cross-sectional capacity of the Kendal River still needs to be enlarged. For sedimentation control, groundsills or sediment retainers can be built, especially in the upper Kendal River channel, because the Upper Kendal Watershed Area is the leading supplier of sediment transportation that enters the Kendal River channel.

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Ethical Approval and Consent to Participate	No, the article does not require ethical approval or consent to participate, as it presents evidence.
Availability of Data and Material/ Data Access Statement	Not relevant.
Authors Contributions	All authors have equal contributions to this article.

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AUTHORS PROFILE

Ahmad Hakim Bintang Kuncoro is a lecturer in the Department of Civil Engineering, Faculty of Engineering, Universitas Semarang, Semarang, Indonesia. Graduate of Master of Engineering (M. Eng.) from the Department of Civil and Environmental Engineering with a focus on Hydro Civil Engineering at Universitas Gadjah Mada (UGM), Indonesia. Bachelor of Engineering (S.T.) degree obtained from Universitas Muhammadiyah Yogyakarta (UMY), Indonesia. Research focuses on hydrology and water resource development, with a particular emphasis on sedimentation. The impact of sedimentation, especially in river channels on the coast, that results in estuary flooding, is a theme that warrants study. The influence of tides and sediment transport along the coast is an interesting area for study. The movement of sediment along the coast affects two conditions: abrasion and deposition at the river mouth. The leading cause of sedimentation in the flood channels of the eastern city of Semarang is the subject of ongoing research. Currently, several studies related to sediment are still being carried out in the upstream area. In the future, we will look at sediment formation from

upstream to downstream in a river channel.

Talitha Zhafira is a lecturer in the Department of Civil Engineering, Faculty of Engineering, Universitas Semarang, Semarang, Indonesia. He graduated with a Master of Engineering (M. Eng.) from the Department of Civil and Environmental Engineering, specialising in structural civil engineering at Universitas Gadjah Mada (UGM), Indonesia. The Bachelor of Engineering (S.T.) degree is obtained from Universitas Muhammadiyah Yogyakarta (UMY), Indonesia. The research focuses on earthquake-resistant building structures and safety screening for buildings against earthquakes and disasters. The influence of a building's shape and the risk of damage it poses to the surrounding area in the event of an earthquake is an interesting topic to study. The impact of an earthquake on a building itself and the risk of the building failing, which can result in other buildings being affected, needs to be researched so that building planning in an area can be synergistic. Coverage of the distance and extent of damage to buildings that fail is essential so that new buildings do not cause problems in an area. Disasters that affect buildings should be researched in the future.

Hendra Masvika is a lecturer in the Department of Civil Engineering, Faculty of Engineering, Universitas Semarang, Semarang, Indonesia. Obtained a Bachelor's degree in Civil Engineering from the Universitas Semarang, Indonesia, and an M. Eng. degree in Civil Engineering from Universitas Gadjah Mada, Yogyakarta, Indonesia. His research focuses on geotechnical engineering and soil mechanics. The research he has carried out and is currently working on includes consolidation, slope stability and soil-bearing capacity. His future research plans include further exploration of soft soil behaviour, soil stabilisation, foundations, and reducing natural disaster risk. The condition of land subsidence in the north of Semarang, a coastal area with soft soil, is an exciting theme for future research. Soft alluvial soil, resulting from sediment deposition, requires investigation into its stability and development risks in areas with similar soil conditions.

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