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A combined hydrological and hydraulic model for flood prediction in Buah river subsystem area, Palembang city

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Abstract

Flood and inundation are problems that vastly impact all sectors and cause huge losses. This study aimed to determine the characteristics of drainage channels, hydrology, and hydraulic flow in the Buah river subsystem to design flood control through various scenarios of discharge analysis for a 10-year return period. This study was carried out to investigate the drainage channel plan's effectiveness to reduce peak flood discharge and occurrence. By using the hydrologic engineering center's – river analysis system (HEC-RAS) and hydrologic engineering center – hydrologic modeling system (HEC-HMS) software, hydrological and hydraulic analysis was performed to examine the drainage channel's capacity in the Buah river. The hydrological and hydraulic methods employed Muskingum-Change and Saint-Venant formula, respectively. The 2008 to 2017 rain data used were obtained from Meteorology Climatology and Geophysics Council (BMKG) of Palembang City. The log-Pearson III method was used to determine design rainfall with return periods of 2, 5, 10, 25, 50, and 100 years. Rainfall intensity was analyzed using the Mononobe method for five-year return period to hyetograph. Also, rainfall intensity was analyzed using the intensity-duration-frequency (IDF) curve to determine the number of years required for the full release of the channel to pass. Based on the results, the highest intensity was detected in a 2-to-100-year return period, where the 5-minute rainfall duration had a value of 200–350 mm/hour. Meanwhile, for 2 hours duration, the highest value recorded was 25-50 mm/hour. The maximum rainfall distribution for 5 minutes of rain was 10 mm, while 120 minutes covered 3 mm. The highest elevation of the Buah river subsystem was in the 100-year return period with a height of 10.3 m, but the lowest occurred in the 2-year return period with a water level of 9.89 m.

Keywords

Hydrology, Hydraulics, Rain intensity, Maximum discharge.

1.Introduction

Various observations have discovered flood and inundation as problems that vastly impact all sectors and cause huge losses [1]. These occurrences are often initiated by changes in the level of water bodies. For example, the Buah river subsystem, one of the 21 river subsystems that form the river flow pattern in Palembang city [2] has low topography of 1.5 m – 15.75 m mean sea level (MSL). It also contains several subsystems ranging from 2 m – 4.24 m MSL. Therefore, areas with a height of less than 4 m MSL always have puddles once there is high tide due to the influence of Musi river tides. The land surface is easily flooded even though there is no rain because of the low condition. The river subsystem's poor drainage is estimated to be the main cause of flooding and inundation problems occurring in the area.

The Buah river subsystem has several flood control facilities which include Kenten valley, public high school 5, Simpang Patal, state electricity company (SEC), and Telecommunication (Telkom) retention ponds. However, the effectiveness of the existing retention pond and drainage system is still unable to reduce the inundation discharge that often occurs. The drainage channels are not functioning optimally because the majority have not been connected.

Based on the described situation, the Buah river subsystem flooding and inundation problem need to be analyzed. This must be considered as a unit in

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changing land use, drainage channel's ability, soil precipitation condition, rainfall intensity, and the ability to drain water. By analyzing the factors affecting the existing drainage system's quality in a hydrological and hydraulic system, proper quality management is expected to be carried out.

This study aims to carry out hydrological and hydraulic analysis of the Buah river subsystem to identify the flow rate magnitude and the existing drainage system's ability to drain water and provide solutions for handling flooding and inundation in the surrounding area.

For the prediction of flooding tendency in the Buah river subsystem, using a combination of hydrologic engineering center's – river analysis system (HEC-RAS) and hydrologic engineering center – hydrologic modeling system (HEC-HMS) software, hydrological and hydraulic analysis was carried out to examine the drainage channel's capacity.

This paper is compiled using systematic writing starting with the background at section one, which presents the problems of flooding that occurred in the study area by discussing the facts of the physical condition of the site and the analysis technique that will be carried out using spatial analysis with hydraulics and hydraulics modeling. In section two, various literature reviews from previous researchers are presented with solving flood and inundation problems with different methods and methods. The methodology, presented in section three, covers the research area's geographical location and physical condition and the parameters and equations used in the analysis. The results and discussion are presented in section four and five, including morphological analysis of the river sub-system area, the study of hydrology, and river hydraulics using 1D and 2D modeling. Finally, conclusions and suggestions for further research are recommended at point five.

2.Literature review

Most studies stated that flooding and inundation are overcome by drainage construction. However, other means are by elevating every building or forming a community to always clean the gutters around residential areas [3]. Using a combined topography-based hydrological model (Dynamic TOP Model) and HEC-RAS modelling [4], surface drainage modeling was conducted in the upper Calder Valley area and Todmorden city at the bottom, to test the response to changes in inundation from runoff water. The flowing process of melted ice into the Yellow river was determined using the Muskingum hydrological model [5] which was modified with a flow hydrograph. The results showed that the simulated hydrograph using the developed model was in accordance with the field measurement results.

However, Lisenbee et al. [6] identified the HYDRUS and GIFMod as the only models that used the Richard's equation to determine infiltration under varying saturation conditions. This study identified a limited drainage configuration, and several modelling presumes vegetation considerations as unnecessary. Hence, many models have been designed and combined to obtain the desired results.

Meanwhile, Abdessamed and Abderrazak [7] (2019) determined the inundation area of Ain Sefra in the Ain Sefra watershed, which is prone to flooding using the HEC-HMS and HEC-RAS rainfall-runoff modeling. By paying attention to the effect of the concrete retaining wall that has been built by the local government or without a retaining wall. Three simulations were performed using return periods of 10, 100, and 1000 years. The hydraulic modeling results show that the presence of retaining walls has reduced the flood area. However, the simulation results also show that the city center is the most affected by flooding.

Using the HEC-HMS modeling, Shakarneh et al. [8] conducted a rainfall-runoff simulation in two sub-watersheds in southern Palestine (Daraja and Al-Ghar). Data on soil properties, land cover, river network, land slope, rainfall, and physical characteristics of the watershed are used as data sources in the analysis. Model calibration was carried out for 20 times of rain runoff in both watersheds. By calibrating the HEC-HMS results, the study results obtained can produce current forecasts that are with climate forecasting results.

The results can be helpful for flood forecasting. To develop low-impact flood management (LID) in small sub-watersheds in urban areas, Tansar et al. [9] conducted a spatial analysis to understand flood dynamics in urban areas by analyzing some small watersheds in China as a study area and divided into three parts, upstream, middle, and downstream. This research aims to show how spatial analysis is carried out to show the effectiveness of urban drainage system (UDS) performance by handling the LID method. The combination of four solutions using the LID method was carried out in the study area, with six and five different rainfall scenarios. The results show that the use of bioretention cells ranks; first, green plants and green canopies are second, and the use of water-permeable pavements ranks last. By placing LID facilities close to locations that frequently flood, obtain optimal benefits in dealing with flooding and reduce the possibility of transferring hydraulic loads to other parts of the UDS.

By integrating the artificial neural network (ANN) model as a hydrological model and HEC-RAS as a hydraulic model, Tamiru et al. [10] (2021) mapped flood inundation in Ethiopia's Baro watershed. Rainfall and daily discharge data for seven years (1999-2005) were used to create a hydrological model on a grid map (30 x 30) m topographical wetness index (TWI). A predictive hydrological model with ANN, integrated with HEC-RAS, to generate flood events along the river has been validated with Nash–Sutcliffe efficiency (NSE). The results of the HEC-RAS modeling were then calibrated using Landsat 8 imagery by classification the flood area using the normalize difference water index (NDWI) interpretation method. The results obtained from the inundation modeling using HEC-RAS correspond to 96% of the interpretation results on the Landsat imagery of floods in 2005 and 2008. On this basis, Tamiru concludes that the integration of HEC-RAS and ANN modeling has increased spatiotemporal certainty in inundation forecasting flood.

