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Calibration and Validation of CN Values for Watershed Hydrological Response

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Abstract

The amount of rainfall can be used to estimate the runoff that enters a reservoir. Runoff is influenced by land use, and soil type greatly affects the amount of runoff that will occur. This study discusses the development of a hydrological model with the application of the Hydrologic Engineering Center (HEC-HMS) in the Karangmumus watershed using soil data that has been verified in the field and divided into soil zones based on soil permeability testing in the laboratory. With the help of Geographic Information System (GIS) and Geospatial Hydrological Model (HEC-GeoHMS) applications, it is possible to identify the flow of the Karangmumus watershed and the Lempake Dam in Kalimantan by simulating the rain runoff process. The hydrological model was developed in the HEC-HMS by recording daily rainfall events from 2009 to 2019. With a daily period, then, the zoning soil type data was entered based on the results of soil permeability testing with the help of the application of the soil conservation curve method (SCS-CN), then discharge transformation, and calculation of water loss, including routing with Muskingum and SCS-Hydrograph applications. Based on the distribution of the CN value, the theoretical runoff is calculated and then calibrated with the observed discharge in 2017 and 2018, and then validated with the observed discharge in 2019, showing good results with a coefficient of determination between 0.89 to 0.92.

Keywords: Hydrological Models; HEC-HMS; Land Permeability; Karangmumus River; Rainfall/Runoff.

1. Introduction

Direct runoff in each watershed is caused by factors such as high rainfall, soil type, regional land cover, and the level of vulnerability of the area to disasters such as floods, winds, and earthquakes. What is certain is that significant natural changes can increase the amount of direct runoff both universally [1] and regionally [2]. The hydrograph model is often used either directly or in conjunction with other software in the study of water availability, area drainage, spillway design, dam operation, impact reduction, and flood risk. In two sub-basins that have different characteristics and areas, runoff can be calculated using the appropriate hydrograph model [3]. Likewise, the discharge in the Karang Mumus River to support the provision of irrigation water and raw water, as well as flood control in Samarinda City, East Kalimantan Province, Indonesia, and the water entering the Lempake Dam, can be calculated using the appropriate hydrograph model. The discharge fluctuations of the Karangmumus River vary greatly from year to year depending on the intensity of the daily rainfall that occurs throughout the year [4]. In the future, good planning is needed for providing storage in the Lempake Reservoir because currently there is a significant change in land use from forest to plantations

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and illegal mining in the upstream area of the Karangmumus watershed. In 2025, there will be additional rice fields from 350 to 800 ha, plus raw water supply increasing from 100 to 250 liters/second, there will certainly be a deficit in the Lempake Dam effective storage in 2050 [4]. Very extreme climatic conditions in early January 2020 with high rainfall intensity caused flooding in Samarinda City and its surroundings. Meanwhile, on the other hand, the long dry season from March to September 2018 caused a water storage deficit in the Lempake Dam.

If in the future there is a drought or water shortage, it will threaten the supply of irrigation water and raw water in the city of Samarinda [5], so it is necessary to make a model that connects rainfall with surface runoff that occurs by considering the factors that influence it [6]. Soil type is one of the main factors affecting runoff. This factor is not enough to just use secondary data; it is necessary to verify in the field and then take sufficient samples to test the permeability level in the laboratory. Furthermore, zoning of the distribution of soil types in the Karangmumus watershed based on its permeability was carried out for modeling runoff with rainfall [7]. HEC-HMS is an application to assist with hydrological runoff modeling created by the Hydrological Engineering Center of the United States Army Corps of Engineers (HEC). HEC-HMS can model the hydrological cycle in an integrated system in a dendritic watershed [8]. In the HEC-HMS application, some components are taken into account, among others: routing, rain loss, and surface runoff. Currently, HEC-HMS is widely developed in modeling because it is more practical and the accuracy of the results is quite good, and it can be validated and calibrated. So that with the results of the integration with geospatial HEC-GeoHMS and Geographic Information Systems (GIS) which results in the GeoHMS ArcView application, hydrological modeling using spatial analysis can be used. With the help of the Digital Elevation Model (DEM), the HEC-GeoHMS application can change the river flow system, including watershed boundaries, into a structure in the hydrological data as a response to watersheds due to surface runoff [9]. A digital elevation model (DEM) is a three-dimensional computer model for graphically presenting altitude data to describe the terrain on planets, moons, and asteroids. The term "global DEM" refers to a discrete global network model. DEM is a common substrate on digitally produced relief maps and is often used in GIS systems [10]. Several parameters are considered in the HEC-GeoHMS application, such as land use factors, determining the distribution of curve number values (CN), and determining the distribution of soil types, especially in the Karangmumus watershed. So far, the determination of CN is only based on the results of secondary soil data collection, such as satellite data or data from the Ministry of the Republic of Indonesia, whose accuracy has not been verified in the field and has not been validated by soil permeability tests in the laboratory. This is an important and new way to find the relationship between runoff and rainfall in a watershed.

In hydrological modeling, many researchers have used the HEC-HMS application. This is because this application can represent flow behavior by simulating the process of direct runoff due to rain that occurs. Based on research conducted by Oleyiblo et al. [11] in the Wan'an & Misai watersheds of China for flood forecasting with the help of the HEC-HMS application, which was then calibrated and then verified with rainfall data from field measurements and the results have a fairly good correlation value. Saedrashed et al. [12] have utilized the application of HEC-HMS in hydrological process modeling as well as computational hydraulic analysis with interface methods, which combine HEC-HMS and HEC-RAS modeling with GIS, including floodplains in the Zab Besar River. After calibration is done and then validated, the results are also quite satisfactory, with a fairly good correlation coefficient. Martin et al. [13] have utilized the Arc-Map and HEC-GeoHMS components to estimate surface runoff by hydraulic flow modeling. HEC-HMS has also been used for modeling runoff and rainfall in several watersheds in Indonesia, including by Affandi et al. [14], who gave the smallest RMSE value of 3.7 while the 2006 Nash method gave the smallest value of -0.2 with the characteristic parameters of the Sampean Baru watershed of Java Island. The same thing has also been done in the Bantimurung Sub-watershed, South Province, where the combination of GIS with HEC-HMS can simulate hydrological modeling quite well [15], using a soil texture map from the Ministry of Agriculture of the Republic of Indonesia, which produces R^2 and NSE values of 0.456, respectively. and 0.595.

The small values of R^2 and NSE indicate that in the future it will be necessary to identify in more detail the parameters that influence watershed modeling in Indonesia, for example, the results of modeling and analysis of discharge generation with HMS-HEC in Menjer Lake, including the results of spatial analysis in ArcGIS the results are quite good because more detailed identification has been carried out, including more rational values for the physical characteristics of the sub-watershed such as the slope factor, CN value, and percentage of water tightness. In addition to a more detailed identification of the parameters, it is also necessary to note that there may be other parameters that affect the balance, such as lake outflow and groundwater flow [16]. In the future, it is necessary to identify more thoroughly the HEC-HMS parameter, then determine which will most affect the conversion of rain data into a runoff. Based on previous research using hydrological modeling in the Lempake watershed using rain incident data and observation discharge data, the results obtained from the CN value obtained from the calibration were 95, and the Initial Abstraction (Ia) value was 0.11. However, the correlation value is quite good, and the relative error rate is still quite large [17], it is necessary to make adjustments to the input data, for example, based on GIS integration with GEO HEC-HMS, which is still rarely done in Indonesia.

