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Statistical Evaluation Performance of Hydrological Analysis

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ABSTRACT

The upstream Brantas watershed is as one of the watersheds in Indonesia that has the urgent affect to the quality and quantity of the water availability in the part of East Java Province. The area of Brantas watershed is about 674 km2. There are 11 rainfall stations in it. The rainfall recording is very necessary for supporting the hydrological analysis of a water structure design. A design will be accurate if the data which support it are valid, so this study intends to evaluate the validity of rainfall data. The sensitivity of the indicators to the model bias, outliers and repeated data is evaluated. The methodology consists of the evaluating of consistency test, absence of tendency, stationer test, persistence test, and outliers test. The result is hoped can support the accurate design of the water resources structure.

Keywords: Consistency, Absence of Tendency, Stationer, Persistence and Outliers.

1. INTRODUCTION

Success in the use of rainfall recording for supporting the hydrological analysis of the hydraulics structure design requires the objective model calibration and verification procedures. Some methods for analyzing the goodness of-fit of observations against the model-calculated values have been proposed but none of them is free of limitations and they are frequently ambiguous.. The statistical performance is an aspect generally ignored which helps in reducing subjectivity in the proper interpretation of the hydrological data performance. The descriptions of various goodness-of-fit testing indicators including their advantages and shortcomings discussions on the each index suitability can be found elsewhere [1, 2, 3, 4, 5, 6, 7]. Among these indicators, the Nash and Sutcliffe (1970) coefficient of efficiency has received considerable attention in hydrological modeling [8, 9, 10, 11, 12].

The upstream Brantas watershed is as one of the watersheds that has the urgent affect to the quality and quantity of water availability in the part of East Java Province. It is also as the location of water sources and it is not far from the estuary. In the several last years, due to the land use change, the geographical condition in the upstream which is part of them is as the mountainous, the global climate change, and the forest fire cause the high level of natural disaster in the upstream Brantas watershed. To solve the problems, there is carried out to evaluate periodically the rainfall and discharge recorder on the upstream Brantas watershed, remembering that the recorders have been built more than 5 years ago. The other solution for preventing the problem is by planning, developing, and controlling the accurate water structure design. However, the accuracy of plan can be reached if there are the optimum accuracy on each analyzing of the hydrological analyses. Hydrological data as the initial input need the accuracy in its recording. One of the problems in Indonesia is there is limited in human resource for handling the rainfall recorder mainly for the more rainfall recorders as well as the uneven distribution of the rainfall recorders. The constraints are more influencing the accuracy of the rainfall data. However, the rainfall and discharge data are to be representative for the region.

There is happened the flooding and area erosion in the study location. It is caused by the high rainfall and it is seldom happened out of the nearest rainfall recorder. To minimize the event, there is carried out to normalize the rainfall stations which are uneven distributed. In additional, it has to be carried out to evaluate the data which consists of the consistence test, the absence of tendency test, the persistence test, the stationer test, and the outliers test.

2. MATERIALS AND METHODS

2.1 Study location

The study location is in the upstream Brantas watershed that is as the supporting area and has the good potency of area development. The upstream Brantas watershed is located in the Batu city as the part of Malang regency and Malang city. The area is about 674 km^2. Map of study location is presented as in the Figure 1.

