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FLOOD MODELLING OF RIAM KIWA WATERSHED USING HEC-HMS

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ABSTRACT

At the end of 2021 to early 2022 several areas in Banjar Regency were flooded. This incident had a major impact on the surrounding area and became a national concern. One of the causes of the disaster was high-intensity rainfall which caused the water in the Riam Kiwa River to overflow. HEC-HMS software was used to simulate the designed flood discharge. This research aims to model the magnitude of the designed flood discharge with return periods of 5, 25, 50, and 100 years. Due to limitations of rainfall data from the field, satellite data from GSMaP were collected. In the distribution of rainfall frequency analysis, the Log Pearson type III method was chosen for calculating designed rainfall. Then, the Modified Mononobe Method was applied to calculate hourly rainfall intensity. Other data i.e., soil types, slope gradient and land use were analyzed using ArcGIS application. These three data produced hydrological parameters which were used as input values in the HEC-HMS using the Soil Conservation Service (SCS) method. Three parameters' values show that Riam Kiwa watershed has more than 90% clay with a slope gradient of 83.58% (steep slope) and land use is predominantly consisted of mixed dryland agriculture (47.73%). From HEC-HMS simulation, it was found that Riam Kiwa watershed with an area of 1781.77 km^2 produces maximum flood discharge ranges from 8,822.3 m^3/s to 17,058.6 m^3/s; with a water volume ranges from 182,991.9 m^3 to 340,889.6 m^3 in 5 years to 100 years return periods, respectively. From the results, it can be concluded that impermeable clay soil and steep slope are the two major factors that contribute to the flooding occurrence in the area.

1. INTRODUCTION

Flood is a disaster that can threaten the existence of buildings and the lives of many people. Floods occur because the river is unable to accommodate the volume of water due to heavy rains that hit an area (Kusumo and Nursari, 2016). In addition, the lack of water catchment areas and drainage systems that are not properly planned or designed can contribute to causing flooding (Rante et al., 2016; Sesunan, 2014).

Floods that occurred at the end of 2021 until early 2022 in several areas of Banjar Regency, South Kalimantan Province were flood events with high rainfall intensity due to the overflow of the Riam Kiwa River (BNPB, 2021). Riam Kiwa river is a tributary of the Martapura River. Based on the monitoring of the Regional Disaster Management Agency (aka BPBD) of Banjar Regency, floods have inundated the Pengaron lowlands up to the knees of adults. At its lowest point, the height reached nearly 2 meters, causing the submergence of 582 houses in the area (Madani, 2022; BNPB, 2021).

The Meteorology, Climatology and Geophysics Agency or BMKG noted that the rainfall that occurred on January 12, 2022, reached 110.2 millimeters (mm). The rainfall is categorized as extreme rainfall. According to data from the Banjarbaru Climatology Station, January 2022 is the peak of the rainy season in South Kalimantan Province (Hidayat, 2022).

One of the studies conducted hydraulically (Wijayanto & Helda, 2022) in the Martapura sub-sub-watershed, South Kalimantan Province was using the HEC-RAS 5.0.7 software with unsteady flow condition to model the flooding. This unsteady flow condition analyzed the changeable water flow in a river to imitate flow of a flood. Basically, flood calculations in a watershed can also be calculated through hydrological analysis (Djafar et al., 2014). This analysis is an important analysis in determining the magnitude of the designed flood discharge so that damage to all aspects of life can be avoided. Another way to calculate the designed discharge is to use the HEC-HMS hydrological model. The HEC-HMS (Hydrologic Engineering Center's - Hydrological Modeling System) model is one of the hydrological models used in analyzing flood discharge at flood system control points (Pasa et al., 2017). It is designed to simulate rainfall-runoff processes based on the watershed characteristics and behaviour, resulting to a good value of field approach (Wiliya and Lasminto, 2022). Therefore, this research uses the HEC-HMS software to apply hydrological modeling in the Riam Kiwa Watershed.

2. THEORETICAL STUDY

Watershed or basin are areas where rainwater falls in areas bounded by mountains and then collects and flows into the main river (Triatmodjo, 2008). Average rainfall in the watershed was analyzed statistically to obtain an appropriate distribution model of rainfall data. The purpose of this frequency analysis is to use the probability distribution to find the relationship between the magnitude of extreme events and the frequency of their occurrence (Anonymous, 2018). Goodness of fit test is a test used to check whether the data distribution is as desired. In this distribution test there is a chi-square test and the Smirnov-Kolmogorov (Soewarno, 1995).