The HEC-HMS hydrological model used in combination with HEC-GeoHMS and GIS is very important for identifying flows by simulating rain runoff processes. The discharge of Al Adhaim Dam has been simulated and compared with the discharge obtained from a flow meter located downstream of the dam by calibrating hydrological parameters for two years and hydrological verification for one year. With a more detailed identification of parameters, finally, the results showed that the correlation coefficient of R^2 was 0.9 for calibration. After being calibrated, the validation of the correlation value is also quite good, with a relatively small error rate [18]. In the future, it is important to optimize model performance; apart from hydrological modeling with calibration, validation also needs to be done [19]. Following up on research on the results of hydrological modeling of the Al-Adhaim Dam, once again it is necessary to combine HEC-GeoHMS and GIS in modeling the Lempake watershed so that the error rate is relatively small and improves from previous research, and then identify parameters in detail and more thoroughly by (1) map data usage. The land verified in the field is then updated on the GIS, (2) for inflow simulation and calculated in more detail with 9 sub-watersheds. Which is smaller, (3) calibration is carried out for 2 years, and the observation data is then validated for 1 year on the model obtained. In addition to a more detailed identification of the parameters, this study also carried out field verification and took 20 soil samples that were tested for permeability to obtain soil type zones based on the level of permeability in the Karangmumus watershed as a correction to the CN value to be simulated.

Furthermore, the results of this study can be used for modeling in adjacent watersheds as well as for the management of water resources management on the island of Kalimantan which in the future has been designed as the capital city of Indonesia. The target of remote sensing integration research, such as DEM which has been controlled by laboratory soil infiltration test results to be developed in hydrological modeling, is then used in the simulation of rain runoff and identification of flow direction in the Karangmumus watershed. The results of the soil permeability test are presented in the form of a zoning map of the soil CN value which is then used as an input parameter for the HEC-HMS model. So that the results of this modeling are expected to help in making water resource management policies in the Karangmumus watershed area so that there is no water deficit to provide irrigation water and raw water in Samarinda City and its surroundings. After the modeling is calibrated and validated, the parameters obtained can be applied to hydrological modeling in the Karangmumus watershed, including other watersheds around the Karangmumus watershed.

2. Locations and Methods

The hydrological model of the Karangmumus watershed was created using HEC-GeoHMS and in particular using DEM on the area under review belonging to the United States Institute of Geological Survey (USGS). HMS inputs including basin boundaries, river flow networks, and all components of the watershed under study are sent to HEC-Geo HMS so that Hydrological Modeling in the Karangmumus watershed can be optimized based on very complete data input including CN values that have been verified by laboratory test results of soil samples in 20 points and a simulation process was run with daily rainfall data recorded from 2000 to 2019. The Karangmumus watershed with the main river being the Karangmumus River is located in the east of Kalimantan Island with the Lempake Dam outlet (Figure 1). The Karangmumus River is the main source of fresh water for East Kalimantan Province. The length of this river is close to 120 km. Lempake Dam is used to draining an area of 350 ha and is almost dry from May to October 2018. On the other hand, flooding also occurred from November to January 2020, because the rainfall intensity is quite high. The average daily rainfall is about 85 mm/day. However, in January 2000 there was a maximum daily rainfall of 135 mm/day and in January 2016 it was 133 mm/day. Although daily rainfall is stable, on average during several months there is rarely rain with temperatures ranging from 14 C to 42 ^{0}C. The Karangmumus watershed can be classified as a green water catchment area whose land cover is a forest with a percentage of 75% and the rest is in the form of resident agricultural areas.

Downstream of the Karangmumus river there is a weir that has been upgraded to a dam with the name Lempake Dam in the Mahakam River area, which is administratively located in Samarinda City, East Kalimantan Province (0° 24' 32.50" South Latitude and 117° 11' 34.43" East Longitude). The area of Samarinda City is 718.00 km^2 and experiences a hot climate with an average air temperature of 28.0 ^{0}C. The lowest air temperature is 23.9 ^{0}C in January and the highest is 32.90C in September. Samarinda City has relatively high humidity and rainfall. The humidity ranged from 77% to 86%. While the average rainfall reached 201.7 mm, with the highest rainfall of 327.1 mm in January and the lowest of 110.4 mm in September. The percentage of sunshine in Samarinda is on average 42%, and the average number of rainy days is 19 days. Based on the hydrological conditions, Samarinda City is influenced by about 20 Watersheds. The Mahakam River is the main river that divides Samarinda City with a width of 300-500 meters, the other rivers are tributaries that empty into the Mahakam river which include: the KarangMumus River with a watershed area of about 218.60 Km^2, Palaran River with a watershed area of 67.68 Km^2, Other tributaries between others, Sungai Loa Bakung, Loa Bahu, Bayur, Betepung, Muang, Pampang, Buffalo, Welcome, Lais, Tas, Anggana, Loa Janan, Handil Bhakti, Loa Hui, Rapak Dalam, Mangkupalas, Bukuan, Ginggang, Pulung, Payau, Balik Crocodile, Banyiur, Sakatiga and Bantuas River.

The urban built area is 17,898 hectares, reaching 24.9% of the total area of Samarinda City. The majority of land use is non-urban built-up areas or rice fields, fields, and plantations. This area is recorded as having an area of 26,049 hectares or 36.28% of the total area. Furthermore, the Light Protected Area is part of the open space that has begun to be processed by the people, with an area of 4,597 hectares or 6.4% of the total area. Overall, the open space of Samarinda City reaches 26,853 hectares, or around 37.4% of the total area.