Armmain et al. [11] (2021) used HEC-RAS 1D hydraulic modeling of river flow in the Kelantan watershed, Malaysia. The aim is to find out the peak of the flood, based on the historic flood. Therefore, modeling, simulations using HEC-RAS were carried out to determine the peak discharge level for each kilometer of river length. The test results show a significance level of R2 of 0.95 to 1, indicating the precision level in using HEC-RAS for the simulation of precision flood events.

Using the Kaleshwaram watershed, Telangana, India, as the study area, Venkatcharyulu and Viswanadh [12] (2021) integrated geographic information system (GIS) and hydrological models using HEC-RAS. Watershed morphometry data were analyzed using GIS techniques. HEC-RAS software is used to simulate rain flow in the catchment area when runoff occurs by utilizing GIS techniques to predict the amount of runoff. Based on the simulation, when rain and runoff occur, the volume simulation can identify river flows based on topography, depth of flow velocity, and flow volume.

Andriani et al. [13] (2022) also uses rainfall and runoff modeling to model the reduction in the magnitude of erosion in the Kuranji sub-watershed, Padang, Indonesia. The modeling is carried out by utilizing the multi-criteria spatial analysis (MCSA) technique in regulating land use patterns in the watershed area, taking into account the dominant land use in steep slope areas to reduce the amount of erosion restrain more surface runoff into the soil. The simulation results carried out by changing the mixed garden on land with a steep slope of 4.5% have reduced the amount of surface erosion by 70-80%. Modified Cunge-Muskingum is used for flood tracking by considering the lateral flow of the river. The model was combined with the soil conservation service curve number (SCN-CN) model to obtain the unmeasured basin area's inflow and lateral flow hydrographs.

Given the complex nature of non-prismatic channels. Research conducted by Bharali and Misra [14] 2021, in the Kulsi river valley, India. Model performance was tested by root mean square error (RMSE), with a peak flow of 50.34 m3/s, peak flow error (39.73%), peak flow time error (–3.44%), total volume error (7.36%), relative error (7.36%), mean absolute error (33.5%), correlation coefficient (0.785), coefficient of efficiency (0.59) and Kling-Gupta efficiency (0.66).

Considering the previous research, solution to the flooding and inundation problem must be viewed in an integrated manner according to several parameters and conditions of the surrounding sub-watershed areas. This requires a combination of various analytical models capable of determining the problems occurring in a sub-watershed. An analysis of the solution to the Buah river inundation is performed using several settlement scenarios. This includes Scenario 1: revitalizing the existing retention ponds and building new retention ponds in the upstream and downstream areas of the Buah river by improving the surrounding drainage outlets and inlets. Scenario 2: Creating a new drainage channel/new channel and functioning it as long storage. Scenario 3: Elevating the walls of the drainage canal in some areas of the basin. Lastly, Scenario 4: Adjusting the elevation of the drainage channel at several points to accelerate the flow of water in the Buah river. All the scenarios are modeled with a combination of hydrological and hydraulic modeling.

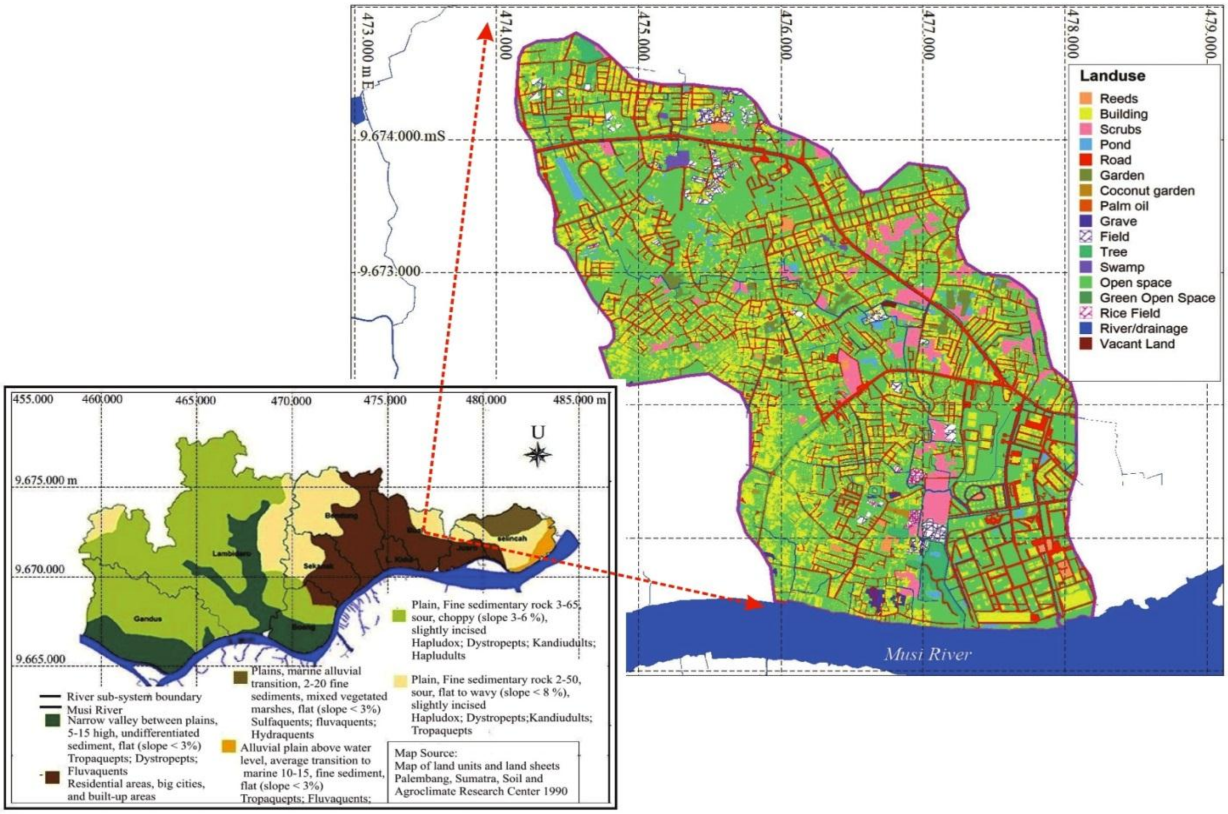
3.Methodology

3.1Research location

The Buah river subsystem is part of the 21 subsystem in Palembang city. Geographically, it is located at 104^o 46' 00" - 104^o 48' 15" east longitude and between - 2^o 56' 31" - 2^o 58' 57" south latitude, while the area is 10,277 Km2. The Buah river empties into the Musi River, which passes through Palembang and divides the city area into two, namely Seberang Ulu and Seberang Ilir. Once the Musi river tide restrains the Buah river flow from upstream, a water pool ends up forming in the surrounding low areas. This condition causes the inability of several river subsystems in the Buah river subsystem to drain rainwater run-off into the Musi River, leading to flooding and inundation in many places.

In understanding the Buah river subsystem conditions, there is a need for hydrological and hydraulic analysis. The result can be applied in determining the areas with inundation tendency, to identify the causes and create solutions or prevention plans subsequently. A combination of primary and secondary data was used in conducting the analysis. The secondary was obtained from spot height, geological maps, satellite imagery of land use, study areas, and rainfall data from Meteorology and Geophysics Agency of Palembang City (BMKG). Meanwhile, the primary was from the river and retention pool cross-section measurement, as well as the tidal data collected directly in the field. In addition, the information included data on hydrology and river hydraulics.

Figure 1 show is a map of soil and rock types within the boundaries of the river subsystem division across the lower area of Palembang City (left figure). Most of the Buah river subsystem (about 70%) is alluvial soil types that have been used as piles of river overflow material, and only 30% are rock plain sediment smooth 2-50 acid, flat to choppy with a slope of < 8%. The land use map (right figure) was obtained from the Palembang city base map scale 1: 1000 (2014) and updated using the interpretation of land use from the satellite pour l'observation de la terre (Satellite for Earth Observation) (SPOT) satellite imagery scale 1: 5000 (2017).