Rainfall intensity is the amount of rainwater that falls and is concentrated in a certain area and time (Loebis, 1992). It is one of the factors which contributes to estimate the designed flood discharge. The Designed Flood Discharge is the maximum discharge calculated based on a certain return period of rainfall on a river or canal. Flood discharge forecasts are used as a basis for planning irrigation buildings so that these buildings can accommodate the amount of flooding that may occur during the return period (Armila and Akbar, 2021).

In this research, ArcGIS application was widely used in all stages. It is an application developed by ESRI (Environmental Research Institute) in analyzing, modeling and managing spatial data effectively and efficiently. One of the important tools used was DEM data processing by describing the shape of the earth's contours. It produced boundaries and area of watersheds, river networks, land use, and soil types (Wijayanto & Helda, 2022).

Then, for analyzing hydrological parameters, the Hydrologic Engineering Center – Hydrologic Modeling System (HEC-HMS) was used. It is developed by the US Army Corps of Engineers which is a software to model the process of rainfall or precipitation and direct runoff from a watershed. The HEC-HMS is designed for a wide geographic area in solving watershed water supply, flood hydrology, and runoff problems in small urban areas or natural watersheds (US Army Corps of Engineers, 2000).

3. METHODS

This research is located in the Riam Kiwa Watershed, Banjar Regency, South Kalimantan Province with a watershed area of 1781.77 km^2. The main river, the Riam Kiwa River, has a length of 175.42 km. Figure 1 represents the Riam Kiwa watershed.

This study used secondary data i.e., rainfall data, soil type, land use, and the delineation of Riam Kiwa watershed. All of this data will be inputted to the HEC-HMS. The first step taken in this research is to process the existing data into the necessary parameters for flood discharge modeling using the HEC-HMS. Due to the limited rainfall data obtained from the BMKG station for the Riam Kiwa watershed area, the GSMap satellite rainfall data was collected. GSMaP is a product of weather satellite data from the Japan Aerospace Exploration Agency (JAXA) which is used to estimate rainfall intensity (JAXA, 2008). After the rainfall data were obtained, the maximum daily rainfall data were analyzed. Later, this data will be entered into the calculation of frequency analysis to obtain an appropriate rainfall data distribution model and tested for compatibility with both of the Chi-square test and the Smirnov-Kolmogorov test (Anonymous, 2018; Soewarno, 1995). After the suitable distribution was selected, hourly rainfall data were calculated using the Modified Mononobe method.