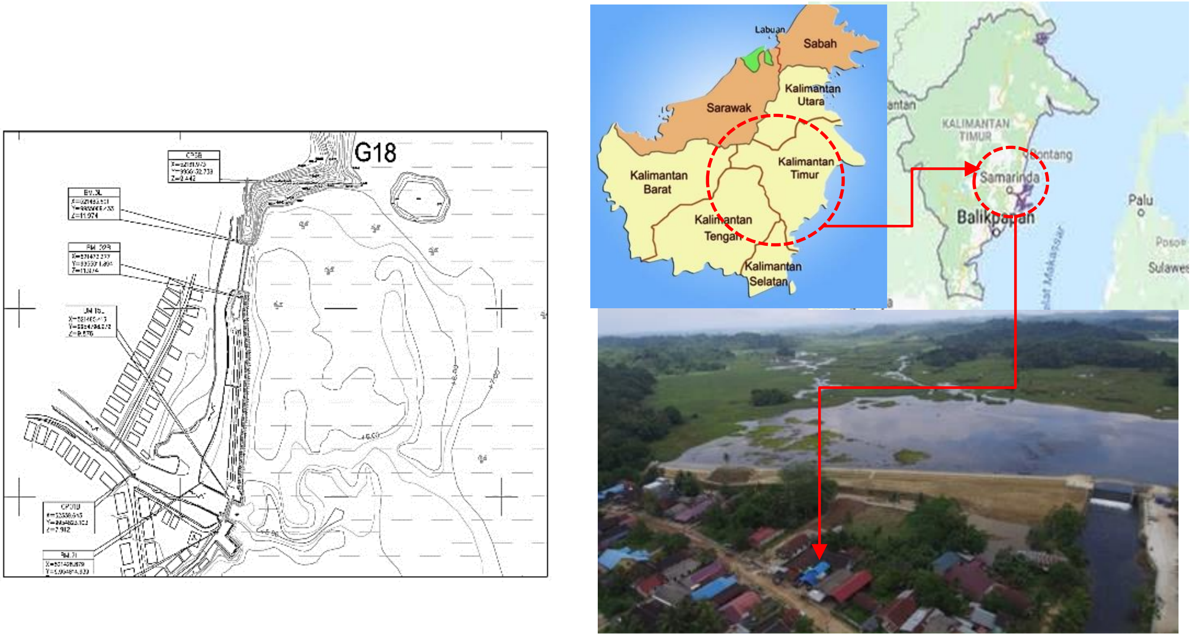


Figure 1. Lempake Dam Layout

The main purpose of the construction of this dam is control. Flooding, irrigation water supply for 350 hectares of paddy fields, and 250 liters/second of raw water for Samarinda City (Figure 1) Lempake Dam is a homogeneous earth-fill type dam with a length of 352 km and a height of 3.5 m. It is about 4 m wide at its highest point. With the highest elevation of +19.5 a.s.l. Built-in 1981 and consists of 1 intake and 2 spillways (Figure 1). Effective storage capacity of 430,000 m^3 with an inundation area of 1,597,730 m^2 and with a design flood discharge of 789 m^3/s. Intake with an under sluice type with a width of 1.5 meters and a height of 2 m equipped with a sliding door with a flow capacity of 1 m^3/second. The main spillway has a light type ogee with a crest elevation of +7.20 and a width of 15 m. The emergency spillway is in the form of a wide threshold with a crest elevation of +7.70 and a width of 10 m. The water table area of the reservoir is 1,597,730 m^2 with a maximum water level elevation of +7,20 m. The maximum reservoir capacity is 4,563,700 m^2 and the minimum water level is +6.50 m as presented in Table 1. The relationship between water level elevation and inundation area and reservoir storage volume is presented in Table 2.

Table 1. Relationship between reservoir water level elevation and inundation area and reservoir storage volume

Water Level Elevation* (m)	Inundation Area (m^2)	Reservoir Volume** (MCM)
6,50	650000	0.100
6.75	930000	0.210
7,00	1100000	0.300
7,25	1620000	0.400
7,50	1700000	0,440
7,75	1850000	0.460
8,00	1950000	0.480
8,25	2050000	0.500
8,50	2150000	0.510
8,75	2250000	0.520
9,00	2350000	0.530
9,25	2450000	0.540
9,50	2500000	0.550
9,75	2600000	0.560
10,00	2700000	0.570
10,25	2750000	0.580

* Water level elevation: meters above sea level.
** MCM: million cubic meters.

Table 2. Relationship of water volume and corresponding elevation in the hydrological year

Date	Elevation** (m)	Capacity (BCM*)
1/16/2017	8,20	0.490
1/16/2018	8,10	0.485
1/16/2019	8,15	0.488
1/16/2020	8,30	0.505

* BCM: Billion Cubic Meters;

** Elevation: meters above sea level

The rainy season starts in October and ends in March for most areas of the island of Borneo. Due to the influence of topography, the average rainfall in the area tends to increase from southwest to northeast. The daily rainfall data obtained comes from the web power data access viewer. In calculating the regional mean rainfall using the Thiessen polygon method, there is only a single point input feature with the corresponding point of the Thiessen polygon closer to the point in it than the other point input features. The perpendicular bisector is obtained for each edge of the triangle to construct the edges of the Thiessen polygon [20]. Figure 2 shows the maximum amount of rainfall during the last ten years for the study area that occurred on January 11, 2001, which was 135 mm.

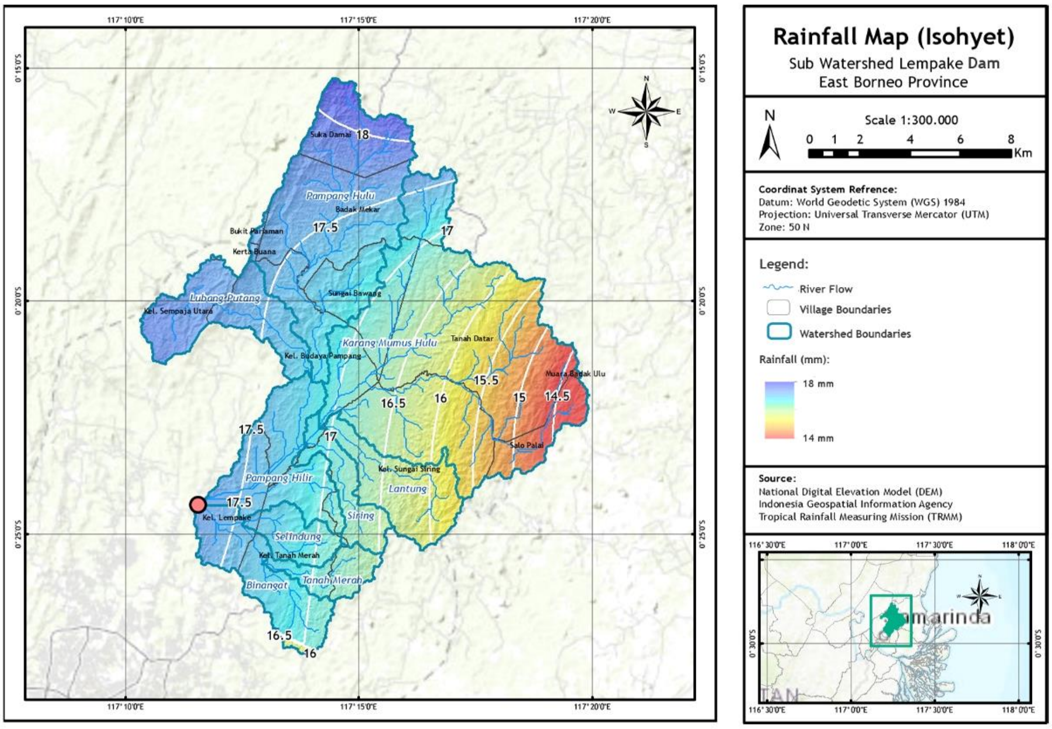


Figure 2. Distribution of maximum daily rainfall at the study site, which occurred on February 20, 2008 (*https://power.larc.nasa.gov/data-access-viewer*)

With the help of HEC-GeoHMS as a geospatial hydrological aid program, researchers can process the spatial so that the flow in the sub-basin is obtained through four data processing using HEC-HMS [21]. Furthermore, in this analysis HEC-GeoHMS is integrated with Arc Map 10.5 so that it can convert daily rainfall data into direct runoff data based on topographic conditions and the shape of the area's surface. Besides that, it is possible to create routes and calculate losses including transformation into a direct runoff. In the use of the HEC-HMS application including the input of meteorological data and the basin model, it is possible to determine the important parameters in the HEC-HMS which are presented in Table 3.