Map Source:
Map of land units and land sheets Palembang, Sumatra, Soil and Agroclimate Research Center 1990

Figure 1 Rock structure, soil, boundaries, and land use of Buah river subsystem

3.2Research methods

The flood tracking model in this study used a hydrological and hydraulic analysis. The Muskingum-change formula was employed in the hydrological method [15] by using the HEC-HMS software [16]. Furthermore, the Saint-Venant formula [17] was applied in the hydraulic process for unsteady flow. Generally, the model used the service of HEC-RAS 5.1.0 software. *Figure 2* describes the stages of carrying out the research. Before carrying out a flood control simulation using both existing and planned conditions based on the designed scenarios, an analysis of the physical state of the Buah river subsystem is first carried out. The investigation was carried out using the Strahler method of spot height data modeled with digital elevation model (DEM)) to obtain the hydraulic parameters [18]. The flow coefficient was obtained from the analysis of land use data and soil types of the Buah river subsystem. Rainfall data were analyzed using the intensity-duration-frequency (IDF) method. The parameters considered include the length of the main channel/drainage, land slope, catchment area, lag time, and time of concentration.

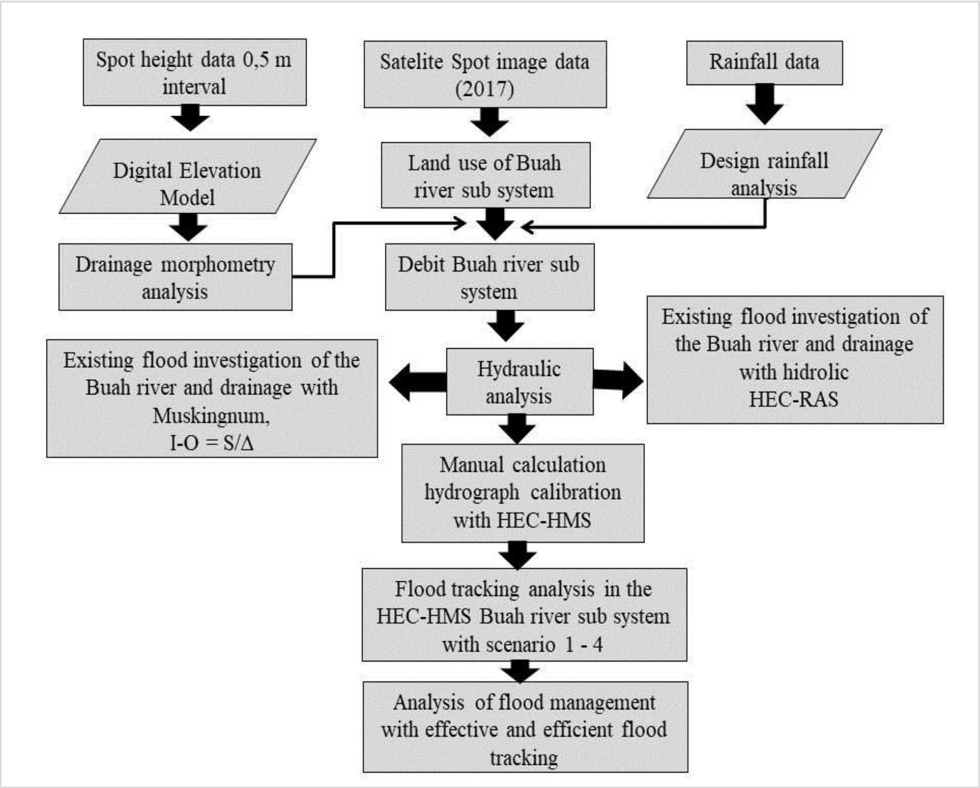


Figure 2 Research flowchart

Concentration-time (Tc) is the time required by the falling rainwater to flow from the farthest point (upstream) to the outlet of the watershed (downstream). Concentration time is influenced by the river length (L) and river slope (S).

The Kirpich equation with modifications [19] was used to calculate the concentration-time as Equation 1.

$$Tc = 14{,}6\ LA^{-0{,}1}S^{-2} \qquad (1)$$

where:
Tc = Concentration time (minute)
L = River length (Km)
A = Area of sub system
S = the river slope (deg)

The relationship between intensity, duration, and frequency of rain, was expressed by the IDF curve. To form the IDF curve, maximum rainfall data with a short duration e.g. 5, 10, and 20 minutes, etc., were needed. Therefore, one way to analyze flood tracking is to use the Muskingum method, where the principle is the continuity of incoming and outgoing discharges [15]. Equations 2 and 3 are flood tracking methods using the Muskingum method with the principle of continuity of incoming and outgoing discharges (Equation 2).

$$I - O = S/t \qquad (2)$$

Which becomes (Equation 3):

$$(I_1+I_2)/2 + (O_1+O_2)/2 = (S_2-S)/\Delta t \qquad (3)$$

Where:
I = inflow (m^3/s)
O = outflow (m^3/s)
S = capacity (m^3)
t = Time (second)

The maximum retention potential value (S) and the initial abstraction (Ia) were calculated using the following Equations 4 and 5:

$$S = \frac{25400}{CN} - 254 \qquad (4)$$

$$Ia = 0.2 \; x \; S \qquad (5)$$

Where:
S= capacity (m3)
CN= Curve Number
Ia= Initial loss

3.2.1Calculation of effective rain using soil conservation service-curve number (SCS-CN) method

To calculate the effective rain loss used the SCS-CN method [14], from the rainfall Hyetograph of the 25 year return period. Cumulative rain loss was calculated using the following Equation 6:

$$\mathrm{Fa}.0.167 = \frac{\mathrm{S(Pt-Ia)}}{\mathrm{Pt-Ia+S}} \qquad (6)$$

Where,
Fa= Cumulative rain loss
S= Capacity potential
Pt= Excess cumulative rainfall at time t
Ia= Initial loss

While the equation was also used to calculate the effective rain use Equation 7:

$$\mathrm{Pe}(0.167) = \mathrm{P_t} - \mathrm{I_a} - \mathrm{F_a}.0.167 \qquad (7)$$

Where,
Pe= Effective precipitation
Pt= Excess cumulative rainfall at time t
Ia= Initial loss
Fa= Cumulative rain loss

4.Results

4.1Analysis of the Buah river subsystem morphometric parameters

The drainage flow pattern was analyzed using the DEM technique by using the spot height data for the study area at a scale of 1: 1000. The distribution of the site's height ranges from -0,04 to 19,47 m above msl. In addition, the Buah river subsystem has a gentle relief, with a slope of 0-3%, and the hillside is only about 2% of the subsystem area, which is in the upper part of the Buah river. Based on the data, it can be said that the river's condition of flow gravity, infiltration, and high run-off is deficient.

The Buah river subsystem has river orders 1-2, while the drainage network was analyzed using geoprocessing model [20] with modeling builder and kriging (*Table1*). Based on geological conditions and types of residential soil in the Palembang big cities area, the number of streams order (Nu+1) in the subsystem is 1.2, normally ranges from 3.0 to 5.0. It is estimated that the drainage pattern is abnormal, a flat area with a flowing drainage system and a high curve number (CN) value. Circularity ratio (Rc) Buah river subsystem = 0,4, which indicates strongly elongated and highly permeable homogenous geologic materials.

Rainwater that falls and collects is less elongated in shape, moderate discharge of run-off and permeability of the subsoil condition as a result, the hydrograph of flow increases and decreases slowly. The frequency density (FS) is the ratio of the rivers' number of the subsystem area. From the analysis results, the Buah river subsystem has a Fs value of 1,1. It is classified according to the nature and quantity of precipitation, the composition of rocks, and the penetrability of the soil in the area to determine the indices of different stages of landscape growth. In general, lower stream Fs helps as a tool in finding the erosional process operating over an area.

