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Original Article

Spatial Modeling for Flood Risk Reduction in Wanggu Watershed, Kendari

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***Abstract* - *Floods are one disaster with a higher incidence rate than other disasters. Floods have a very significant impact on human life around the world. Floods can also cause social conflicts and conflicts of interest, environmental problems, and economic effects. Therefore, the spatial and temporal study of flood dynamics is essential in water resources management and disaster risk reduction. This study aims to develop a hydrological spatial model to predict discharge for flood risk reduction in the Wanggu Watershed, Kendari City. The model used in this study is Hec-HMS with the calculation of the Gridded SCS Curve Number loss method, ModClarck transform, and Recession method for baseflow calculations. The model calibration uses a measured discharge with statistical parameters Nash Sutcliffe (NSE) and PBIAS. The results showed that the spatial model for predicting outflow in the Wanggu watershed reached the optimum condition at a recession constant of 0.95. The result shows that the spatial model can predict peak outflow and time with high accuracy based on statistical parameters NSE 0.72 and PBIAS 0.17%.*

Keywords - *Flood, Hec-HMS, Hydrology, Spatial model, Watershed.*

1. Introduction

Floods are one disaster with a higher incidence rate than other disasters [1]. Floods have a very significant impact on human life around the world [2]. Floods can also cause social conflicts and conflicts of interest [3], environmental problems [4], and economic impacts [5]. Therefore, the spatial and temporal study of flood dynamics is essential in water resources management and disaster risk reduction [6].

The Wanggu River Basin, located in Kendari City, Indonesia, is one of the areas with a high frequency of flooding. In 2013 the largest flood disaster occurred, with one person dead and 2769 displaced. Another flood incident occurred in 2018, which swamped hundreds of houses. One of the problems faced by the Kendari City government in reducing the risk of flood disasters is the lack of spatial information about the conditions of areas that are potentially affected by floods which can cause material and non-material losses. The unavailability of this information can exacerbate the losses incurred if this flood disaster occurs in the future.

Research on spatial modeling has been widely carried out [7][8][9]. Spatial flood risk modeling will provide maximum results if supported by good data. In particular, the hydrologic model can give an overview of the watershed's response to rainfall in the amount of runoff. Converting rain to flow discharge is a scientific process that requires a lot of complex data and information. There are many variables in the watershed system as input characteristics with variations in space and time. Spatial modeling is an approach to overcome this very complex process and to imitate the properties and features of the watershed under study.

Hydrological simulations using computer systems have developed a lot and become one of the essential elements for understanding flow characteristics in watersheds as a result of development developments in an area [11]. Hydrological modeling research uses spatial data to predict the magnitude of runoff in watersheds. The Hec-HMS model is one of the hydrological models developed by the US Army Corps Engineers. It is used in many variations of hydrological simulations and is currently in version 4.10 [10]. In 2017 [11] conducted a study using the Hec-HMS model to simulate runoff in a calibrated watershed with measured data. The results of this study indicate that the Hec-HMS model is reliable for predicting outflow in the watershed.

One of the previous studies conducted in 2021 [24] examines the spatial modeling of the structure of water masses in the Jeneberang River Estuary, Makassar, Indonesia. The study results provide information on the spatial distribution of the parameters of the water mass structure, namely salinity, temperature, and water density. Research on hydrological modeling can use spatial data to predict runoff in watersheds.

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The input data are topography, land use, and rainfall. Acquisition of land use data can use multispectral satellite imagery or Synthetic Aperture Radar (SAR). In 2019 [13] conducted research using Sentinel 2B satellite imagery to update land cover information in Makassar. In 2022, [14] ran a SAR analysis to monitor land-use changes in Wanggu Watershed.