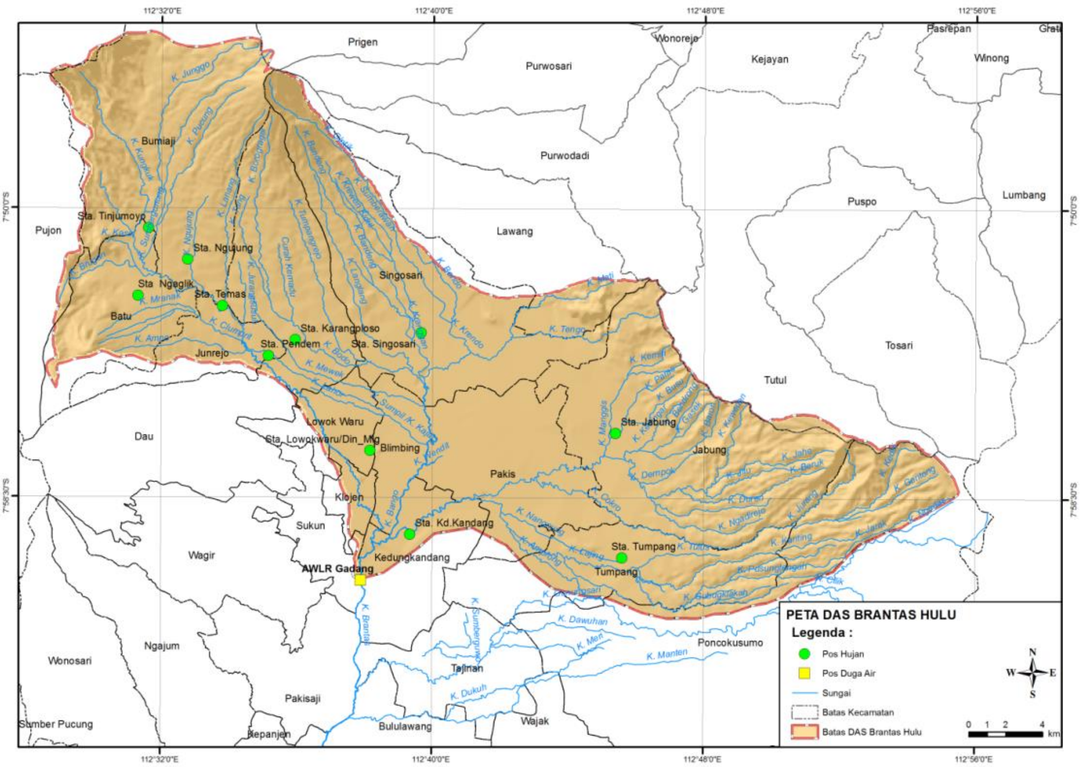

Fig. 1. Map of the upstream Brantas watershed

2.2 Data

The secondary data are needed in this study which consists of:

1. The daily rainfall data from 11 rainfall stations during the 10 years.
2. The daily discharge data from discharge recorder during the 10 years.

2.3. Steps of study

Systematically, the steps of study are presented as in the Table 1.

Table 1 Steps of the study

No.	Steps of study	Method	Data	Target
1.	Consistency test of rainfall data	Double mass curve	Daily rainfall	To evaluate the consistency and homogeneity of rainfall data
2.	Filtering of rainfall and discharge data	1. Absence of tendency 2. Stationer 3. Persistence 4. Outliers	Daily rainfall	To make certainty of the variant homogeneity and data reliability on the maximum and minimum value so it can be used for the next analyses

3. RESULTS AND DISCUSSION

The consistency test of rainfall data is carried out by using the double mass curve. The double mass curve is used if there are more than one recorder, however RAPS method is used if there is only one recorder.

3.1. Analysis of rainfall data

There are 11 rainfall stations that are affecting the upstream Brantas watershed. The hydrological analysis in this study needs the rainfall data from all of the rainfall stations such as the daily rainfall data from 2006 until 2015. However, for carrying out the consistency test, is used the yearly rainfall data from 2006 until 2015. Table 2 presents the yearly rainfall data in the upstream Brantas watershed.

Table 2 The rainfall data in the upstream Brantas watershed

Year	Rainfall data in each station (mm)										
	Tinju moyo	Ngaglik	Ngujung	Temas	Pendem	Karang ploso	Singo sari	Blim bing	Kd kandang	Jabung	Tum pang
2006	1,264	1,251	1,163	1,124	1,549	1,688	1,645	2,117	1,403	2,150	2,247
2007	1,558	1,592	1,615	1,546	1,514	1,333	818	1,911	1,760	2,054	2,157
2008	1,949	1,776	1,861	1,704	1,801	1,388	719	1,775	1,683	1,700	1,959
2009	1,605	1,471	1,548	1,641	1,562	1,082	2,416	1,727	1,903	1,309	1,917
2010	2,818	2,813	3,108	2,520	2,706	3,407	4,776	3,846	3,376	3,582	3,766
2011	1,748	1,338	1,651	1,318	1,260	2,469	2,631	2,074	2,084	2,615	2,660
2012	1,842	1,305	1,619	1,466	1,369	1,955	2,053	1,547	1,650	2,464	2,193
2013	2,542	2,223	2,882	2,151	1,632	1,983	2,683	2,458	2,377	2,471	2,419
2014	1,737	1,257	1,690	1,542	1,525	1,609	2,039	3,197	1,411	1,877	2,036
2015	1,433	1,176	1,406	1,359	1,530	1,020	1,625	1,667	1,802	1,368	1,797
mean	1,850	1,620	1,854	1,637	1,645	1,793	2,141	2,232	1,945	2,159	2,315

