Analysis of Design Flood Discharge Based on Measured Rainfall Data and Satellite Rainfall Data in Tukad Petanu Watershed, Gianyar Regency

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Abstract. Design flood discharge analysis is required in the planning of water structures in a watershed. The unit hydrograph method is commonly used in designing flood discharge calculations that require rainfall data in the analysis. Current technology makes it possible to use satellite data as an alternative to data from rain gauge stations whose distribution is very limited. The rainfall data used in this study uses measured rainfall data from rain gauge stations and the PERSIANN satellite. The calculation results from both data will then be validated with the river flood discharge recorded at the Tukad Petanu Hulu AWLR Station and see the suitability. This research shows that the amount of design flood discharge in Tukad Petanu watershed analyzed using Nakayasu SUH based on measured rainfall data for 5, 10, 25, 50, and 100-year return periods is 58.16 m^3/sec, 67.99 m^3/sec, 82.76 m^3/sec, 95.88 m^3/sec, and 110.81 m^3/sec, while based on PERSIANN satellite rainfall data for the same return period of 77.19 m^3/sec, 83.64 m^3/sec, 90.62 m^3/sec, 94.84 m^3/sec, and 98.51 m^3/sec, respectively. The design flood discharge in the Tukad Petanu watershed based on measured discharge data at the Tukad Petanu Hulu AWLR Station for the same return period is 15.75 m^3/sec, 24.94 m^3/sec, 42.47 m^3/sec, 61.28 m^3/sec, and 86.63 m^3/sec, respectively. The level of conformity of the design flood discharge generated by the Nakayasu Method using measured rainfall data and the PERSIANN satellite has a higher value than the discharge data at the AWLR Station for all return times.

Keywords: Flood, Hydrograph, Measured Rain, Satellite

1 Introduction

Design flood discharge analysis is used in waterworks planning, especially to determine the amount of design flood discharge in a watershed. Design flood discharge is an estimate of the maximum planned discharge in a river or natural channel with a certain return period that can be flowed without endangering the surrounding environment and river stability (Sarminingsih, 2018). Flood discharge estimates need to be done to

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minimize damage to water structures in the watershed (Mulyandari & Susila, 2020). Therefore, flood discharge plans need to be calculated to anticipate floods that will occur by carrying out flood control planning in a river (Lestari, 1970).

The design flood discharge in a watershed can be calculated by utilizing river discharge record data found at Automatic Water Level Recorder (AWLR) stations in the watershed or by using measured rainfall data found at rain gauge stations. For areas that have discharge recording devices, the design flood discharge can be directly calculated by frequency analysis. If there are no discharge recording devices in the area, then the design flood discharge can be determined using rainfall data in the area (Pariartha, 2013). There are three ways to estimate the design of flood discharge, namely statistical, empirical and hydrograph methods (Z & Rifa'i, 2018). The synthetic unit hydrograph method is a commonly used method in the calculation of design flood discharge, where this method requires rainfall data in its analysis.

Rainfall data used to calculate design flood discharge generally comes from weather observation measurements at rainfall stations. However, the availability of this data is still a problem in Indonesia, because the distribution of rainfall stations throughout Indonesia is still uneven (Misnawati et al., 2018). With the development of current technology, there are many ways to obtain rainfall data information, one of which is by using satellite technology (Wirabuana, 2023). One of the satellite-based rainfall data that can be used is Precipitation Estimation from Remotely Sensed Information Using Neural Network (PERSIANN) (Nguyen et al., 2018). So far, research on the use of PERSIANN satellite rainfall data has not been applied in the form of synthetic unit hydrographs to predict design flood discharge.

Based on the above description, the author intends to conduct further research on the utilization and accuracy of PERSIANN satellite rainfall data when applied to the Nakayasu Synthetic Unit Hydrograph (SUH). The Nakayasu SUH method is widely used in determining peak flood discharge in waterworks planning in Indonesia (Soemarto, 1999).