The drainage density (Dd) of the Buah river subsystem ranges from 0.46 to 1.42 km/km2. Dd Value is the ratio total length of streams to the basin area [20]. The Dd value also indicates the stream development and its spacing. In the Buah river subsystem, the Dd value is less than 1 km/km2. Hence, indicating that the drainage conditions in the Buah river subsystem are imperfect and constantly inundated.

Table 1 Morphometric parameters of the Buah river sub-system

Parameter of Linear	**River orders**					
	n1	**n2**	**n3**	**n4**		
	6	5	NA	NA		
	Length (L)					
	Number of river orders	Total river orders (Km)	Length of the river (Km)	Rb		average Rb
	11	6.7	5.4	1.2		1.2
Parameter of Area	Area	around	Dd	Fs	Dt	NA
	(km^2)	(km)	(km/km^2)	(km^{-1})		NA
	9.9	17.8	0.7	1.1	0.3	NA
Parameter of relief	H	Rn	Tc	C	Rc	NA
	(m)		(minute)			NA
	19.75	19.1	15.3	0.69	0.4	NA

Description: n1-4 = River orders; Nu = Total number of river orders; Rb = Bifurcation Ratio; Dd = Drainage density; Fs = Stream Frequency; Dt = Texture Ratio; H = Total Basin Relief; Rn = Rugedness number; Tc = Time concentration; C = Infiltration coefficient; Rc = Shape of sub catchment

4.2Rescaled distance cluster combine

The correlation between Dd, H, Rn, C, and Q in the study area can be seen in *Table 2*. However, the correlation obtained from the H and Dd values' multiplication has a less strong correlation between variables with values of 0,542 respectively. *Table 2* also shows the roughness level does not strongly correlate with the runoff coefficient or by discharge (Q) with a solid correlation value of 0,319 (significant level 0.001).

The correlation between the *Fs* variables and the vegetation/unbuilt area is -0.206, and the relief is 0.427, the Dd value is 0.554, the texture ratio is 0.806, and the roughness value is Rn = 0.532. Therefore, the correlation of *Fs* with vegetation has a negative value, meaning it has an inverse relationship.

Texture comparison (Dt) correlates the order of one river system and the subsystem's circumference. In terms of Buah river, the Dt value depends by rock, soil, climate, relief, channel head, valley density, source area and the landscape evolution [18].

Furthermore, the relief ranges from 14.5–25.75 m and the surface layer's soil infiltration belong to the standard–low–deficient class with the average watertight value at the location is 15.75 (low).

Geological conditions based on soil type produced from weathering of rocks found in the Buah subsystem, which tends to be clayey and flood plain sediment. Moreover, low infiltration C catchment 84,2554 indicates a possibility of higher surface run-off values.

Drainage texture depends on the underlying lithology, infiltration capacity and relief aspect of the terrain [20]. Therefore, the runoff coefficient value is represented based on conditional and geological data as well as infiltration capacity, which are closely related. In contrast, the relief is indicated by the difference in height (H).

Table 2 Correlation between Dd, H, Rn, C, and Q

		Dd	**H**	**Rn**	**C**	**Q**
Dd	Pearson Correlation	1	0.542	0.905^{**}	0.437	0.934^{**}
	Sig. (2-tailed)		0.132	0.001	0.239	0.000
	N	9	9	9	9	9
H	Pearson Correlation	0.542	1	0.836^{**}	0.259	0.560
	Sig. (2-tailed)	0.132		0.05	0.501	0.117
	N	9	9	9	9	9
Rn	Pearson Correlation	0.905^{**}	0.836^{**}	1	0.358	0.908^{**}
	Sig. (2-tailed)	0.001	0.005		0.344	0.001
	N	9	9	9	9	9
C	Pearson Correlation	0.437	0.259	0.358	1	0.319
	Sig. (2-tailed)	0.239	0.501	0.344		0.403

		Dd	H	Rn	C	Q
	N	9	9	9	9	9
Q	Pearson Correlation	0.934**	0.560	0.908**	0.319	1
	Sig. (2-tailed)	0.000	0.117	0.001	0.403	
	N	9	9	9	9	9

**. Correlation is significant at the 0.01 level (2-tailed).

Based on the results of the combined cluster analysis conducted on the Buah subsystem Dt, H, and C variables using the average linkage, the trend in the study site indicates that the Dt value is strongly influenced by relative spacing of streams. Meanwhile, the rock or soil type and the infiltration value not indicate that higher surface run-off and lower in- filtration rate [18].

4.3Land use

Based on the interpretation of 2014 aerial photographs and 2017 satellite pour l'observation de la terre-7 (SPOT-7) imagery, at scale 1: 5000, 68.02% is still non-urban land use, with the largest utilization 58.1096%, green open space and gardens at 7.67% (*Table 3*).

Table 3 Distribution of the percentage of land use and the calculation of the CN value, as well as the percentage of watertight of the Buah river subsystem

Land Use	Area (km^2)	CN	A x CN	% Imp	% Wt Area
Garden	0,1010	88	8,8910	5	0,0688
Grave	0,0069	84	0,5828	5	0,0047
Reservoir/ Lake	0,0069	72	0,4995	2	0,0019
rice field	0,0267	88	2,3485	2	0,0073
Open space	4,2632	80	341,0589	2	1,1604
Build area	1,4978	95	142,2934	85	17,3267
Street	0,8528	90	76,7564	100	11,6067
Weeds	0,0499	78	3,8899	2	0,0136
Field	0,0689	88	6,0590	2	0,0187
Scrub	0,3849	77	29,6398	5	0,1048
tree plant	0,0778	79	6,1444	5	0,0529
Vacant land	0,0030	79	0,2390	2	0,0008
Swamps	0,0080	88	0,7003	2	0,0022
Total	7,9410	100	619,1029		30,3694

Wt = watertight

Based on *Table 3*, the average CN and the percentage of watertight area Buah river subsystem can be calculated as under (Equation 8):

$$C_{Catchment} = \frac{\sum_{i=1}^{n} C_i A_i}{\sum_{i=1}^{n} A_1} \quad (8)$$

$$= \frac{619{,}1029}{7{,}3479} = 84{,}2554$$

Based on the map of land units and soil sheets in Palembang, South Sumatra, the geological condition of the Buah river subsystem is swamp sediment, with materials consisting of mud, silt, and sand.

4.4Time concentration (*Tc*)

The value of Tc can be estimated using hydrometric data. The parameters used in calculating Tc (Equation 9), are:

Main channel length (L) in km = 6,129 km
= 20452,756 ft

Retensi potensial maksimum (S) = 34,636 mm
= 1,389 inch

Average slope (Y)= 2,033%

Catchment Area (A)= 7,9410 km2

$$T_c = \frac{L^{0,8} \times (S+1)^{0,7}}{1140 \,.\, Y^{0,5}} \quad (9)$$

$$= \frac{6{,}129^{0,8} \times (1{,}389+1)^{0,7}}{1140 \,.\, 2{,}033^{0,5}}$$

$$= 3{,}180 \text{ hours}$$

The value of Tc in the Buah river subsystem is 3,180 hours. This describes all its morphometric parameters correlate with the drainage network to determine the effect on inundation in the main channel as a whole.

4.5Rain intensity

Four methods of calculating rain distribution, namely normal, Gumbel, Standard log, and log-Pearson type III, were used to analyze the design rainfall. The results showed the log-Person III distribution was appropriate for the design rainfall analysis with

Cs=1.352 and Ck = 5.974. In addition, the calculation of rainfall intensity in the two-year return period for 25 minutes rain duration using the Mononobe method can be seen in the IDF curve (*Figure 3*).