Table 3. Parameter setting in the HEC-HMS application in the Karangmumus watershed

No	Model	Method	Initial abstraction (mm)
1	Order of loss rate parameters	Curve of SCS	CN and Impervious Area (%)
2	Routing constant value	Muskingum Method	Dimensionless weight (X); Travel Time (K)
3	Run off Transform	SCS Unit Hydrograf	Lag Time (min)

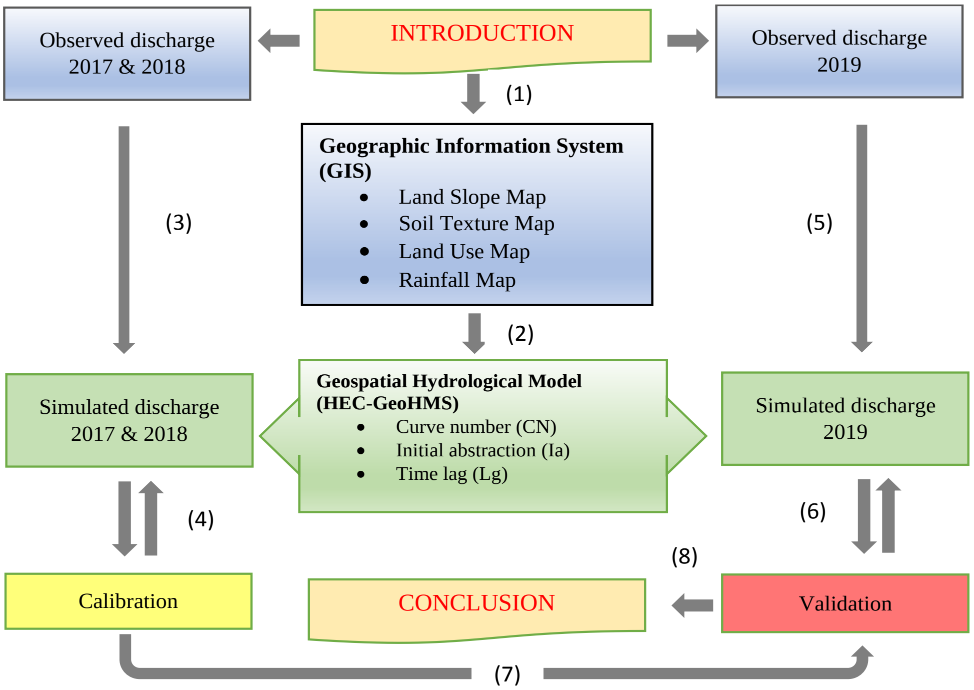


Figure 3. Flowchart of research methodology

3. Results and Discussions

The flow variation at the watershed outlet is calculated by considering the response to rain data for 3 years, with 6 sub-watersheds according to the river network. Furthermore, to calculate runoff, the SCS-CN method is used, while to calculate the transformation, loss calculation, and routing of each sub-watershed, Muskingum, and unit hydrograph are used. The calibration process is used by comparing the results of the field measurement discharge with the theoretical discharge generated by the HEC-HMS analysis. To determine the topography of the watershed using semi_DEM the results are presented in Figure 4, which has been modified by the authors of the United States Geological Survey (USGS) web [22].

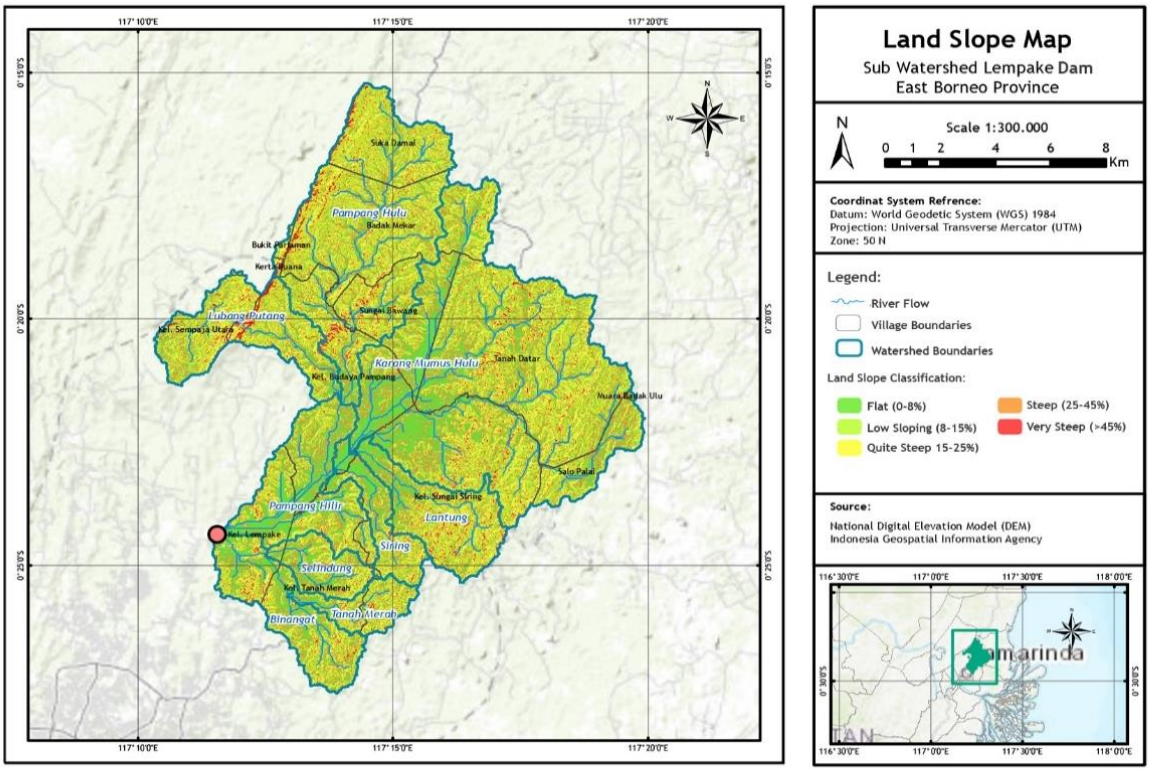


Figure 4. DEM map of the Karangmumus watershed modified by the authors from the United States Geological Survey (USGS) web

The initial processing in the development of hydrological modeling with HEC-GeoHMS is presented in Figure 5. The stages are making a raw digital elevation model, filling the sink, making low directions, determining catchment polygons, doing basin rasters, and making flow accumulation. When finished processing, then the model that has been obtained is exported into the HEC-HMS application. Additional processing can be done with the application of HEC-GeoHMS including the determination of other hydrological parameters such as curve numbers. The next step is to identify the distribution of soil types. To get a map of the types of data in the Karangmumus watershed, access the online: *http://www.fao.org/soils-portal/data-hub/soil-maps-and-databases/harmonized-world-soil-database-v12/en*. Furthermore, the preparation of a soil-type map at the research location was carried out. Based on the soil type map in Figure 6, it can be seen that the soil types in the Karangmumus watershed tend to be divided into 3 textures, namely coarse, medium and fine. The soil type map at the research location is converted from a raster file to an advanced processing file. To calculate the number of curves in addition to the soil type map, it is also necessary to include a land use map. Land use maps are needed because they contribute to surface runoff and topsoil erosion [23].