Meanwhile, Tropical Rainfall Measurement Mission (TRMM) showed promising results regarding rainfall data in Wanggu Watershed [15]. Based on historical studies, hydrological spatial modeling in the Wanggu watershed can use satellite data for collecting land use and rainfall data. Empirical equations can use to analyze the hydrological condition of the watershed. Several practical calculation methods ran to have an excellent ability to predict watershed discharge. In 2001 [16] studied the Gama I hydrograph's sensitivity in determining the flood discharge design. In 2018 [17] compared Synder, Gama I, and Nakayasu Synthetic Unit Hydrographs (HSS) with measured discharge data in the Jeneberang Watershed. The results showed that HSS Nakayasu could better predict discharge in the Jeneberang watershed.

Based on the results of previous studies, the spatial model is an essential element in determining a watershed system's hydrological characteristics. An excellent spatial model will provide accurate information and data that can be used in reducing flood risk. Therefore, this study aims to develop a hydrological spatial model to predict surface runoff for flood risk reduction in the Wanggu Watershed.

2. Study Area

An essential element in preparing a hydrological spatial model is related to the characteristics of the watershed. The study area of this research is Wanggu watershed, Kendari City. Analysis of the parts of the Wanggu watershed used to compile the primary data in calculating the watershed's hydrologic condition. The study of watershed characteristics includes the preparation of basin models, meteorological models, parameters of water loss or loss models, transforms, baseflow, and routing models. The data has a spatial reference to produce a spatial model of the Wanggu watershed hydrology. The Basin Model is a primary hydrological boundary data containing information on the area of the watershed, the length and slope of the river, the location of the watershed outlet, and other technical information related to the Wanggu watershed.

National Digital Elevation Model (DEMNAS) data with a spatial resolution of 0.27 ArcSecond or 8.3 meters use to create a basin model. The first step is quality control (QC) river data obtained from the Indonesian Geospatial Information Map issued by the Indonesian Geospatial Information Agency (BIG).

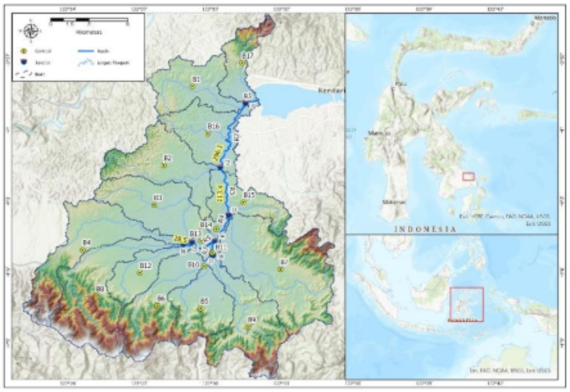


Fig. 1 Research Location

Quality control ensures that the synthetic river formed from the results of DEMNAS data processing follows the actual river flow in the field. The QC data use in the terrain reconditioning process before making the basin model. The Basin model contains morphometric characteristics of the Wanggu watershed (Fig. 1 and Table 1).

3. Materials and Methods

3.1. Rainfall Data

Rainfall data used in this study is daily rainfall data obtained from the Meteorology, Climatology, and Geophysics Agency at two stations, namely the Kendari City Maritime BMKG Station and Ranomeeto BMKG Station. Rainfall data is used on flood events for June 2 to July 28, 2018 (Fig. 2, 3, and 4)

Table 1. Basin Model Characteristics

Basin	Longest Flowpath Length (Km)	Longest Flowpath Slope	Basin Area (Km^2)	Drainage Density (Km/Km^2)
B1	12.422	0.008	21.19	0.34203
B2	13.462	0.012	27.20	0.28526
B3	14.017	0.007	26.13	0.16045
B4	23.156	0.023	32.21	0.07745
B5	10.497	0.046	20.72	0.30576
B6	14.562	0.043	26.38	0.06425
B7	18.004	0.014	51.18	0.15366
B8	22.895	0.025	38.41	4.28856
B9	17.161	0.030	28.62	1.04769
B10	1.878	0.002	0.036	0.87964
B11	2.601	0.001	1.414	0.21918
B12	11.080	0.017	13.24	1.00052
B13	3.537	0.016	2.224	0.06747
B14	3.891	0.013	2.610	0.29897
B15	11.786	0.016	15.86	0.36855
B16	11.824	0.010	21.32	0.22016
B17	10.252	0.037	13.15	0.09475