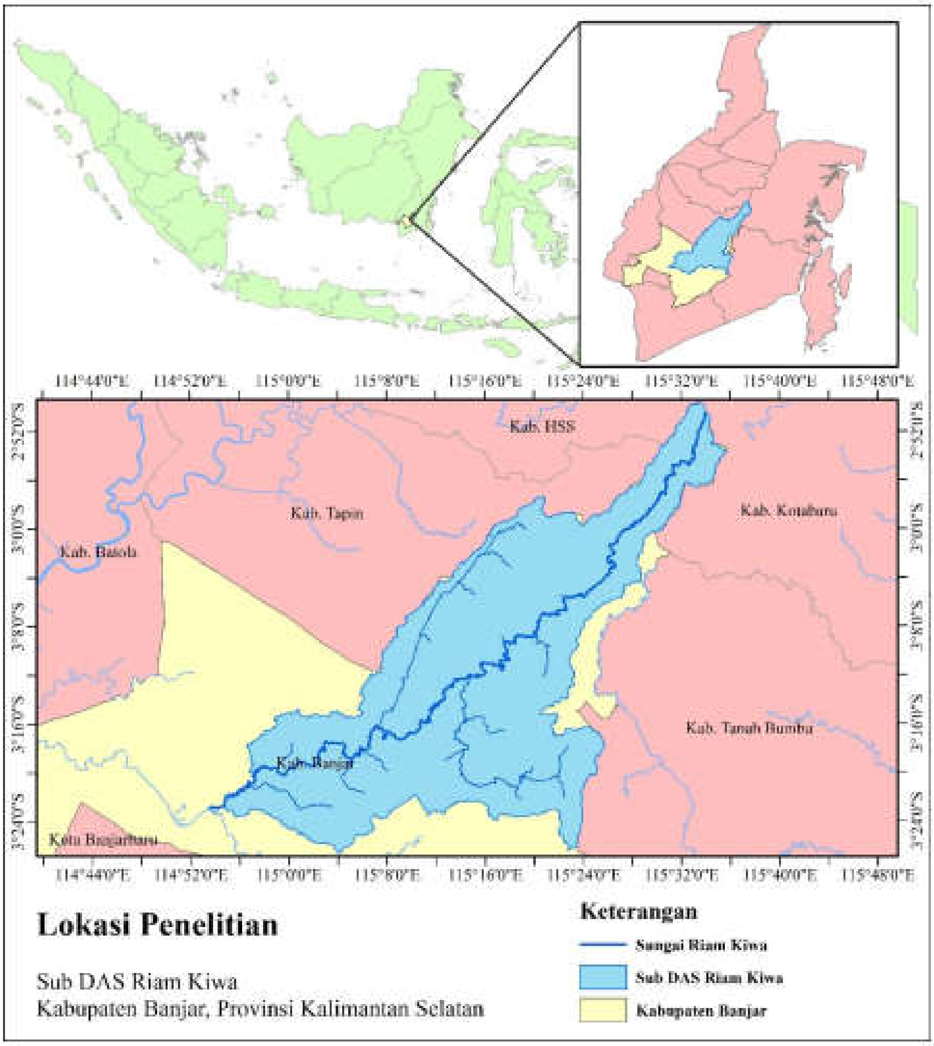

Figure 1. The Riam Kiwa Watershed

The Riam Kiwa watershed map were obtained from DEMNAS delineation data processing using ArcGIS HEC-GeoHMS (BIG, 2018). This process stage generated the river pattern network and its sub-watershed areas which were used as HEC-HMS inputs for the basin model. In this study, the amount of flood discharges was computed using the SCS curve number by estimating the effective rainfall from surface runoff (SCS, 1972; Sitanggang et al, 2014). SCS Curve Number consists of several parameters that must be put in, namely initial abstraction, SCS Curve Number, percent of impervious stage, and lag time (US Army Corps of Engineers, 2000; USDA NRCS, 2005; Tikno et al., 2012; Apriyanza et al., 2018; Sultan et al., 2022). This method takes data on soil type, slope and land use as input parameters and then processes them using ArcGIS.

4. RESULTS AND DISCUSSION

The GSMaP rainfall data used comes from three coordinates of rain stations in the Riam Kiwa watershed. The rain stations include Atayo, Lawa Baru, and Madurejo. The three stations calculated the maximum areal rainfall using the Thiessen Polygon method as shown in Figure 2. The results of calculating the rainfall for the Thiessen polygon area can be seen in Table 1.