Through this research, it is expected that findings/innovations will be obtained that satellite rainfall data can be used as a solution in predicting the design flood discharge that occurs in the Tukad Petanu watershed, where the calculation of design flood discharge generally uses measured rainfall data at rain gauge stations which so far still has limitations both in terms of distribution, quantity, and quality of data.

2 Methodology

The method in this research is quantitative by using primary and secondary data analysis methods to solve problems. This research begins with primary data collection based on field surveys and secondary data collection obtained from related agencies. Field surveys were conducted by identifying the location of the flood discharge estimation post at the Tukad Petanu Hulu AWLR Station and the condition of the flood water level at that location. Interviews were also conducted with the surrounding community to find out the characteristics of floods that had occurred.

Secondary data was obtained from relevant agencies in the form of measured rainfall data and measured flood discharge in the river. Satellite rainfall data can be downloaded directly via the internet according to the satellite used. These data are used to empirically analyze the design flood discharge calculated by the Nakayasu SUH Method. Other secondary data are river morphology and watershed land cover data which are used as basic data in projecting future land cover changes.

The results of the design flood discharge analysis from the two rainfall data are then validated with the results of the recording of flood discharge that occurs at the AWLR Station. Furthermore, the level of conformity of the resulting flood discharge is evaluated.

3 Result and Discussion

3.1 Result

Primary Data Collection. From the survey results to the research location, it is known that the position of the Tukad Petanu Hulu AWLR Station is located in Bedulu Village, Ubud District, Gianyar Regency. Geographically the station is located at coordinates 8°31'36.54” S and 115°17'17.10” E. The recording equipment installed is currently in good condition and functioning normally, where reporting of recording results is carried out periodically by the Bali Penida River Basin Center as the manager.

Secondary Data Collection. Secondary data needed to support this research are watershed topographic maps, discharge recording data at AWLR Station, measured rainfall data and satellite rainfall data. These data are used to analyze the design flood discharge in the Tukad Petanu watershed with various return times.

Watershed Topography Map. The topographic map of the Tukad Petanu watershed was obtained from the Geospatial Information Agency in the form of the 2024 Rupa Bumi Indonesia (RBI) Map. This map is used to determine watershed characteristics consisting of watershed area (A), main river length, runoff coefficient (C) obtained from existing land cover conditions. Based on the results of the digitization, it can be seen that the catchment area of the Tukad Petanu Hulu AWLR Station has an area of 58.92 km^2 and the length of the main river is 32.73 km.

AWLR Discharge Record Data. The type of AWLR discharge recording data used in this study is daily discharge data from the Tukad Petanu Hulu AWLR Station managed by the Hydrology Unit of the Bali Penida River Basin Center. The availability of data is relatively complete with a length of 27 years of observation data starting from 1992 to 2018.

Measured Rainfall Data. The rainfall data used was sourced from Tampaksiring, Tegalalang and Pengotan Rainfall Stations. The data availability is relatively complete and has a data length of more than ten years of observation. Tampaksiring Rainfall Station has 18 years of observation data starting from 1998 to 2015, Tegalalang Rainfall Station has 23 years starting from 1992 to 2015, and Pengotan Rainfall Station has 25 years starting from 1992 to 2017. Rainfall conditions in the research location can be known by using the Theissen Polygon Method by making a polygon line from the rainfall recording stations located around the watershed concerned and dividing it into several areas formed by polygons from each station. From Figure 1 it can be seen that the rainfall stations that influence the rainfall occurring in the catchment area of the Tukad Petanu Hulu AWLR are Tegalalang and Pengotan Stations, while Tampaksiring Station has no effect on the catchment area. So that for the analysis of regional rainfall in the Tukad Petanu Hulu AWLR catchment area, data from these two stations will be used.