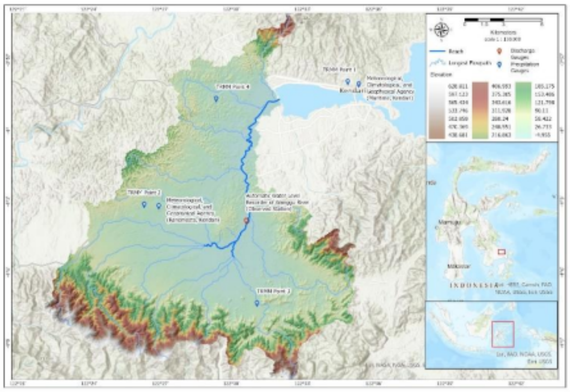


Fig. 2 Rainfall and Observed Station

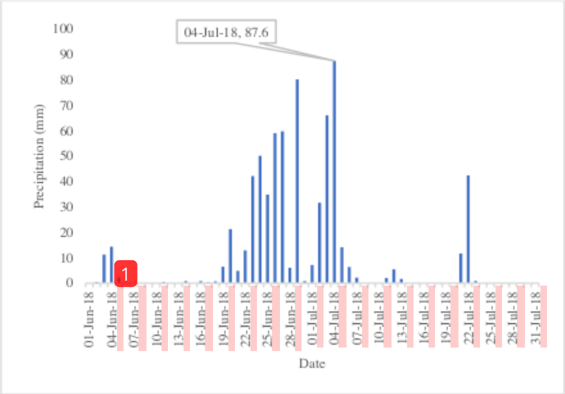


Fig. 3 Precipitation Data of Meteorological, Climatological, and Geophysical Agency (Maritime, Kendari)

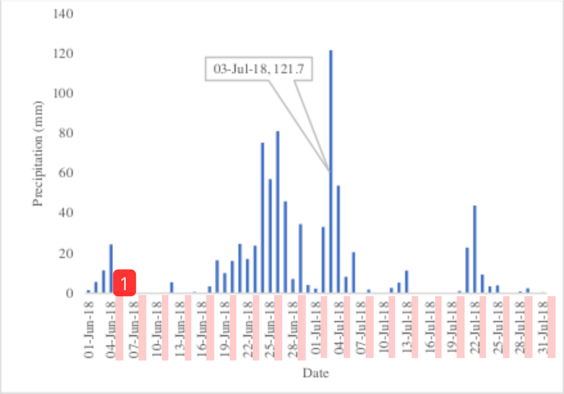


Fig. 4 Precipitation Data of Meteorological, Climatological, and Geophysical Agency (Ranomeeto, Kendari)

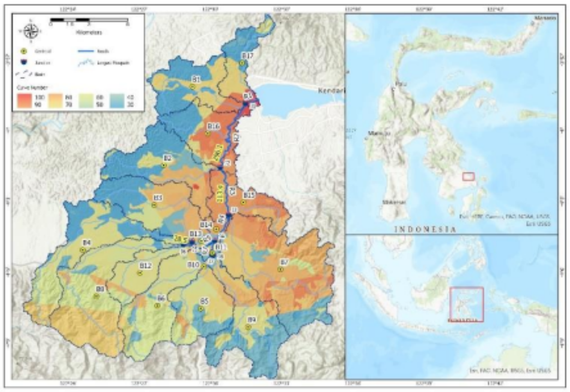


Fig. 5 Gridded SCS Curve Number of Wanggu Watershed

3.2. Loss

The parameters used in the hydrological modeling consist of loss, transform and baseflow with the help of Hec-HMS 4.10 software. The components in hydrological modeling for the calculation of loss parameters are Initial Abstraction (Ia), Curve Number (CN), Impervious, and Lag Time (T_{lag}) [25]. The method used in the hydrological analysis of parameter loss is the Soil Conservation Service Curve Number (SCS-CN). Soil hydrological groups in the SCS Curve Number are determined using soil type characteristics and texture obtained from the soil map. From the features of the soil, then the CN value is determined for each type of land use [19][20][2]. The classification of CN values is in table 2.