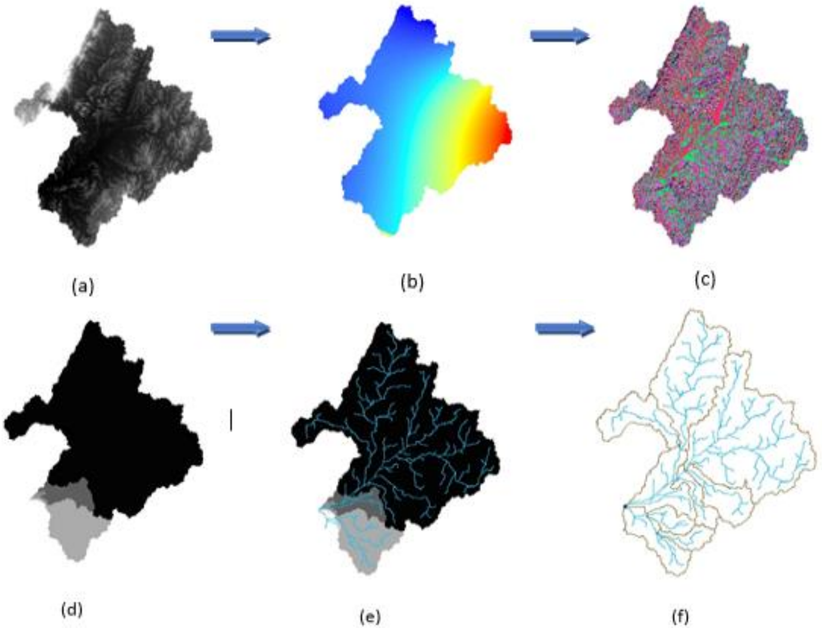


Figure 5. Stages and process of building a watershed model: (a) conceptualizing a digital elevation model; (b) filling the sink; (c) low direction; (d) catchment polygons; (e) basin raster; (f) accumulation of flow

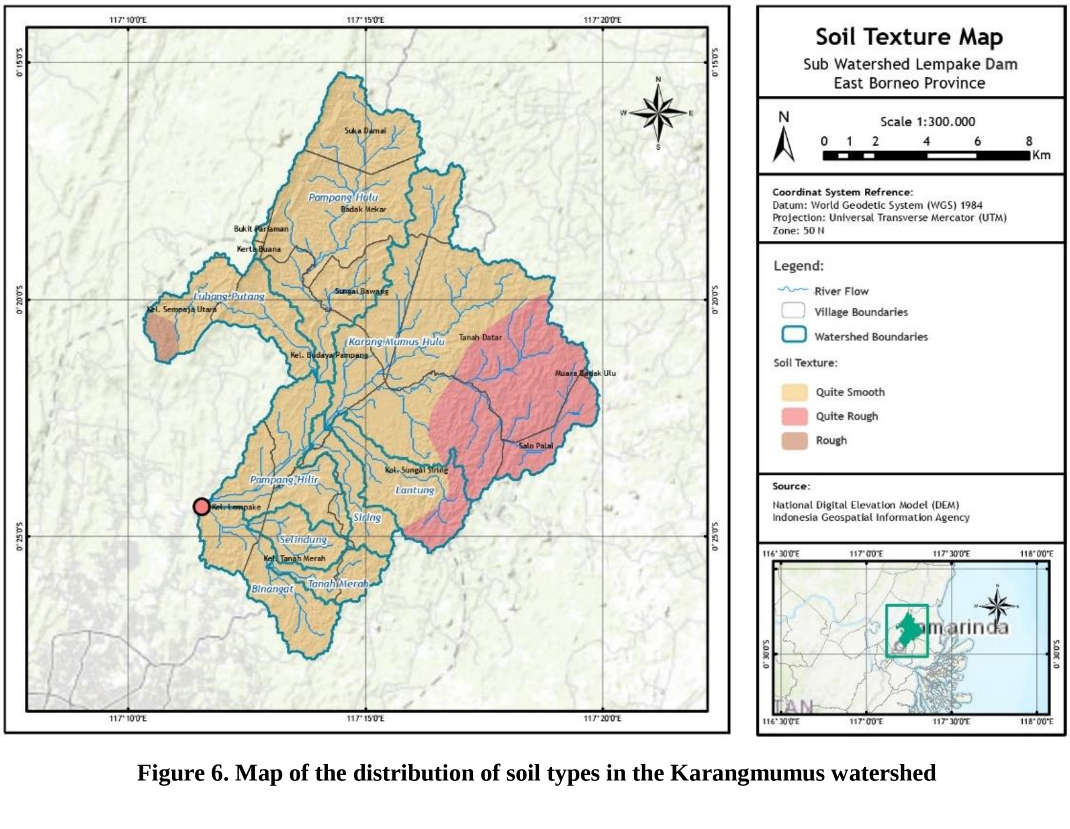


Figure 6. Map of the distribution of soil types in the Karangmumus watershed

Furthermore, the land use map that has been obtained is overlaid with a soil-type map to calculate the number of curves. The procedures for obtaining a land use map in the Karangmumus watershed include taking a map of the distribution of soil types to the website *http://due.esrin.esa.int/page_globcover.php*, (accessed on March 27, 2022). From the map, it is then exported into an Arc Info map, then copied as needed for the area under study only and then the raster file is converted to a file for processing purposes. Then the land use distribution file is overlaid with a map of the distribution of soil types in the same file format. The map of the distribution of land use in the Karangmumus watershed is presented in Figure 7. Based on the map, it can be seen that the distribution of land use is in the form of forest areas, paddy fields, and several settlements.