Satellite Rainfall Data. In this study, PERSIANN satellite rainfall data (0.25o x 0.25o) is used in the form of daily rainfall data for 24 years starting from 2000 to 2003. In the development of science, PERSIANN data is used in various studies such as drought monitoring, soil moisture analysis, hydrological modeling, and also flood analysis (Nguyen et al., 2018). This data can be obtained by accessing directly from the University of California, Irvine (UCI) website (http://chrsdata.eng.uci.edu/) and downloading it in the form of a .csv file that has previously set the research location to be reviewed on a digital map in real time. The rainfall data obtained is then inventoried and sorted according to the time of rainfall events so as to form a continuous data series.

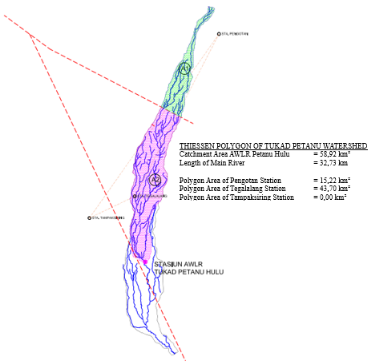

Figure 1. Thiessen Polygon CA AWLR Tukad Petanu Hulu

Data Quality Test. Discharge record data from the AWLR Station and rainfall data from the rainfall station are used as initial data in the analysis process. Before these data are used in the analysis process, statistical tests must first be carried out so that the validated data can be considered in accordance with actual conditions. This data validation is an initial inspection step to ensure that the data is in accordance with the specified criteria and is considered accurate.

The data quality tests carried out are consistency test, homogeneity test (trend test), stationary test, and precision test. The results of these tests show that all data meet the test requirements and can be used for further analysis.

Regional Rainfall Analysis. In this study, the Thiessen Polygon Method was used because of the limited and uneven distribution of rainfall stations. This method is used to determine the station that affects the amount of rainfall in the study area, so that through the intersection of the polygon lines formed will be seen rainfall station to be used. The three rainfall stations that have been drawn on the watershed map are then calculated the percentage of their influence on the catchment area under review.

Bias Correction Satellite Rain. Satellite rainfall data is corrected with the Bias Correction Linear Scaling method. This method is used to reduce the bias between satellite rainfall data and measured rainfall data. This method is used by providing a coefficient for each month, then the coefficient is multiplied by the satellite rainfall data obtained. The Bias Correction Scaling Linear method is a simple method used to adjust the average bias. The formula used in Bias Correction Scaling Linear is as follows (Kurnia et al., 2020):

$$P_{cor,m} = P_{raw,m} \times \frac{\mu(P_{obs,m})}{\mu(P_{raw,m})} \quad (1)$$

Where,
$P_{cor,m}$ = corrected satellite rainfall
$P_{raw,m}$ = modeled satellite rainfall
$\mu(P_{obs,m})$ = average measured rainfall
$\mu(P_{raw,m})$ = average satellite rainfall
Data correction was carried out for monthly rainfall using the equation $P_{cor,m}$ as above. From the correction results, a correction equation was produced with the equation: y = 1.0778x + 24.169. The PERSIANN satellite annual maximum daily rainfall data after correction can be seen in the table below.

Table 1. PERSIANN Satellite Annual Maximum Daily Rainfall Data After Correction (mm)

No.	Year	AMDR	AMDR *(correction)*
1	2001	74.64	104.62
2	2002	96.37	128.04
3	2003	69.53	99.11
4	2004	76.68	106.81
5	2005	44.05	71.65
6	2006	101.09	133.12
7	2007	84.49	115.23
8	2008	53.83	82.19
9	2009	52.14	80.37
10	2010	49.74	77.78
11	2011	54.68	83.10
12	2012	40.59	67.92

No.	Year	AMDR	AMDR *(correction)*
13	2013	48.34	76.27
14	2014	44.37	71.99
15	2015	65.10	94.33

Design Flood Discharge Analysis Using Measured Discharge Data. Based on the results of testing the suitability of the frequency distribution, it is known that the results of the design flood discharge analysis with the Log Pearson Type III Method produce values that meet the Smirnov Kolmogorof and Chi Square Tests. From the results of the calculation of the statistical parameters of the design flood discharge with the Log Pearson Type III method, the average value of Log X = 0.898 and S LogX = 0.376 is obtained, and then the calculation of the design flood discharge with the frequency distribution according to the return time sought.