Table 2. Basin Model Characteristics

Land Use	**Hydrologic Condition**	**Curve Number for Hydrologic Soil Group**			
		A	**B**	**C**	**D**
Pasture, grassland, or range-continues forage for grazing	Poor Fair Good	68 49 39	79 69 61	86 79 74	89 84 80
Grassland	-	30	58	71	78
Brush-brush-weed-grass-mixture with a brush is the primary element	Poor Fair Good	48 35 30	67 56 48	77 70 65	83 79 77
Woods-grass combination	Poor Fair Good	57 43 32	73 65 58	82 76 72	86 82 79
Woods	Poor Fair Good	45 36 30	66 60 55	77 73 70	83 79 77

Loss parameters in the Hec HMS model using Gridded SCS-CN spatial data. The range of SCS-CN coefficient values in the Wanggu watershed is 30 to 100. The SCS-CN 100 value is used for the land cover of water bodies. Meanwhile, the SCS-CN 30 value is obtained for forest land cover in the upstream watershed (Fig. 5)

3.3. Transform

This parameter is a runoff analysis method that describes surface runoff, storage, and energy loss when water flows from the watershed to the river channel. The transformed model is an approach model used to convert excess rain into outflow in the watershed. The Transform method used in this study is the ModClark method. The ModClark form represents two essential processes in transforming rain into surface runoff. These include translation or movement of water to the outlet and attenuation or reduction of discharge [21]. The equation used is as follows.

$$\frac{dS}{dt} = I_t - O_t \qquad (1)$$

Where dS/dt is the amount of water storage at time t, It is the average outflow at time t, and O_t is the amount of discharge at time t. The calculation of concentration and storage time is carried out using the equation 2 and 3 as follows

$$T_c = 2.2 * \left(\frac{L * L_c}{\sqrt{Slope_{10-85}}}\right)^{0.3} \qquad (2)$$

$$\frac{R}{R + T_c} = 0.65 \qquad (3)$$

Where T_c is the time of concentration in hours, L is the longest flow path in miles, L_c is the centroid of the flow path in miles, Slope 10-85 % is the average slope of 10 – 85% of the longest flow path in units of ft/mile, and R coefficient of storage [19]. The results of the calculation of Concentration time (T_c) and Time Lag (T_{lag}) in the Wanggu watershed shows in table 3.

Table 3. Concentration time (Tc) and Time Lag (T_L)

Reach	Length (Km)	Slope	Tc (Minutes)	Time Lag (Minutes)
R1	1.24	0.00127	38.98	23.39
R2	7.86	0.00038	493.47	296.08
R3	4.75	0.00105	188.94	113.37
R4	2.62	0.0001	153.61	92.17
R5	2.33	0.00039	142.13	85.28
R6	1.03	0.00075	47.56	28.53
R7	1.25	0.00017	146.94	88.16
R8	0.16	0.0031	12.27	7.36

3.4. Baseflow

Estimating baseflow and surface runoff is needed to analyze hydrological conditions in a watershed. Those include interactions between surface and sub-surface water, the effect of urbanization on surface runoff, and the health of water habitats in rivers. The baseflow parameter is the amount of flow not formed directly by rainfall or can be defined as a flow created in a river without a direct contribution of rain. The recession method is used for baseflow calculations with the following equation.

$$Q_t = Q_o k^t \qquad (4)$$

Baseflow calculations performed using measured discharge data at the observation station. Q_t is the base flow at time t, Q_0 is the initial baseflow at the initial time of calculation t_0, and k is an exponential constant. The exponential constant (k) is the ratio of t and t_0 [10]. These components used to calibrate the spatial model in the Wanggu watershed

3.5. Model Calibration

Model calibration determines the optimum value of the parameters used that represent the actual conditions or characteristics of the watershed in the field. The calibration is carried out by determining the parameter values for the watershed characteristics as model inputs. The calibration is carried out to obtain a calculated hydrograph close to or similar to the measured data [22].