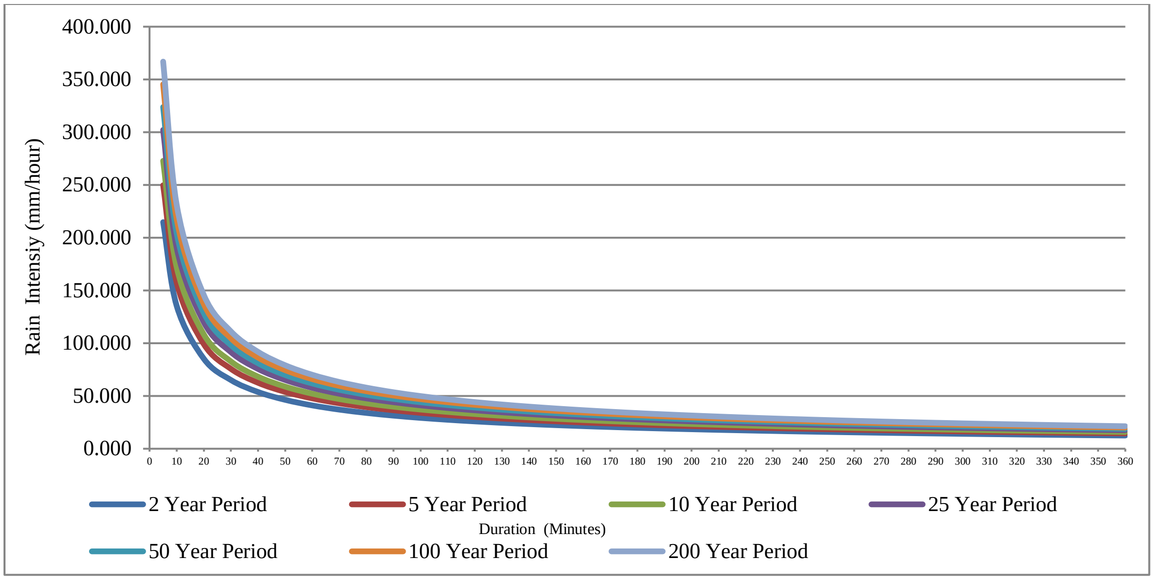


Figure 3 IDF Curve at the Buah river subsystem

4.6Rainfall distribution

Design rainfall distributed in hours or minutes of rain depth (hyetograph) considers the design flood discharge. One method that can be used to distribute daily to hourly rainfall is the Mononobe modified method (*Figure 4*).

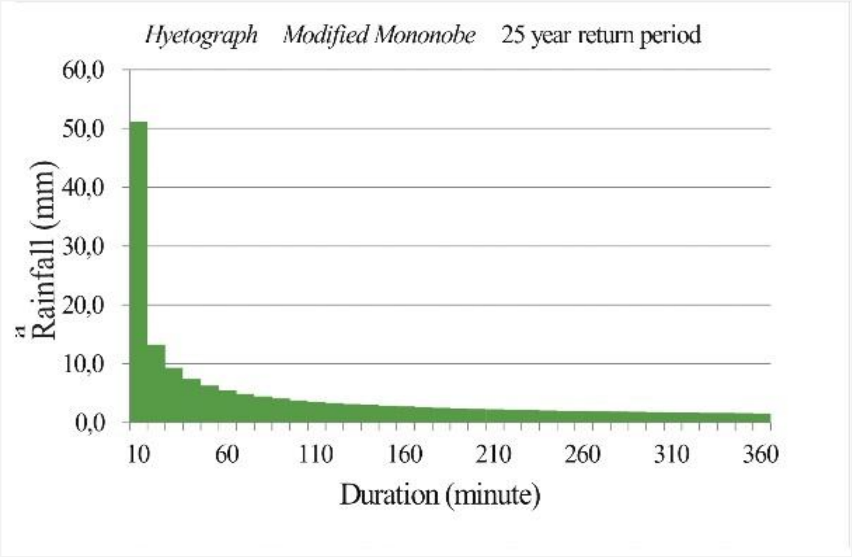


Figure 4 Hyetograph with Mononobe modified 25-year return period

4.7Calculation of effective rain on the Buah river subsystem retention pond

Adequate precipitation was calculated using the SCS-CN method. The CN value was identified based on the type of land used in each subsystem of the Buah River.

Land use types in the study site were buildings, open spaces, ponds, and roads (see *Table 3*). The recapitulation of CN values and S, Ia Values in each retention ponds (*Table 4* and *Table 5*).

Table 4 Recapitulation of CN values for the study site

No.	Retention location	Average CN number	Combined CN number
1.	Simpang Patal retention pond sub system	80.9925	84
2.	SMAN 5 retention pond sub system	93.0911	97
3.	Telkom retention pond subsystem	87.1309	91

Table 5 Recapitulation of S and *Ia* Values in each retention pond

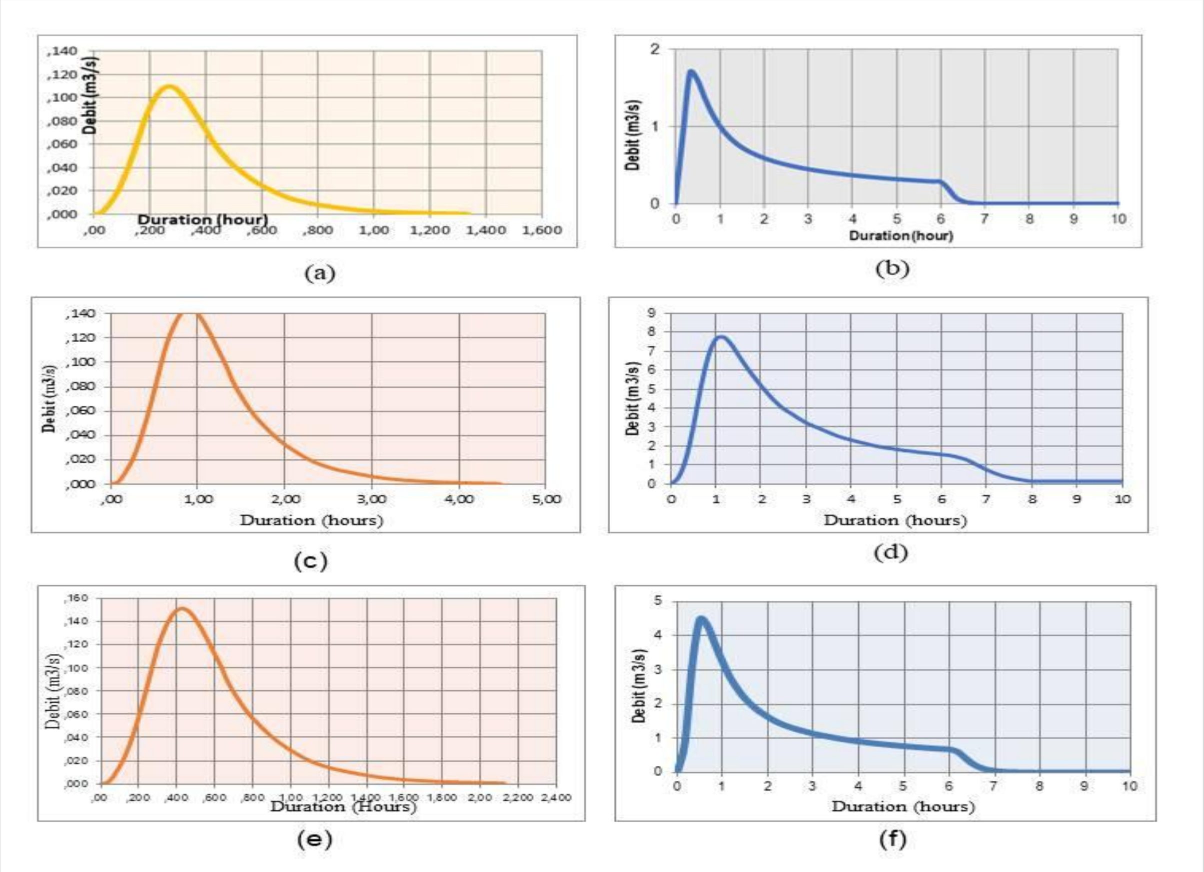
Name of retention pool	S (mm)	I_a (mm)
Simpang Patal	48.3809	9.6762
SMAN 5	7.8556	1.5711
Telkom	25.1208	5.0241

4.8Hydrograph and direct run-off

The unit hydrograph and direct runoff discharge for the study site were analyzed based on the division of 3 boundaries of the river subsystem, which contained three retention ponds: (a) Simpang Patal retention pond; (b) public high school 5 retention ponds; and (c) Telkom retention pond. Separation is carried out to see the ability of the retention pond to accommodate excess water at the time of maximum rainfall.