The results of the calculation are then depicted in the form of a graph presented in Figure 2. The graph shows that the amount of design flood discharge in the Tukad Petanu watershed using measured discharge data at the Tukad Petanu Hulu AWLR Station for a return period of 2, 5, 10, 25, 50, and 100 years is 15.75 m^3/sec, 24.94 m^3/sec, 42.47 m^3/sec, 61.28 m^3/sec, and 86.63 m^3/sec, respectively.

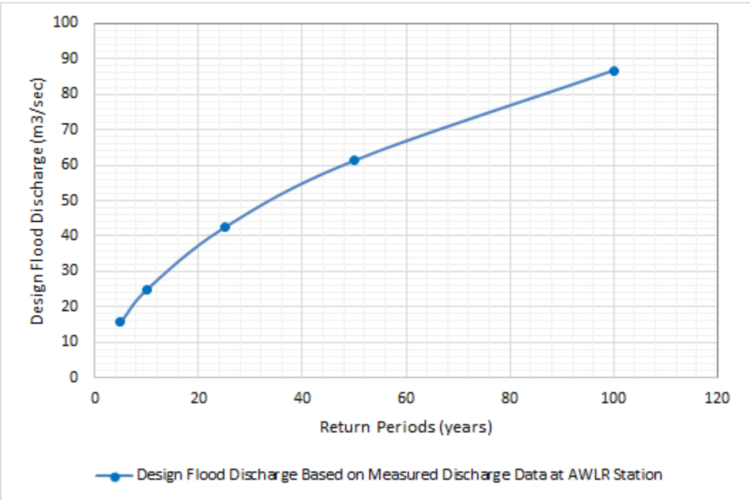

Figure 2. Graph of the Design Flood Discharge of Tukad Petanu Watershed Based on Measured Discharge Data at Tukad Petanu Hulu AWLR Station

Analysis of Nakayasu SUH Design Flood Discharge Using Measured Rainfall Data. Based on the results of the calculation of the Nakayasu SUH rise and fall curves in the Tukad Petanu Hulu AWLR Catchment Area, it is known that the characteristics of flooding that occurs in the Tukad Petanu watershed show that the peak hour occurs at 3.68 hours with a peak discharge for a rainfall unit of 1 mm is 3.88 m^3/sec. From these results, the unit hydrograph calculation is then carried out to determine the amount of design flood discharge at various return times as shown in Figure 3.

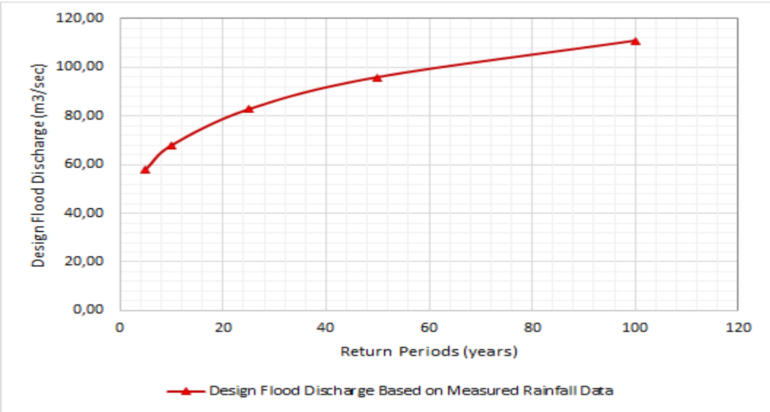

Figure 3. Graph of the design flood discharge of Tukad Petanu watershed based on measured rainfall data

The graph above shows that the amount of design flood discharge in the Tukad Petanu watershed using measured rainfall data for a return period of 2, 5, 10, 25, 50, and 100 years is 58.16 m^3/sec, 67.99 m^3/sec, 82.76 m^3/sec, 95.88 m^3/sec, and 110.81 m^3/sec, respectively.