Source: General Work Institution of Water Resources, East Java province (2017)

Table 3 Consistency test of Tinjumoyo rainfall station

Year	Tinjumoyo station		The other stations	
	Yearly rainfall (mm)	Cumulative (mm)	Average (mm)	Cummulative (mm)
2006	1,264	1,264	1,634	1,634
2007	1,558	2,822	1,630	3,264
2008	1,949	4,771	1,637	4,900
2009	1,605	6,376	1,658	6.558
2010	2,818	9,194	3,380	9,948
2011	1,748	10,942	2,010	11,958
2012	1,842	12,784	1,762	13,720
2013	2,542	15,326	2,328	16,048
2014	1,737	17,063	1,818	17,866
2015	1,433	18,496	1,475	19,341

Source: own study

3.2. Consistency test of rainfall data

The consistency test is carried out for knowing that there is happened the environmental change or not related to the detail record.

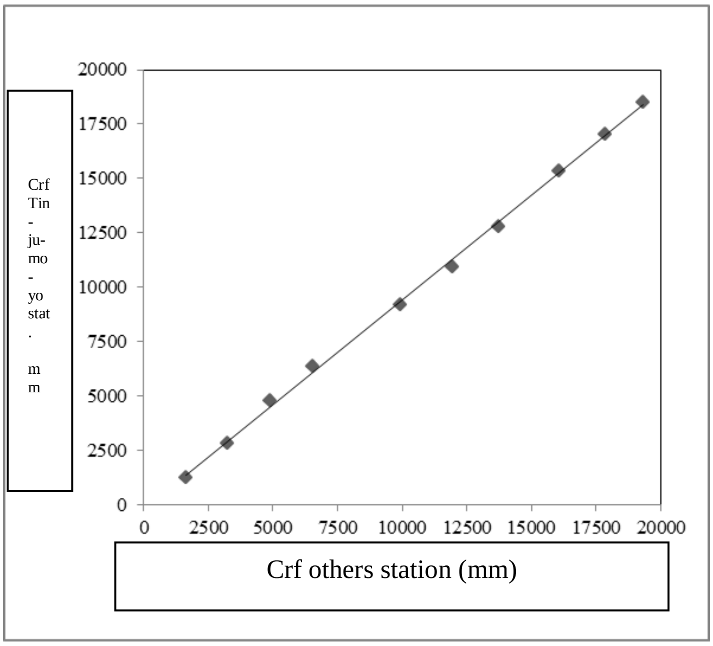

Fig. 2 Consistency test for Tinjumoyo rainfall station

If the result of consistency test shows that the rainfall data of a station is consistent, it means that there is no environmental change and detail record change during the data recording. In this study, it is used double mass curve which intends to know the inconsistent data that is indicated by the line deviation from the straight line in the beginning. If there is happened the deviation, the data has to be corrected due to the beginning one. The concept of this method is to compare the cumulative of one yearly rainfall data with the cumulative average yearly rainfall data from the other stations. Then, the cumulative data are plotted each in the x and y coordinates. Table 3 and Figure 2 present the consistency test for the Tinjumoyo rainfall station. For the other rainfall stations are carried out the consistency test with the same way.

3.3 The absence of tendency test

The absence of tendency test is carried out for knowing there is no trend or variant in the data. If there is trend in the data, the data is not suggested for hydrological analysis mainly related with the probability analysis. The data is said well if the data are homogeny; it means that the data come from the same population. In this study, Table 4 presents the absence of tendency test for the Tinjumoyo station. However, for the other stations can be carried out with the same way and the recapitulation is presented in the Table 5.