The direct run-off discharge calculation uses a 25-year return period with 10-minute intervals for 24 hours. The analysis results showed the peak discharge of the three sites were 1.711 m3/s occurring at the 20th minute, 7.749 m3/s occurring in 1 hour 10 minutes, and 4.488 m3/s occurring within 30 minutes, respectively.

The unit hydrograph and direct run-off discharge for the study site are presented in *Figure 5*, namely (a) hydrograph and (b) direct run-off of the Simpang Patal retention pond; (c) hydrograph and (d) direct run-off of the public high school 5 retention pond; and (e) hydrograph and (f) direct run-off of the Telkom retention pond.

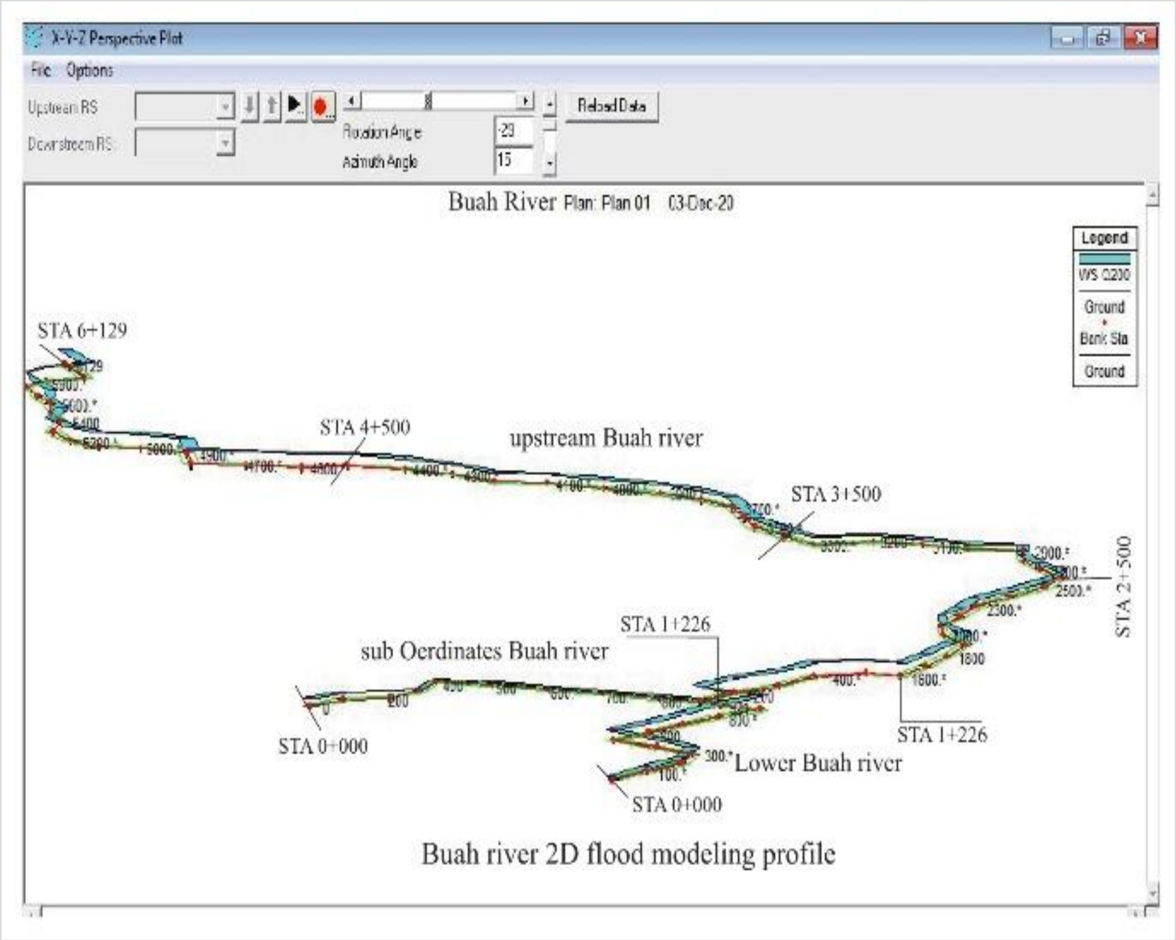


(a) (b) (c) (d) (e) (f)

Figure 5 Hydrograph of SCS synthesis unit and direct run-off of retention ponds: (a) hydrograph and (b) direct run-off of Simpang Patal retention ponds; (c) hydrograph and (d) direct run-off of public high school 5 retention ponds; (e) hydrograph and (f) direct run-off of Telkom retention ponds

4.9Hydraulic modelling

Modeling or imitating the flood face based on the results of the unit hydrograph analysis and direct runoff is carried out to prove several scenarios designed to provide input for flood management in the Buah river subsystem. The Simulation of the floodwater level profile obtained using the HEC-RAS 5.0.7 program is displayed in cross-sectional and longitudinal formats, with return periods of 2.5, 10, 25, 50, and 100 years. The river/channel flow scheme includes the length and direction of the river/channel flow. In the Buah river, the flow is divided into several stations (STA), each having a different cross-sectional shape. For example, the modeling of the Buah river is divided into three parts, namely the upstream Buah river (STA 1 + 500 until 6+229), the lower Buah river (STA 0+000 until 1+500), and the subordinate Buah river (STA 1+226 until 0+000). And in each section, three retention ponds are included in the scheme. *Figure 6* shows the longitudinal profile of the floodwater level simulation for the scenario of a 25-year return period in the Buah river subsystem. Moreover, the river overflow generated from the simulation process was used as a boundary condition to further simulate surface run-off in a 2D flow model.