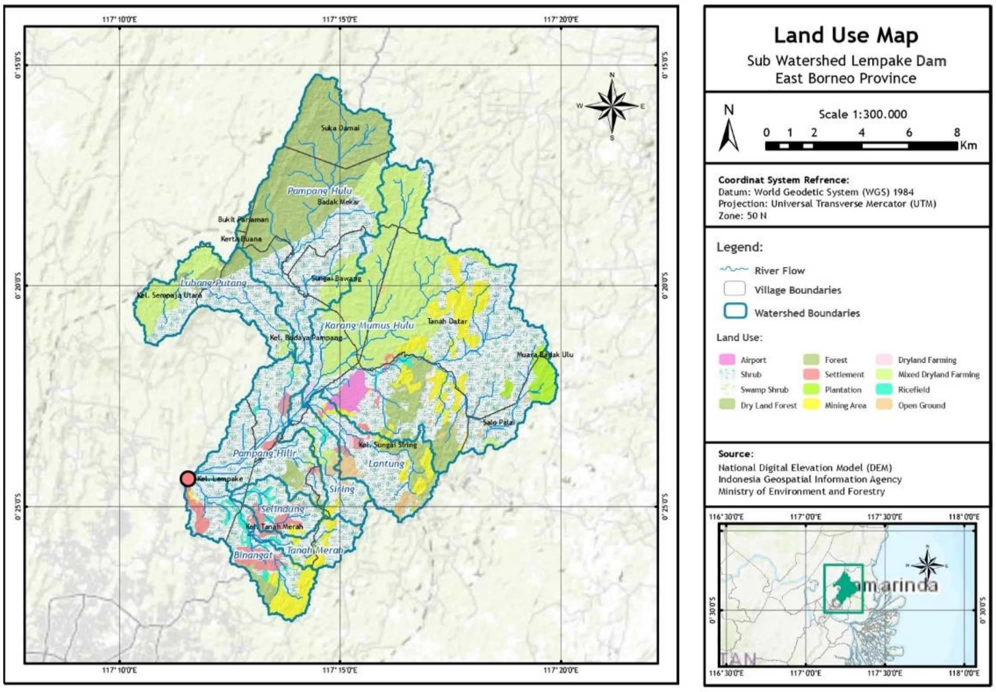


Figure 7. Classification of land use in the Karangmumus watershed

Land use maps and soil type distribution maps were compiled to obtain a Curve Number (CN) grid file and used for modeling in HEC-HMS. Furthermore, the CN value will be used to obtain hydrological parameters and determine the flow characteristics of each sub-watershed for modeling purposes [14]. Based on Figure 8, the distribution of CN values is between 46 to 91 with the category of soil that has high infiltration with permeable soil type.

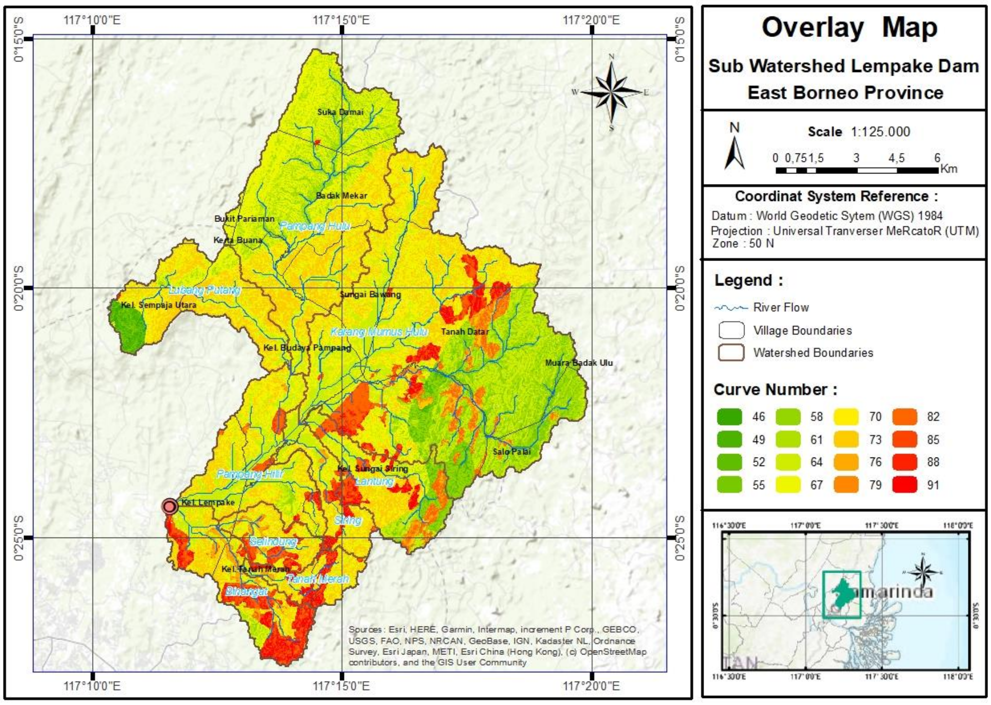


Figure 8. Calculation of curve figures for the Karangmumus watershed

3.1. Parameter Estimation

In doing the modeling can be done with sensitivity analysis [24, 25], to get the key parameters and precision for calibration, it can also use fundamental sensitivity analysis using partial differentiation. This method is the simplest which involves parameter values one by one [26]. The loss model in HEC-HMS is calculated by subtracting the volume of water intercepted, infiltrated, stored, evaporated, or transpired by the volume of rainwater [14]. Calculate direct surface runoff based on the results of the planned rainfall calculation, which is carried out using the lost curve number for services on soil conservation (SCS curve number). For the loss model, SCS-CN has two parameters: the number of curves (CN) and initial abstraction (Ia). The default initial abstraction ratio is equal to 0.2 but then varies after model calibration. CN is a function of soil type and use of land estimated using the HEC-GeoHMS toolkit from Arc Map 10.5. The percentage of imperviousness for each sub-basin is assumed to be 0% (all watersheds are assumed to be completely see-through). As for getting the CN value in each Sub-watershed, the following Equation 1 is used [27]:

$$CN = \frac{\sum A_i C.N_i}{\sum A_i} \tag{1}$$

CN is the curve number that corresponds to each sub-watershed, while Ai is the area of each sub-watershed (km^2). The Ia value is obtained by multiplying the abstraction potential value S (mm) with the loss coefficient. Abstraction potential (S) is a function of the CN value, then the S value can be determined using Equation 2 [27]:

$$S = \frac{1000-10.CN}{CN} \tag{2}$$

In hydrological modeling with the HEC-HMS application, namely by simulating the process of excess from direct runoff in the watershed, including transformation excess of rainfall that occurs at a direct runoff point [14]. In carrying out the analysis, the SCS method unit hydrograph is used to convert the excess rain that occurs into a direct runoff. The magnitude of the time lag parameter in the sub-watershed is taken into account when processing data using HEC GeoHMS whose output is stored in the form of an attribute table in the data layer for each sub-watershed. For the pause time in the sub-watershed, it is initially presented in hours and then with converted into minutes using HEC-HMS using Equation 3:

$$Lag = \frac{(S+1)^{0.7} L^{0.8}}{1900.Y^{0.5}} \tag{3}$$

where S is the maximum retention in mm as presented in Equation 2, lag is the lag time of the occurrence of the basin in hours, L is the hydraulic length in the catchment watershed (the longest waterway) in feet and Y is the slope value. from the watershed in the form of a percent (%). The estimation of the value of the transformation model and the Loss parameter is presented in Table 4.