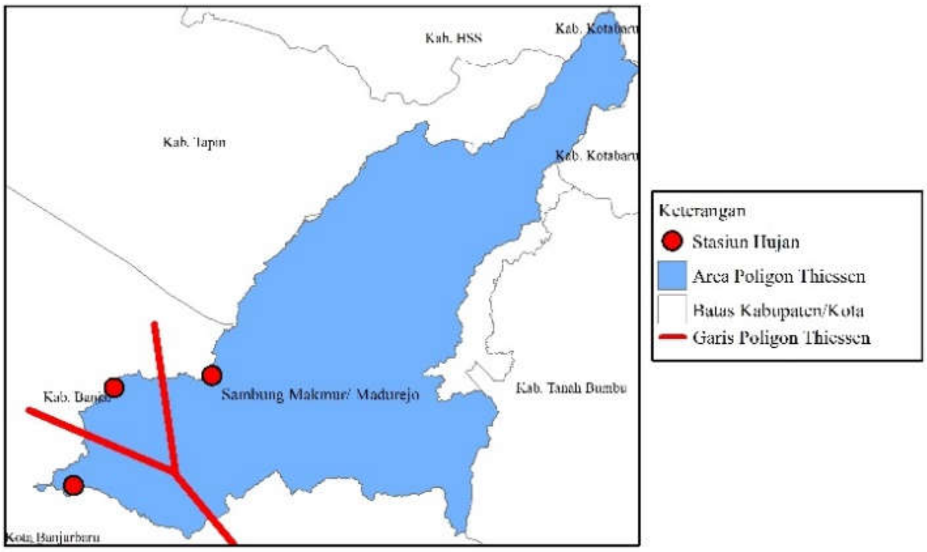

Figure 2. Areal Rainfall with Thiessen Polygon Method

Table 1. GSMaP Maximum Daily Rainfall

No.	Year	Maximum Daily Rainfall (mm)			R max (mm)
		Sta. Atayo	Sta. Lawa Baru	Sta. Madurejo	
		122.68	91.97	1567.12	
1	2001	52	197	193	183.44
2	2002	69	117	134	129.02
3	2003	77	65	82	80.39
4	2004	197	101	107	112.82
5	2005	66	99	77	77.53
6	2006	179	116	152	152.41
7	2007	134	52	78	80.17
8	2008	185	132	117	122.16
9	2009	70	42	51	52.11
10	2010	122	151	185	178.56
11	2011	171	162	199	195.52
12	2012	162	182	174	173.65
13	2013	150	192	163	163.33
14	2014	190	163	183	182.49
15	2015	71	118	108	106.23
16	2016	121	139	132	131.67
17	2017	111	74	67	70.16
18	2018	186	79	103	107.27
19	2019	107	59	64	66.39
20	2020	93	126	103	103.21
21	2021	184	110	97	104.06

Sub-watersheds delineation comes from DEM data processing using HEC-GeoHMS. The steps include DEM Reconditioning, fill sinks, flow direction, flow accumulation, stream definition, stream segmentation, catchment grid delineation, catchment polygon processing, drainage line processing, and adjoint catchment processing (Mewarde, 2019). The results obtained are the Riam Kiwa watershed which is divided into seven sub-watersheds as shown in Figure 3.

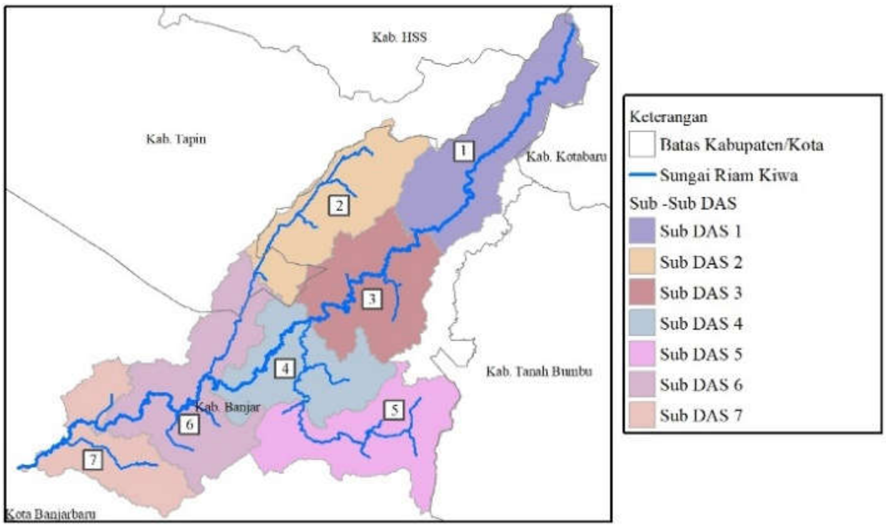

Figure 3. Riam Kiwa Watershed with seven sub-watersheds

4.1 Hydrological Model Parameters

Apart from the area of the sub-watersheds, the parameters required for HEC-HMS input are curve number, percent of impervious, initial abstraction, and time lag. It is necessary to process data on soil types, slope gradient and land use using HEC-GeoHMS. The process connects to the Hydrological Soil Group (HSG). This HSG consists of groups of A, B, C, and D soil type with different rates of infiltration (McCuen, 1998). The different soil types in Riam Kiwa watershed can be seen in Figure 4.