Model evaluation is carried out to determine the model's ability to predict discharge on the watershed. The results of the hydrological modeling simulation have deviations from the measured data in the field. Differences in model parameters with characteristics in the field cause deviation. Performance appraisal is carried out based on statistical criteria, which include Coefficient of Determination (R^2), Nash-Sutcliff Efficiency (NSE), and Percent Bias (PBIAS) [23]. The statistical measures are calculated using equations 5 to 7.

$$R^2 = \left(\frac{\sum_{i=1}^{n}(Q_{0i} - \overline{Q_0})(Q_{mi} - \overline{Q_m})}{\sqrt{\sum_{i=1}^{n}(Q_0 - \overline{Q_0})^2}\sqrt{\sum_{i=1}^{n}(Q_{mi} - \overline{Q_m})^2}}\right)^2 \qquad (5)$$

$$NSE = 1 - \frac{\sum_{t=1}^{T}(Q_m - Q_0)^2}{n\sum_{t=1}^{T}(Q_0 - \overline{Q_0})^2} \qquad (6)$$

$$PBIAS = \frac{\sum_{i=1}^{n}(Q_0 - Q_m)^2}{\sum_{i=1}^{n} Q_0} \qquad (7)$$

Where Q_o is the discharge of the observation, $\overline{Q_0}$ Is the average discharge of the observation, Q_m is the discharge of the model, and $\overline{Q_m}$ is the average discharge of the model. The criteria used in evaluating the hydrological model are shown in table 4.

Table 4. Hydrological model calibration criteria

Criteria	R^2	NSE	PBIAS
Very Good	$R^2 > 0{,}85$	NSE > 0,80	PBIAS<±5
Good	$0{,}75 < R^2 < 0{,}85$	0,70 < NSE < 0,80	±5< PBIAS<±10
Fair	$0{,}6 < R^2 < 0{,}75$	0,50 < NSE < 0,70	±10<PBIAS< ±15
Poor	$R^2 < 0{,}6$	NSE < 0,5	PBIAS > ±15

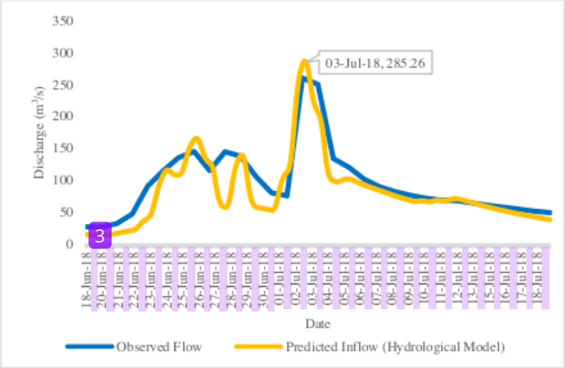


Fig. 6 Precipitation Data Calibration

Table 5. Model calibration based on Recession Constant

Recession Constant (0 - 1)	Nash-Sutcliffe (NSE)		PBIAS (%)	
	Value	Criteria	Value	Criteria
0.6	0.092	Poor	43.92	Poor
0.7	0.274	Poor	38.67	Poor
0.8	0.519	Fair	29.85	Poor
0.9	0.762	Good	13.25	Fair
0.91	0.771	Good	10.91	Fair
0.925	0.771	Good	7.08	Good
0.926	0.77	Good	6.81	Good
0.93	0.767	Good	5.72	Good
0.95	0.72	Good	0.17	Very Good
0.96	0.67	Good	3.49	Very Good