Table 4. The Estimation of The Value of The Transform Model and The Loss Parameter

Sub Basin of Karangmumus	Basin Area (km^2)	Slope of Basin (%)	Number of Curve (CN)	Abstraction of Potential (mm)	Ia Factor (mm)
Lubang Putang	15,1713	3,19	67	125,10	25,02
Lantung	12,4701	3,88	82	55,76	11,15
Karang Mumus Hulu	75,0985	0,64	64	142,88	28,58
Selindung	5,8054	8,34	91	25,12	5,02
Tanah Merah	5,2583	9,60	91	25,12	5,02
Binangat	12,8284	3,77	91	25,12	5,02
Pampang Hilir	16,8506	2,87	76	80,21	16,04
Pampang Hulu	42,3442	1,14	67	125,10	25,02
Siring	6,7601	7,16	91	25,12	5,02

When there is a flow due to direct runoff into the river, it sometimes weakens because it is influenced by storage in the channel. The Muskingum method is used in routing the HEC-HMS application with an equalized flow system [28]. So, in the modeling, two parameters are calibrated, namely K and X. K is a parameter with a time unit ranging from 1 to 5 hours, while X is a dimensionless parameter with a value coefficient value between 0 to 0.5. X is the factor due to the relative flow at the Dam Lempake level which is assumed to be equal to 0.1 as the initial value at the time of calibration and then continues to be corrected during the calibration. The value of K can be calculated by Equation 4:

$$K = \frac{L}{V_W} \tag{4}$$

where V_W is the flow velocity when peak discharge occurs, whose value is determined to be 1.5 times the average velocity value, with the velocity value obtained at the flow meter site. The factor L is the length of the flow range. The value of K is also used to calibrate within limits using Equation 4 so that the simulated hydrograph is similar to and almost close to the observed hydrograph in the field. Direct runoff in a watershed with a dendritic watershed model can be simulated using a hydrological modeling method using the HEC-HMS application. By referring to the initial process with the HEC-GeoHMS application, then, imports are carried out with the HEC-HMS application as a basin-shaped file. The hydrological modeling system in the Karangmumus sub-watershed using the HEC-HMS application is presented in Figure 9. Valid and complete input data is very important in the use of the HEC-HMS application. The roots of modeling rain into runoff have good accuracy and are dedicated to the results of field observations. The parameters that are calculated include loss parameters such as initial abstraction and percentage of imperviousness, number of curves, routing parameters (k and x), and transformation parameters or lag time. Furthermore, these parameters are added to each sub-watershed with range options either automatically or manually from the attribute table values in the GIS application. The data measuring temperature, rain height, evaporation, and discharge are added to a time series using a data manager. Tables that express the relationship between elevation and the area of dams can be added as paired data. Furthermore, in 3 years of hydrology, 2017, 2018, and 2019, it was made into three files and then input as rainfall data in the meteorology folder. For running, the daily rain starts on January 1 at 00:00 then ends on December 31.

Figure 9. The modeling system of Hydrology in Karangmumus watershed using HEC-HMS

3.2. Model Calibration

In calibrating using rain data from the 2017 and 2018 hydrological years. Manual calibration is used to determine the magnitude of the varying parameter values, and then the optimal value for the Muskingum Method parameters (k, x) is obtained by comparing the direct runoff simulation results with direct runoff from field observations. The magnitude of the Loss Model and Transform Model parameters are obtained using the explanation in the previous section, while the Lempake dam technical data and other data needed to support the running of the HEC-HMS program application, such as dam inundation area, overflow elevation, dam peak elevation, and so on, were obtained from the Ministry of PUPR of the Republic of Indonesia.

3.3. Comparison of Simulation and Observation Hydrographs and Model Validation

After calibration, the direct runoff from the simulation results with the HEC-HMS application is compared with the direct runoff from field observations in 2017 and 2018, which is presented in Figure 10, which shows different results but has a trend and an almost identical value. The simulation results with the HEC-HMS application in this study show an acceptable level of conformity with the trend, and the shape of the hydrograph seems somewhat compatible (the R^2 value for the 2017 calibration period is 0.88, while the value for the 2018 calibration year is 0.91). The results of the comparison of R^2 values are presented in Figure 11.

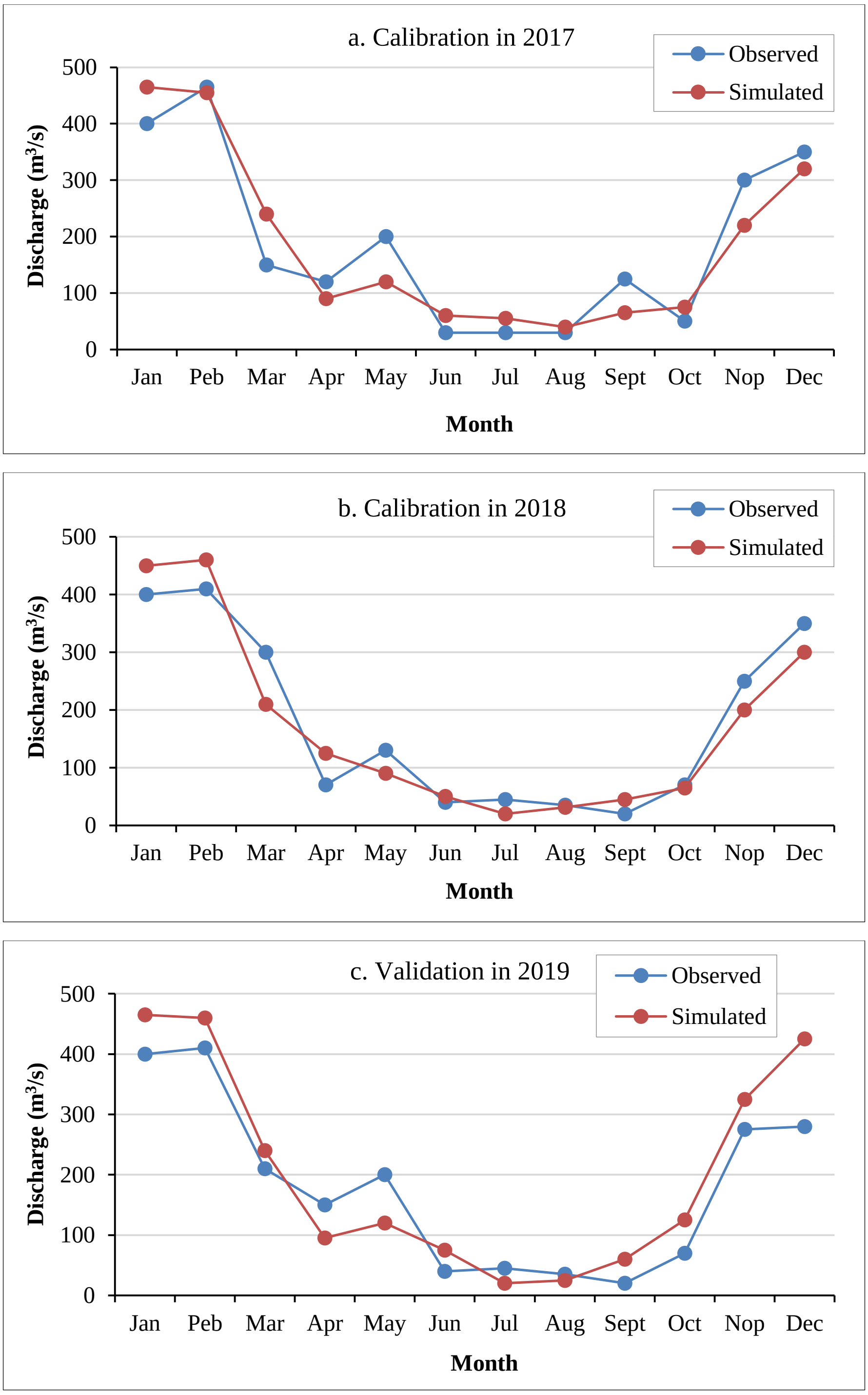
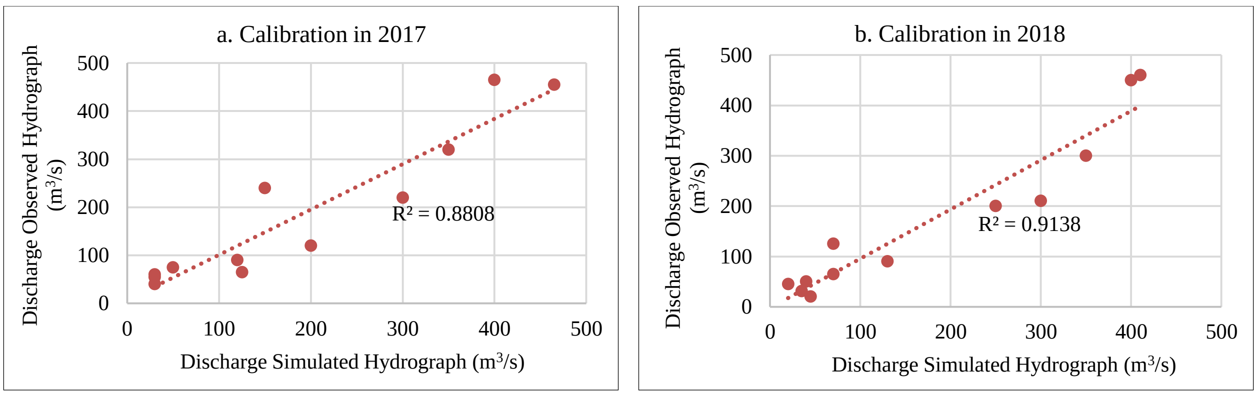