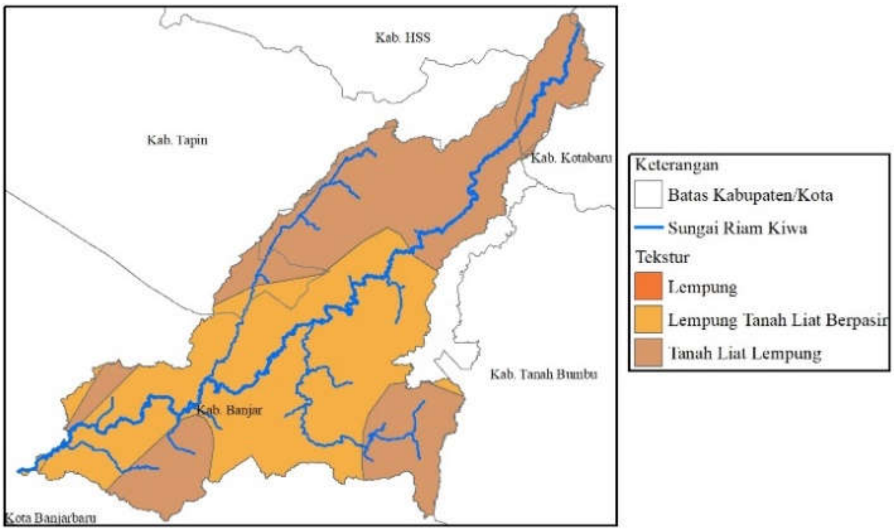

Figure 4. Soil Type in Riam Kiwa Watershed

Figure 4 shows that Riam Kiwa Watershed is predominantly occupied by soil type of sandy clay loam as much as 51.23% of the area, followed by 48.76% clay loam and 0.01% loam. Based on HSG soil types, loam soil is categorized in group B, sandy loam in group C and sandy clay loam in group D, respectively. Based on the topography, slope gradient is represented in Figure 5.

Figure 5 shows that the steep slope (as indicated in red color) shapes the Riam Kiwa Watershed. They were flat, undulating, rolling, moderately steep, and steep. The largest one is steep slope, which occupies 83.58% of the watershed area. The upstream parts are on mountainous area, while the downstreams are in the Martapura River.

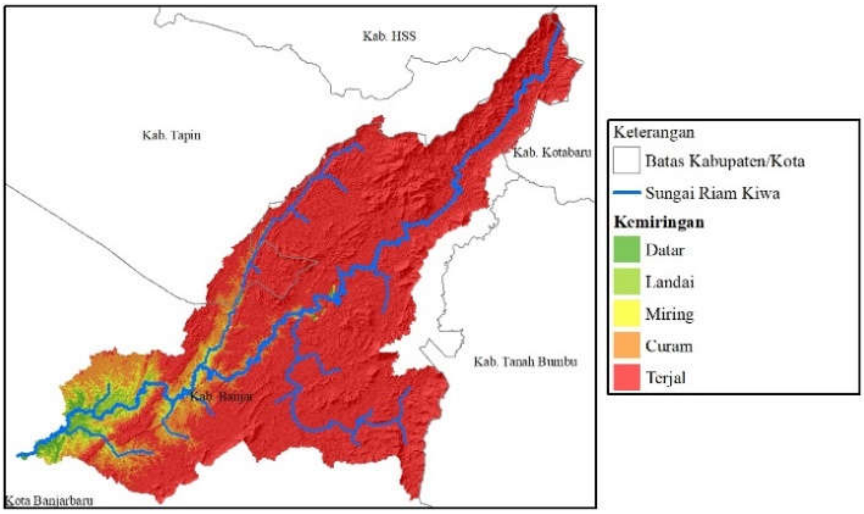

Figure 5. Slope Gradient in Riam Kiwa Watershed

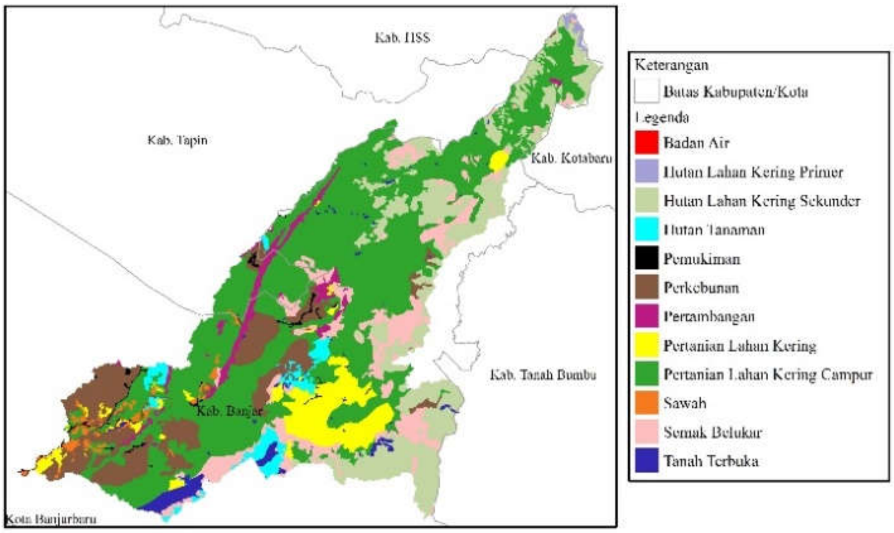

Figure 6. Land Use in Riam Kiwa Watershed

According to data from BPDASHL Barito in Figure 6, the Riam Kiwa Watershed has 8 types of land use. Among these types, most of them are mixed dryland agriculture which covers almost 47.68% of the watershed area. The changes in land use can inflict the changes in water balance and hydrological cycle of the area (Rahmawati et al, 2019). These land uses together with soil type and slope gradient were analyzed by using ArcGIS. The results of this analysis are used in the calculation stage to determine the values of the SCS parameters in each sub watershed. The result of parameter values can be seen in Table 2.