Analysis of Nakayasu SUH Design Flood Discharge Based on PERSIANN Satellite Rainfall Data. The results of the calculation of the design flood discharge from the unit hydrograph according to the return period are shown in Figure 4. The graph shows that the amount of design flood discharge in the Tukad Petanu watershed using PERSIANN satellite rainfall data for return periods of 2, 5, 10, 25, 50, and 100 years is 77.19 m^3/sec, 83.64 m^3/sec, 90.62 m^3/sec, 94.84 m^3/sec, and 98.51 m^3/sec, respectively.

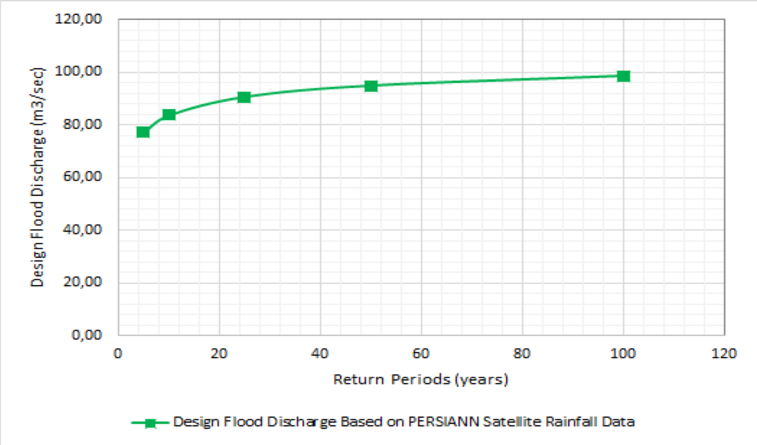

Figure 4. Graph of the design flood discharge of Tukad Petanu watershed based on persiann satellite rainfall data

3.2 Discussion

The design flood discharge for various return times in the Tukad Petanu watershed based on measured and satellite rainfall data is validated with the results of the analysis of the design flood discharge according to the return times that occur at the Tukad Petanu Hulu AWLR Station and the resulting level of conformity is seen. The method used in validating this research uses a statistical analysis method by finding the Volume Error (V_E), Relative Error (R_E), and Root Mean Square Error (R_{MSE}) values for each rainfall data used (Wirabuana, 2023). The design flood discharge at various return times at the Tukad Petanu Hulu AWLR Station is used as the control discharge (Q control) in this statistical analysis. The following are the results of the statistical analysis of design flood discharge with various return times described in tabular form as follows.

Table 2. Statistical analysis of the design flood discharge of the Tukad Petanu hulu AWLR station catchment area

Return period (years)	Q control (m^3/sec)	Measured rainfall data (Y)			PERSIANN satellite rainfall data (Y)		
	X	Q (m^3/sec)	| X-Y |	$(X-Y)^2$	Q (m^3/sec)	| X-Y |	$(X-Y)^2$
5	15.75	58.16	42.41	1798.73	77.19	61.44	3774.56
10	24.94	67.99	43.05	1853.51	83.64	58.71	3446.78
25	42.47	82.76	40.29	1623.61	90.62	48.15	2318.42
50	61.28	95.88	34.59	1196.71	94.84	33.55	1125.82
100	86.63	110.81	24.18	584.70	98.51	11.88	141.11
Total	231.07	415.60	184.53	7057.26	444.80	213.73	10806.70

After statistical tests, it can be seen that the average V_E value for design flood discharge from measured rainfall data = 79.86% and from PERSIANN satellite rainfall data =

92.50%. The average R_E value for design flood discharge from measured rainfall data = 15.97% and from PERSIANN satellite rainfall data = 18.50%. While the average R_{MSE} value for design flood discharge from measured rainfall data = 37.57 and from PERSIANN satellite rainfall data = 46.49.