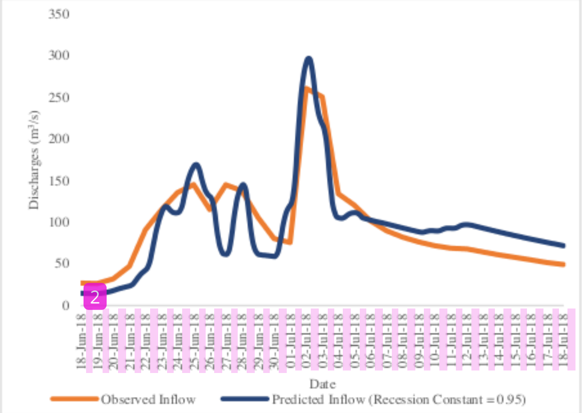


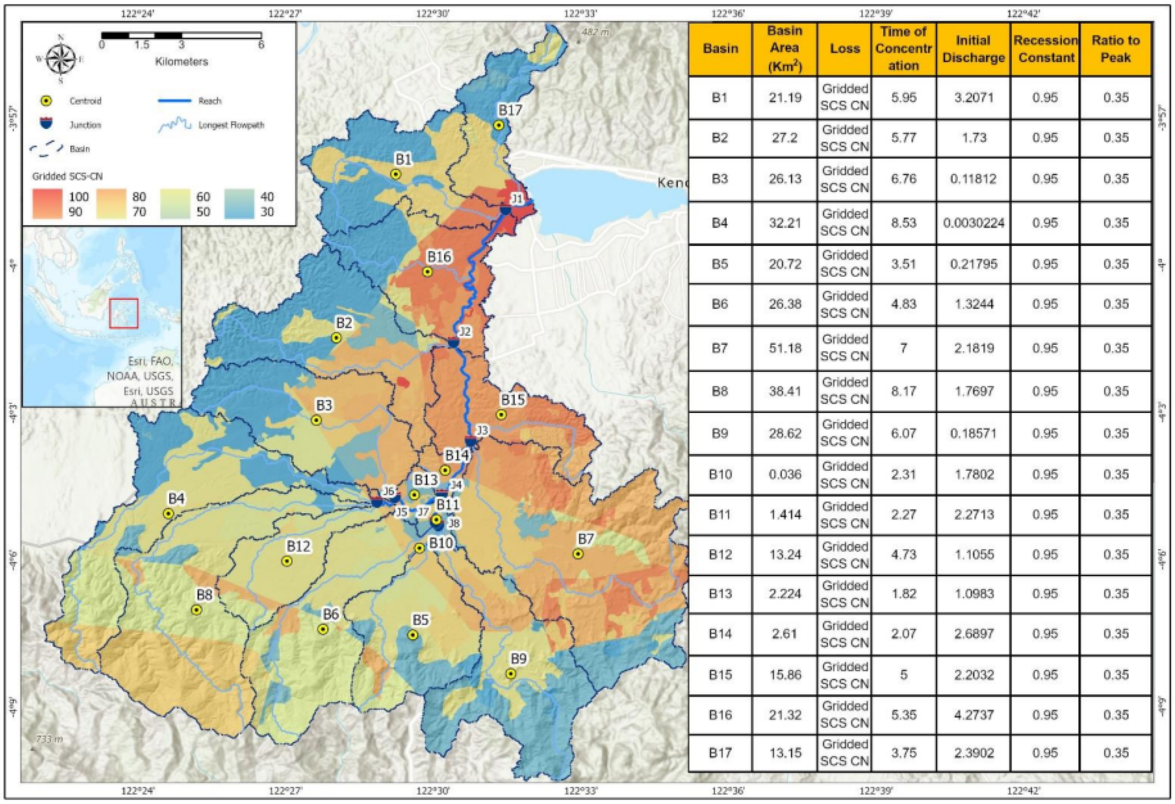
Fig. 7 Calibration of Predicted Inflow based on Recession Constant