Table 2. Hydrological Parameters for Input HEC-HMS

Description	Unit	Sub-Watershed Name						
		1	2	3	4	5	6	7
Area of Sub-Watersheds	km^2	300.87	238.43	255.54	223.95	263.36	313.00	186.63
Curve Number (CN)		79.95	78.75	76.89	76.15	77.87	77.33	78.61
Impervious	%	7.22	12.78	10.87	9.07	6.09	13.35	8.55
Inital Abstraction (Ia)	mm	12.74	13.71	15.27	15.91	14.44	14.89	13.83
Time Lag (T_L)	minutes	65.82	74.75	88.08	129.81	66.22	162.93	122.88

From Table 2, it can be seen that the Riam Kiwa sub-watersheds has the widest area in Sub DAS 6 with an area of 313 km^2, while the smallest area is 186.63 km^2 in Sub DAS 7. Based on HSG, Curve Number (CN) ranges from 76.15 to 79.95 indicated that most of the soil were categorized into class C and D which has low to very low infiltration rate. As a result, they would contribute to high surface run off.

Percent of impervious ranges from 6.09 to 13.35 which represents the magnitude of water absorption ability of the land. The higher the value the lower the ability. Most of the land is mixed dryland agriculture. The initial abstraction values were obtained from CN values. They range from 12.74 mm to 15.91 mm. The higher the values the higher water loss before infiltrating so discharge value becomes smaller. Time lag (T_L) value has ranges from 65.82 minutes to 162.93 minutes. Its originated from steep predominance in topography of the watershed.

4.2 Modeling of Designed Flood Discharge with HEC-HMS

The Basin model of the Riam Kiwa Watershed in the HEC-HMS modeling is composed of seven sub-watersheds with one outlet located downstream. In addition, there are also junctions and reachs as connecting elements. This model basin can be seen in Figure 7.

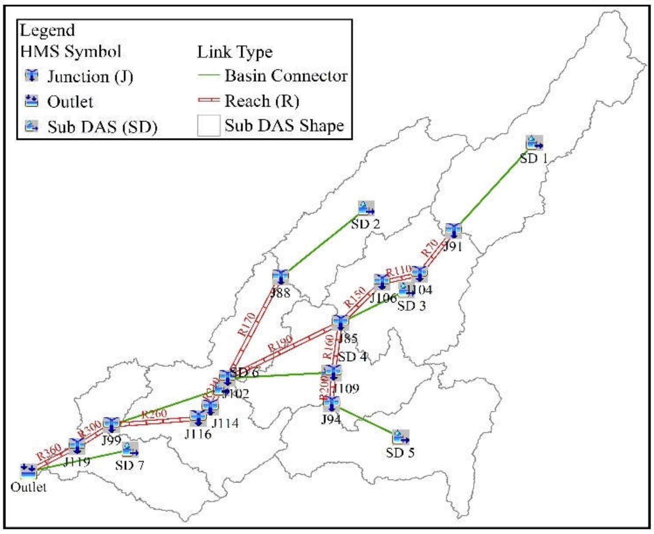

Figure 7. Sub-watershed Model for Input HEC-HMS

In modeling with the HEC-HMS, it also uses the land parameters as input values in the basin model. The parameters used are "loss" and "transform" components These components use the SCS Curve Number and SCS Unit Hydrograph methods. The loss components include curve number, impervious, and initial abstraction, while the transform component is the time lag. By adding the rainfall data input, the HEC-HMS simulation running results are flood discharge hydrographs from various return periods as represented in Figure 8.

Based on Figure 8, it can be seen that the peak hydrograph flood output discharge occurs at the 3rd hour in 5-, 25-, 50-, and 100-year return periods. The characteristics of the rain and watershed affect the shape of the hydrograph. Rain characteristics can be in the form of intensity, direction of motion, and duration of rain. The greater the rain intensity, the faster the hydrograph rises, and the peak discharge also becomes larger (Limantara, 2010). The value of the hydrograph for each hour at various return periods can be seen in Table 3 which shows the values of water discharge at certain times, with different return periods. From Table 3, it can be seen that the water discharge is expected to increase over time, and a higher return period indicates a higher water discharge. This shows that floods that occur with higher return periods are expected to be larger. The table can be used to predict the level of flooding that will occur at certain times and with different return periods, as well as to take necessary precautions to prevent or reduce the impact of flooding.