Based on the statistical test results above, it can be seen that the design flood based on measured rainfall data and the PERSIANN satellite have different result values, but the two rainfall data have a fairly close difference in V_E, R_E, and R_{MSE} values. The design flood discharge generated by measured rainfall data has lower V_E, R_E, and R_{MSE} values compared to the PERSIANN satellite rainfall data. This can be caused by various factors, including the fact that the test was conducted by comparing rainfall data with discharge data and the method used in calculating the design flood discharge. If the calculation results of the above design flood discharge are depicted in the form of a composite graph, it will look like in Figure 5.

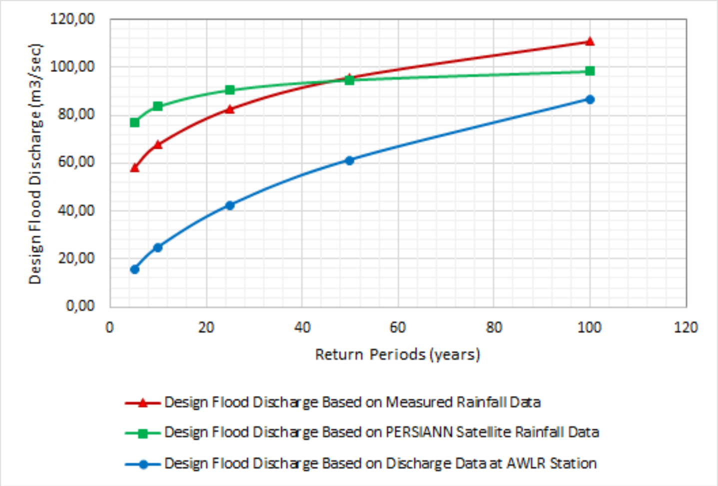

Figure 5. Comparison chart of design flood discharge analysis results based on measured Rainfall Data and PERSIANN Satellite against Design Flood Discharge Based on AWLR Data

The graph above illustrates that the design flood discharge with measured rainfall data produces lower discharge at 5, 10, and 25-year return periods, but produces higher discharge at 50 and 100-year return periods compared to the design flood discharge with PERSIANN satellite data. The design flood discharge from both rainfall data has a higher value than the design flood discharge with AWLR discharge data for all return periods. From these results, it is concluded that PERSIANN satellite rainfall data can be an alternative data as a solution to the limitations of existing rainfall data measurement stations in Indonesia, especially on the island of Bali.

4 Conclusion

Based on the results of the analysis conducted, it can be concluded that: 1). The magnitude of the design flood discharge in the Tukad Petanu watershed analyzed using the Nakayasu SUH based on measured rainfall data for 5, 10, 25, 50, and 100 year return periods is 58.16 m^3/sec, 67.99 m^3/sec, 82.76 m^3/sec, 95.88 m^3/sec, and 110.81 m^3/sec, while based on PERSIANN satellite rainfall data for the same return period in order are 77.19 m^3/sec, 83.64 m^3/sec, 90.62 m^3/sec, 94.84 m^3/sec, and 98.51 m^3/sec; 2). The magnitude of the design flood discharge in the Tukad Petanu watershed based on the measured discharge data of the Tukad Petanu Hulu AWLR Station for the return period of 5, 10, 25, 50, and 100 years is 15.75 m^3/sec, 24.94 m^3/sec, 42.47 m^3/sec, 61.28 m^3/sec, and 86.63 m^3/sec respectively; 3). The level of conformity of the design flood discharge generated by the Nakayasu SUH Method is based on measured rainfall data and the PERSIANN satellite has a higher value than the design flood discharge based on AWLR discharge data for all return periods. The design flood discharge based on PERSIANN satellite rainfall data has an R_E value of 18.50%, while based on measured rainfall data it is 15.97%. The V_E value for the design flood discharge based on measured rainfall data is 79.86%, while the PERSIANN satellite rainfall data is 92.50%. For the R_{MSE} value, the PERSIANN satellite rainfall data produced a higher value of 46.49 compared to the measured rainfall data of 37.57.

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