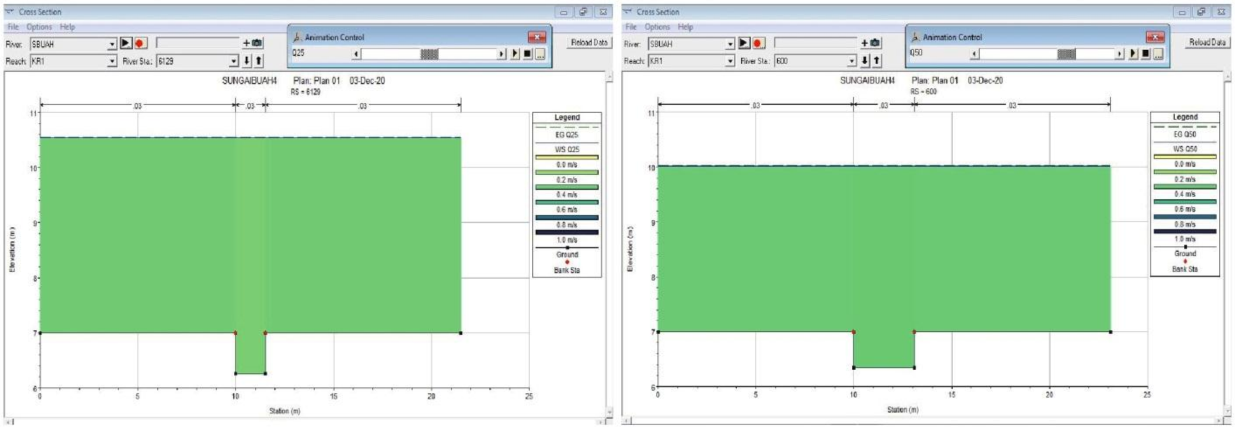


Rotation Angle -23

Azimuth Angle 15

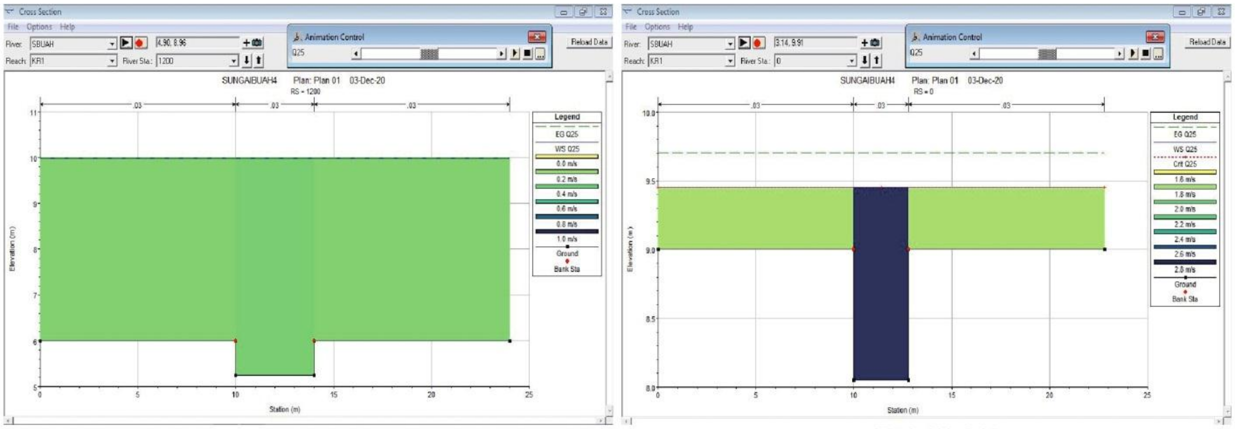
Figure 6 Simulation of the longitudinal and 2D flow model profile of the Buah river subsystem with HEC-RAS

The results of the 2D flood simulation in the subsystem were obtained with the HEC-RAS 5.0.7 program using run-off hydrograph data from the Buah river. The cross-section of the Buah river channels STA 0+000, STA 0+ 600, STA 1+200 and STA 6+229 can be seen in *Figure 7.*



STA 6+129, Q 25

STA 0+600, Q 25



STA 1+200, Q 25

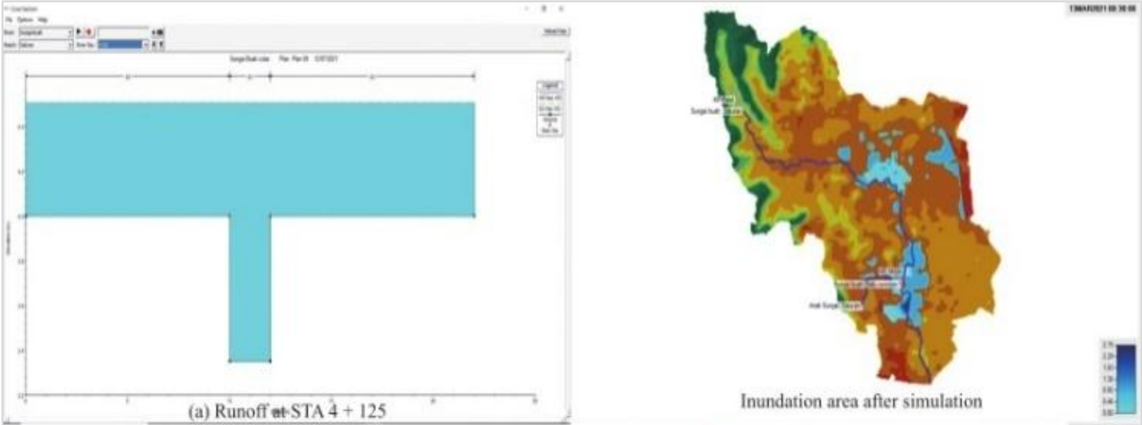
STA 0+000, Q 25

Figure 7 Simulation using HEC-RAS, a cross-section Buah river, STA 0+00, STA 0+600, STA 1 + 200 and STA 6+229 rivers with Q in the 25-year return period

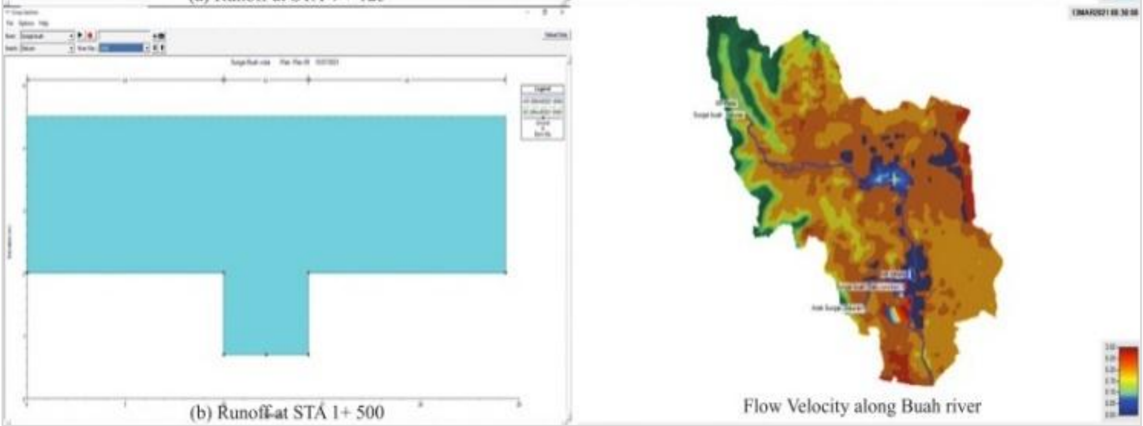
5.Discussion

The Buah river subsystem is an area with all urban and industrial activities, such as residential areas, Industry of PT. Pupuk Sriwijaya, the Business for palembang trade center (PTC), the Education Center for elementary schools, senior high schools to higher education are in the Buah river subsystem. When viewed from the morphometric data of the Buah river subsystem, the Dd value is 0.7 Km/Km2, meaning less than 1 Km/Km2, which indicates that the drainage conditions in the Buah river subsystem are poor and will constantly be inundated. With a FS value of less than 1.1, the fruit river subsystem will be difficult to absorb water. High Fs are associated with material impermeability in the subsurface layer, vegetation cover, high relief conditions, and low infiltration capacity. When viewed from the value of soil texture (T) based on geological and soil data, the T value shows the number 0.3. Illustrates With a T value equal to 0.3, the surface of the Buah river subsystem is influenced by the underlying geological conditions, which is represented by the type of soil which is the result of weathering of rocks, which tends to be clayey and alluvial. Low infiltration of less than 28 mm/hour so that the tendency of higher surface runoff values. Likewise, the effect of the relief of the river subsystem, its rock infiltration capacity, and the ease of the river subsystem. The relief condition in the Buah river sub system is 19.75 m with soil infiltration capacity for the surface layer in standard–low–shallow class with low-class dominance.

Concentration time (Tc) in the Buah river subsystem is 15.3 minutes. The Tc value Illustrates that it takes the longest to drain water from the farthest distance to the outlet. All morphometric parameters in each river subsystem are correlated with the drainage network to determine the effect on inundation in the main channel as a whole. Modeling by substituting the retention pond parameters on the Buah river includes the area of the pond, the elevation of the pond, and the surface height of the retention pond. In general, the condition of the retention pond in the Buah river subsystem has decreased in function. That is due to the silting of the pond due to sedimentation, which varies from 0.5m to 1.5m, damage to control building facilities such as inlet and outlet in the retention pond. In addition, increasing the area or adding a new retention pond is challenging due to limited land, the high cost of land acquisition, and the length of time for infiltration or evaporation, due to the condition of the soil structure and increased sedimentation. Runoff data from the Buah river subsystem 2D flood simulation results obtained using the HEC-RAS 5.0.7 program showed an expansion of inundation at the minimum downstream water level elevation. However, at the maximum discharge in the 25-year return period, there was an expansion of inundation and its height ranged from 0-2.696 m with a flood velocity of 0-3.094 m/s (see *Figure 8*).