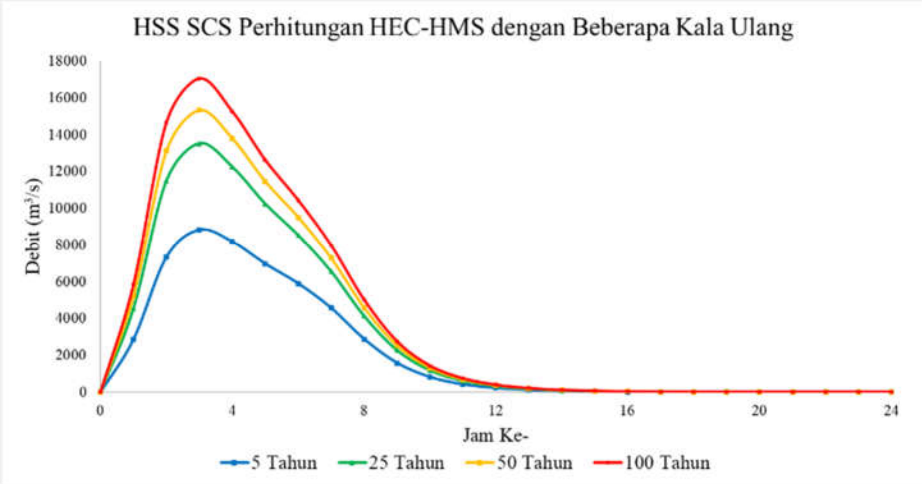

Figure 8. HSS HEC-HMS Modeling

Table 3. Flood Discharge Output HEC-HMS

t (Hours)	Output Discharge HEC-HMS (m^3/s)			
	5 Years	25 Years	50 Years	100 Years
0	0	0	0	0
1	2854.2	4542.5	5206.6	5839.5
2	7334.9	11498.4	13126.2	14673.4
3	8822.3	13519	15336.7	17058.6
4	8176	12242.9	13799.8	15270
5	6971.2	10230.7	11466.5	12630.6
6	5897.2	8521.8	9510	10438.9
7	4565.5	6540.7	7282	7977.6
8	2883	4117.4	4580.1	5014
9	1584.8	2262.6	2516.7	2754.8
10	822.2	1174.6	1306.8	1430.7
11	428.6	613.2	682.4	747.4
12	229	327.9	365	399.9
13	122.5	175.3	195.1	213.7
14	66.9	95.8	106.6	116.8
15	36.7	52.5	58.4	64
16	19.1	27.1	30	32.8
17	9.6	13.5	15	16.4
18	4.5	6.4	7.1	7.7
19	2.1	2.9	3.2	3.5
20	0.7	1	1.2	1.3
21	0.1	0.1	0.2	0.2
22	0	0	0	0
23	0	0	0	0
24	0	0	0	0

The results of HEC-HMS modeling also produce discharge values and peak volumes for each hydrological element with various return periods which can be seen in Table 4. From Table 4, it can be seen that by increasing the return period used in the HEC-HMS modeling, the value also increases both in terms of discharge and volume. The outlet is a hydrological element that has a maximum discharge and volume. With a discharge value and peak volume of 8,822.3 m^3/s and a water volume of 182,991.9 m^3 (5 years return period), the discharge is 13,519.0 m^3/s with a volume of 273,479.0 m^3 (25 years return period), discharge of 15,336.7 m^3/s with a volume of 308,144.2 m^3 (50 years return period), and discharge of

17,058.6 m^3/s with a volume of 340,889.6 m^3 (100years return period), respectively. This is due to the outlet as the last place, which is downstream of the sub-watershed elements, junctions and reach so that it must have the largest discharge value and volume of the other hydrological elements.

In another study on the Riam Kiwa River Astambul Kota Section with area of 0,83 km^2, the discharge results range from 2,229.527 m^3/s to 3676.494 m^3/s with a return period of 2 years to 100 years. This study used HECRAS 4.1.0 modeling, and the results found that the capacity of the river could not accommodate flood discharges with repeated periods that occurred (Noor & Utomo, 2013).