4. Results and Discussion

The hydrological spatial model was prepared using rainfall data at two Meteorological, Climatological, and Geophysical Agency stations during the flood period in July 2018. The measured discharge at the observed station is used to calibrate the spatial model. The rhythmic rain and discharge data are from the 2018 flood, June 18 to July 18, 2022. The equations used for model evaluation are equations 5, 6, and 7, with model performance criteria based on the classification in Table 4. Initial calibration calculates by testing the quality of BMKG rainfall data against measuring data at the Kendari City AWLR station using a constant recession coefficient of 0.9 and a Ratio to Peak (RTP) of 0.35. The calibration results obtained NSE values of 0.76, PBIAS 5.19%, and R^2 0.82. The results of the calibration of the spatial model on BMKG rainfall data are shown in Figure 6.

The statistical parameters NSE, PBIAS, and R^2 also show that the BMKG rain data is suitable for predicting outflow discharge in the Wanggu watershed. Figure 6 shows that the expected outflow has a peak discharge value more significant than the peak discharge measured in the field. The difference value is because of the influence of the surface runoff coefficient or the baseflow coefficient, which is too large, so the hydrological spatial model produces a discharge more significant than the measured data in the field. In other conditions, it is also shown that the predicted outflow discharge value in the BMKG data is smaller than the measured data, indicating the influence of baseflow on the hydrological spatial model of the Wanggu watershed. The initial analysis results show that the spatial model requires calibration to improve capabilities. Calibration is carried out at a constant recession coefficient so the model can produce inflow predictions close to the measured discharge in the field. The results of model calibration with recession coefficient simulation are shown in Table 5.

NSE is one of the model performance indicators. The higher NSE value shows the better performance of the model. The simulation results show that the NSE value is included in the excellent category in the range of the recession coefficient value of 0.9 - 0.95 and is not feasible at 0.96. Meanwhile, the smaller PBIAS value shows the better performance of the model. Based on the table, the PBIAS value reaches its minimum condition when the recession constant is 0.95. The calibration shows that the simulation results with variations in the recession coefficient (K) value; the optimum K value for the Wanggu watershed hydrological spatial model is 0.95. The simulation results show statistical parameters with a value of 0.72 (Good) and PBIAS of 0.17% (Very Good). These results show that the baseflow recession coefficient is 0.95, which follows the hydrological characteristics of the watershed. The results of the outflow prediction based on the hydrological spatial model in the 2018 flood events are shown in Figure 7.



Basin	Basin Area (Km²)	Loss	Time of Concentration	Initial Discharge	Recession Constant	Ratio to Peak
B1	21.19	Gridded SCS CN	5.95	3.2071	0.95	0.35
B2	27.2	Gridded SCS CN	5.77	1.73	0.95	0.35
B3	26.13	Gridded SCS CN	6.76	0.11812	0.95	0.35
B4	32.21	Gridded SCS CN	8.53	0.0030224	0.95	0.35
B5	20.72	Gridded SCS CN	3.51	0.21795	0.95	0.35
B6	26.38	Gridded SCS CN	4.83	1.3244	0.95	0.35
B7	51.18	Gridded SCS CN	7	2.1819	0.95	0.35
B8	38.41	Gridded SCS CN	8.17	1.7697	0.95	0.35
B9	28.62	Gridded SCS CN	6.07	0.18571	0.95	0.35
B10	0.036	Gridded SCS CN	2.31	1.7802	0.95	0.35
B11	1.414	Gridded SCS CN	2.27	2.2713	0.95	0.35
B12	13.24	Gridded SCS CN	4.73	1.1055	0.95	0.35
B13	2.224	Gridded SCS CN	1.82	1.0983	0.95	0.35
B14	2.61	Gridded SCS CN	2.07	2.6897	0.95	0.35
B15	15.86	Gridded SCS CN	5	2.2032	0.95	0.35
B16	21.32	Gridded SCS CN	5.35	4.2737	0.95	0.35
B17	13.15	Gridded SCS CN	3.75	2.3902	0.95	0.35

Fig. 8 Hydrologic Spatial Model of Wanggu Watershed

Based on the inflow graph, the magnitude of the discharge and the time of the peak discharge that occurred during the flood incident can be seen. The simulation results show that the peak discharge occurred on July 3, 2018, at 04:00 AM at 296.8 m^3/s, while the measured release was 258.93 m^3/s. These results indicate that the predicted discharge generated by the spatial model is greater than the measured discharge in the field. However, based on the NSE and PBIAS parameter values, the hydrological spatial model is excellent at predicting the inflow.