Figure 10. Comparison of observed and simulated discharge at Lempake Dam (a) Calibration in 2017; (b) Calibration in 2018; and (c) validation in 2019



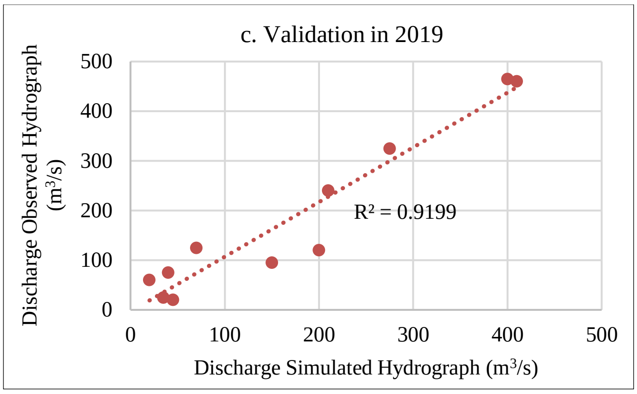


Figure 11. The results of the regression distribution plotting (a) Calibration of the Lempake Dam in 2017; (b) Calibration of the Lempake Dam in 2018; and (c) Validation of Lempake Dam in 2019

Similar results were obtained by Oleyiblo et al. [29] for R^2 of 0.9, for the Misai and Wan'an watersheds in China with the HEC-HMS application. Tassew et al. [15], have compared the direct runoff observed with the HEC-HMS simulation results and resulted in an R^2 of 0.925 and reliability of the NSE model of 0.884. Based on these results, this model is suitable for use in simulations of hydrology in the Gilgel Abay watershed. Including the modeling carried out in the Al-Adhaim, Northern Iraq, watershed, the results of R^2 are quite good at 0.92 [18, 30]. Similarly, Barbosa [12] has seven different formulas to investigate hydrological performance with the HEC-HMS method: MAE, RSR, RMSE, NSE, R^2, KGE, and PBIAS, which finally succeeded in obtaining the conclusion that the HEC-HMS model can represent hydrological processes on the distribution of watersheds investigated effectively, efficiently, and with good accuracy. So based on the explanation of the results of this study compared to the results of other researchers, it can be concluded that this model can perform quite well and can perform simulations to get satisfactory results. Furthermore, the results also show that the time lag and the percentage of watertight areas do not significantly affect direct runoff. The main influences are the number of curves and the initial abstraction. Based on the previous research for several watersheds in Indonesia, it still produces quite large variations [7, 8]. With significant land use changes, high soil variations, and being in an equatorial position, the results of this study at the same time describe watersheds in Indonesia. It is not enough just to use GIS data but must also verify that there are land and land use data and then verify the existence of land use data. Rain data that results from Peru GIS integrated with Geo HEC-HMS will produce a model that is relatively close to field conditions.

4. Conclusion

The HEC-HMS hydrological model can be used in combination with GIS and HEC-GeoHMS in identifying the transformation of rain into a direct runoff, the time lag and the percentage of impermeable areas do not significantly affect direct runoff. The main influences are the number of curves and the initial abstraction. The hydrological modeling in the Karangmumus watershed with the Lempake Dam outlet, which compares the direct runoff from field observations in 2017 and 2018, is presented in Figure 9, which shows different results but has a trend and an almost identical value. The simulation results with the HEC-HMS application in this study show an acceptable level of conformity with the trend, and the shape of the hydrograph seems somewhat compatible (the R^2 value for the 2017 calibration period is 0.88, while the value for the 2018 calibration year is 0.91). Furthermore, it was validated by direct runoff from observations in the 2019 hydrological year, which obtained a fairly good R^2, with an R^2 value of 0.92, higher than the 2017 hydrological year and the 2018 hydrological year. In hydrological modeling with HEC-HMS in the Karangmumus watershed, the data can be exported further. can generate 2-dimensional flood inundation maps using additional HEC-RAS applications, including forecasting rain height using a suitable program for predicting long-term flood events.

5. Declarations

5.1. Author Contributions

Conceptualization, N.S.R.; methodology, N.S.R.; software, A.E.W.; validation, I.U., K.M. and N.S.R.; formal analysis, A.E.W.; investigation, I.U.; resources, K.M.; data curation, I.U.; writing—original draft preparation, N.S.R.; writing—review and editing, N.S.R.; visualization, A.E.W.; supervision, N.S.R.; project administration, N.S.R.; funding acquisition, N.S.R. All authors have read and agreed to the published version of the manuscript.

5.2. Data Availability Statement

The data presented in this study are available on request from the corresponding author.

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5.4. Conflicts of Interest

The authors declare no conflict of interest.

6. References

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