Table 4. Output HEC-HMS Modeling in Each Hydrological Elements

Hydrological Elements	Peak Discharge (m^3/s)				Volume (m^3)			
	5 Years	25 Years	50 Years	100 Years	5 Years	25 Years	50 Years	100 Years
Sub DAS 1	2053.9	3175.0	3610.0	4022.1	31866.0	47338.4	53248.0	58824.1
Sub DAS 2	1561.3	2406.8	2735.7	3047.7	25352.1	37566.1	42235.0	46641.8
Sub DAS 3	1391.9	2127.3	2426.9	2715.8	25775.9	38662.0	43606.9	48281.0
Sub DAS 4	1015.4	1562.4	1783.0	1992.7	21937.5	33140.4	37448.0	41522.6
Sub DAS 5	1656.6	2608.0	2979.6	3332.7	26374.1	39694.1	44802.7	49630.4
Sub DAS 6	1385.3	2104.8	2382.8	2646.0	32381.5	48258.6	54342.2	60089.4
Sub DAS 7	933.0	1437.6	1633.3	1818.7	19304.8	28819.6	32461.4	35900.4
Outlet1	8822.3	13519.0	15336.7	17058.6	182991.9	273479.0	308144.2	340889.6
J85	4927.0	7706.8	8791.4	9821.4	84016.0	125694.4	141657.6	156735.4
J88	1561.3	2406.8	2735.7	3047.7	25352.1	37566.1	42235.0	46641.8
J91	2053.9	3175.0	3610.0	4022.1	31866.0	47338.4	53248.0	58824.1
J94	1656.6	2608.0	2979.6	3332.7	26374.1	39694.1	44802.7	49630.4
J99	7989.5	12208.6	13839.5	15383.8	163687.2	244659.4	275682.8	304989.2
J102	6877.4	10757.6	12272.8	13712.5	131305.6	196400.8	221340.6	244899.8
J104	2025.8	3133.0	3562.7	3969.9	31866.0	47338.4	53248.0	58824.1
J106	2011.5	3111.6	3538.6	3943.2	31866.0	47338.4	53248.0	58824.1
J109	1633.2	2572.5	2939.5	3288.2	26374.1	39694.1	44802.7	49630.4
J114	6823.9	10568.0	12057.4	13472.6	131305.6	196400.8	221340.6	244899.8
J116	6822.7	10473.5	11950.1	13353.1	131305.6	196400.8	221340.6	244899.8
J119	7943.4	12151.5	13779.0	15320.4	163687.2	244659.4	275682.8	304989.2
R70	2025.8	3133.0	3562.7	3969.9	31866.0	47338.4	53248.0	58824.1
R110	2011.5	3111.6	3538.6	3943.2	31866.0	47338.4	53248.0	58824.1
R150	1968.5	3047.1	3465.8	3862.7	31866.0	47338.4	53248.0	58824.1
R160	1609.5	2536.5	2898.7	3242.9	26374.1	39694.1	44802.7	49630.4
R170	1509.0	2327.6	2646.0	2948.2	25352.1	37566.1	42235.0	46641.8
R190	4686.7	7339.3	8374.8	9358.4	84016.0	125694.4	141657.6	156735.4
R200	1633.2	2572.5	2939.5	3288.2	26374.1	39694.1	44802.7	49630.4
R210	6823.9	10568.0	12057.4	13472.6	131305.6	196400.8	221340.6	244899.8
R230	6822.7	10473.5	11950.1	13353.1	131305.6	196400.8	221340.6	244899.8
R260	6811.9	10389.9	11771.1	13078.3	131305.6	196400.8	221340.6	244899.8
R300	7943.4	12151.5	13779.0	15320.4	163687.2	244659.4	275682.8	304989.2
R360	7889.3	12081.4	13703.4	15239.9	163687.2	244659.4	275682.8	304989.2

5. CONCLUSION

From this study it can be concluded that impermeable clay soil and steep slope are the two major factors that contribute to the flooding occurrence in Riam Kiwa Watershed. Three parameters' values show that watershed has more than 90% clay with a slope gradient of 83.58% (steep slope) and land use is predominantly consisted of mixed dryland agriculture (47.73%). The result of HEC-HMS simulation shows that Riam Kiwa watershed with an area of 1781.77 km^2 produces maximum flood discharge ranges from 8,822.3 m^3/s to 17,058.6 m^3/s; with a water volume ranges from 182,991.9 m^3 to 340,889.6 m^3 in 5 to 100 years return periods, respectively. These results show that this large watershed has a potentially severe impact on the surrounding area if a flood event occurs with these magnitudes. It is recommended to conduct further research including analysis of structural and non-structural flood prevention for this area.

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