Calibration results and watershed morphometric data are then used to construct hydrological spatial models. The spatial model contains information on the morphometric characteristics of the watershed and hydrological parameters. The hydrological spatial model of the Wanggu River Basin can be seen in Figure 8.

Based on figure 8, B7 is the largest sub-basin with an area of 51.18 km^2 or 14.97% of the Wanggu watershed area. The broader the watershed, the greater the resulting discharge. Based on the spatial model, B7 has the potential to contribute a significant runoff to the Wanggu River Basin.

Table 6. Average CN of The Basin Model

No	Sub-Basin	Sub-Basin Area (Km²)	Sub-Basin Area (%)	Average Curve Number (CN)
1	B1	21.19	6.20	51.16
2	B2	27.2	7.96	50.30
3	B3	26.13	7.64	55.34
4	B4	32.21	9.42	54.06
5	B5	20.72	6.06	60.33
6	B6	26.38	7.72	60.81
7	B7	51.18	14.97	72.44
8	B8	38.41	11.23	65.86
9	B9	28.62	8.37	52.33
10	B10	0.036	0.01	64.58
11	B11	1.414	0.41	52.83
12	B12	13.24	3.87	65.56
13	B13	2.224	0.65	59.58
14	B14	2.61	0.76	73.56
15	B15	15.86	4.64	84.08
16	B16	21.32	6.24	70.19
17	B17	13.15	3.85	56.10

In addition to the parameters of the watershed area, the spatial distribution of surface runoff coefficients (CN) is an essential variable in reducing flood risk. The greater the CN value, the greater the surface runoff generated in the watershed. The results of the analysis of the runoff coefficient of the Wanggu river basin can be seen in table 6.

The analysis of the runoff coefficient results based on the curve number shows that sub-basin B15 has the highest CN value of 84.08. The area of the B15 sub-basin is 15.86 Km^2 or 4.64% of the total watershed area. The second highest CN is sub-basin B14 73.56, but with a small area of 2.61 km^2 or 0.76% of the total area of the watershed. Subbasin B7 has the third highest CN value, 72.44, and has the most prominent area of 51.18 Km^2. The extent of sub-basin B7 is 14.97% of the total area of the watershed. Based on the results of the data analysis, the B7 sub-basin is an area that requires treatment for flood risk reduction. One policy that can be implemented is to reduce the runoff coefficient through vegetative conservation activities.

Predicting inflow discharge and peak time can be used as an early warning system for flood risk reduction. Information on peak discharge and arrival time is critical in reducing disaster risk. The resulting hydrological spatial model has been able to predict the inflow amount with a reasonable accuracy level with the NSE coefficient value of 0.71 and PBIAS of 0.17%. Further research is needed using hydrological spatial models and rain prediction satellite data to model inflow predictions in the Wanggu watershed. In addition, a study of river capacity is required to determine the potential for flood events based on forecasts of inflow discharge and river capacity.

5. Conclusion

Prediction data of peak inflow time and discharge can be used to develop a flood early warning system. The spatial model for predicting inflow in the Wanggu watershed reaches its optimum condition at a recession constant of 0.95. The resulting spatial model can predict the peak inflow time and discharge with reasonable accuracy based on statistical parameters NSE 0.72 (Good) and PBIAS 0.17% (Very Good).

The inflow discharge prediction generated by the spatial model has a value greater than the measured discharge. These results indicate that further studies are needed regarding the runoff coefficient. In addition, other studies are required concerning the flood early warning system for calculating the river's carrying capacity.

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