(a) Runoff at STA 4 + 125

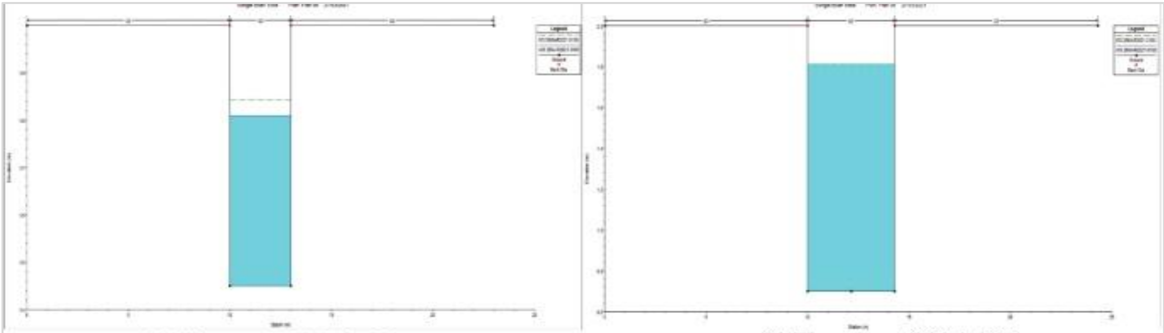
Inundation area after simulation


(b) Runoff at STA 1+ 500

Flow Velocity along Buah river

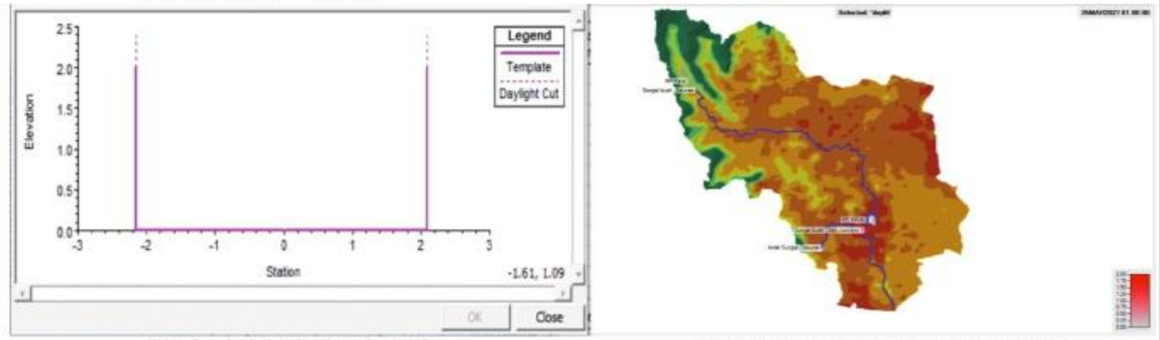
Figure 8 Simulation using HEC-RAS, a cross-section of the Buah river, (a) STA 4+125 and (b) STA 1 +500 (left); right is the top spatial images of flood depths ranging from 0 – 2,696 m/s with flow velocity depicted; and bottom are speed ranging from 0–3.094 m/s.

Because the existing channel is not able to accommodate the discharge for a return period of 25 years, a new channel is planned. To design a new channel, the geometry of the channel section is divided into two, the Buah river channel and the Buah river subordinates. For the Buah river channel, the width of the channel is 4.3 m, but the height of the dam is from 1.3 m to 2 m. and for Buah river subordinates, the width of channel is 2 m, but the height of the dam's size is from 0.55 m to 1.5 m. The modeling results based on the new cross-sectional design obtained a decrease in the water level and did not cause the inundation. Hydraulics modeling shows the average flood height for the Buah river channel as high as 1.54 m. and the Buah-Lower channel is 0.89 m tall, and subordinates is 1.81 m high (see *Figure 9*). A complete list of abbreviations is shown in *Appendix I.*



(a) Flow rate at STA 0+50

(b) Flow rate at STA 1+500



(c) plan height design channel

(d) Simulation results found no puddels

Figure 9 Simulation using HEC-RAS, a cross-section of the Buah river, (a) STA 0+50 and (b) STA 1 + 500 (top figure), and channel cross section design (bottom left) and spatial pictures along the Buah river that is no longer flooded for the 25 year return period (bottom right)

6.Conclusion and future work

In general, the peak discharge of the Simpang Patal, public high school 5, and Telkom retention ponds were 1.711 m3/s at the 20th minute, 7.749 m3/s in 1 hour 10 minutes, and 4.488 m3/s at the 30th minute, respectively. Highest elevation of the Buah subsystem was in the 100-year return period, with a height of 10.3 m from the channel bottom. Conversely, the lowest elevation was found in the 2-year return period, with a height of 9.89 m from the channel bottom.

1. The SCS method's peak discharge for every 1mm of rainfall (Qp) is 0.721 m3/second. With this peak discharge, the peak runoff value (Q) based on the direct runoff hydrograph in the Buah river sub system of 47.472 m3/second will occur at the 30th minute.
2. Characteristics of flood inundation with a 2D hydraulic flow model at minimum conditions, with a flood depth of 0 – 2.51 m and a flow velocity (V) of 0 – 3.08 m/s, will result in an inundation area of 0.015 square kilometers.
3. The capacity of the fruit watershed drainage channel cannot handle 25 years of flood discharge. The discharge for the 25th anniversary is 47.472 m3/s, more significant than the storage capacity discharge of 11.18 m3/s.
4. The research shows that the level of effectiveness of flood control in the Buah river subsystem is 65 percent, and for the Buah river subordinates, it is 37 percent of the existing conditions.

A location analysis is needed for the addition of a new retention pond, considering the increase in height up to a 5-year return period, the retention pond and the existing drainage system in the Buah river subsystem have not been able to overcome the flood events that occurred.

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Conflicts of interest

The authors have no conflicts of interest to declare.

Authors contribution statement

Firdaus: Contributed to the field data collection survey and secondary data, data analysis, hydrology and hydraulics modeling, and writing research paper journals. **Dinar Dwi Anugerah Putranto:** Contribute to analysis related to DEM analysis and various runoff analyzes related to soil type, slope type, and land-use to watershed landscape analysis and systematic preparation of paper writing. **Imrotul Chalimah Juliana:** Contribute to the analysis of CN and the magnitude of the run-off and discussion of research results and examine the conclusions of the results of the analysis.

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Appendix I

S. No.	Abbreviation	Description
1	ANN	Artificial Neural Network
2	BMKG	Geophysics Agency of Palembang
3	CN	Curve Number
4	Dd	Drainage Density
5	DEM	Digital Elevation Model
6	Dt	Texture Comparison
7	FS	Frequency Density
8	GIS	Geographic Information System
9	HEC-HMS	Hydrologic Engineering Center – Hydrologic Modeling System
10	HEC-RAS	Hydrologic Engineering Center's – River Analysis System
11	IDF	Intensity-Duration-Frequency
12	LID	Low-Impact Flood Management
13	MCSA	Multi-Criteria Spatial Analysis
14	MSL	Mean Sea Level
15	NDWI	Normalize Difference Water Index
16	NSE	Nash–Sutcliffe Efficiency
17	PTC	Palembang Trade Center
18	Rc	Circularity Ratio
19	RMSE	Root Mean Square Error
20	SCS-CN	Calculation of Effective Rain Using Soil Conservation Service-Curve Number
21	SCN-CN	Soil Conservation Service Curve Number
22	SEC	State Electricity Company
23	SPOT	Satellite Pour L'observation De La Terre (Satellite for Earth Observation)
24	STA	Several Stations
25	Tc	Concentration-Time
26	TWI	Topographical Wetness Index
27	UDS	Urban Drainage System