Table 4 The absence of tendency test for the rainfall data in the Tinjumoyo station

No.	Year	Yearly rainfall (mm)	Ranking			dt	dt^2
			Year	Yearly rainfall	Rt		
1	2006	1,264	2010	2,818	5	4	16
2	2007	1,558	2013	2,542	8	6	36
3	2008	1,949	2008	1,949	3	0	0
4	2009	1,605	2012	1,842	7	3	9
5	2010	2,818	2011	1,748	6	1	1
6	2011	1,748	2014	1,737	9	3	9
7	2012	1,842	2009	1,605	4	-3	9
8	2013	2,542	2007	1,558	2	-6	36
9	2014	1,737	2015	1,433	10	1	1
10	2015	1,433	2006	1,264	1	-9	81
Total							198
N							10
Kp							-0,20
T							-0,577

Hypothesis:

Hypothesis is accepted if t < tc →			Absence in tendency (Rt and Tt are independent
Hypothesis is not accepted if t>tc →			tendency
analysis			Conclusion
± a/2	2,5 %	2,306	-0,577 < 2,306
Two tails test	t_{table}		Ho is accepted
dk	8		data are not tendency

Source: own study

Note:

X = rainfall data

Rt = ranking of hydrological variable in the periodic series

dt = the difference of Rt and Tt

n = number of data

KP = correlation coefficient of Spearman rank

t = calculated value of t-test

Table 5 Recapitulation of the absence of tendency test result

No	Rainfall station	The absence of tendency value (t calculated < t table)		Test result
		t calculated	t table	
1.	Tinjumoyo	-0.577	2.306	independent
2.	Ngaglik	0.763	2.306	independent
3.	Ngulung	-0.651	2.306	independent
4.	Temas	0.017	2.306	independent
5.	Pendem	0.541	2.306	independent
6.	Karangploso	-0.051	2.306	independent
7.	Singosari	-0.840	2.306	independent
8.	Blimbing	0.120	2.306	independent
9.	Kedungkandang	-0.614	2.306	independent
10.	Jabung	0.017	2.306	independent
11.	Tumpang	0.434	2.306	independent

Source: own study

3.4 Stationer test

Stationer test is carried out for evaluating the stability of the variant and the mean of periodic series. The stationer test is carried out by using the method of F-distribution. The methodology is to divide the data into two or more groups. Every group is evaluated by using F-distribution. If the variant value is stable, then it is continued by evaluating the stability of the mean value. However, if the variant is not stable, then it is not needed to evaluate the stability of mean value. Table 6 presents the stationer test of rainfall data in Tinjumoyo station. However the stationer test for the other stations can be carried out with the same way and the recapitulation of it is presented as in the Table 7.

Table 6 Stationer test of the rainfall data in the Tinjumoyo station

No	Group-1		No	Group-2	
	Year	X (mm)		Year	X (mm)
1	2006	1,264	6	2011	1,748
2	2007	1,558	7	2012	1,842
3	2008	1,949	8	2013	2,542
4	2009	1,605	9	2014	1,737
5	2010	2,818	10	2015	1,433

N_1 = 5 X_1 = 1,838.80 S_1 = 598.93 dk_1 = 4	N_2 = 5 X_2 = 1,860.40 S_2 = 410.93 dk_2 = 4
Variant stability test	Conclusion
$F = \frac{N_1 . S_1^2 (N_2 - 1)}{N_2 . S_2^2 (N_1 - 1)}$ = 2.124 F table: Fc = 6.390	2.124 < 6.390 Ho is accepted Data variant is stationer/ homogen
Mean stability test	Conclusion
$\sigma = \left(\frac{N_1 S_1^2 + N_2 S_2^2}{N_1 + N_2 - 2} \right)^{\frac{1}{2}}$ = 1,378.094 $t = \frac{\overline{X}_1 - \overline{X}_2}{\sigma \left(\frac{1}{N_1} + \frac{1}{N_2} \right)^{\frac{1}{2}}}$ = -0.025 dk= $N_1 + N_2 - 1$ = 8	-0.025 < 2.306 Ho is accepted Data variant is stationer/ homnogen

two tailed test = 2.50%, Fc=2.306	

Source: own study

Note

X = rainfall data

dk = degree of freedom

X_n = mean rainfall

F = variant stability test

n = number of data

σ = mean stability test

S = deviation standard

Table 7 Recapitulation of stationer test result

No	Rainfall station	Stationer test (y calculated < t table)				Test result
		Variant stability		Mean stability		
		t calc	t tab	t cal	t tab	
1.	Tinjumoyo	2.124	6.390	-0.025	2.306	stable
2.	Ngaglik	1.989	6.390	0.362	2.306	stable
3.	Ngujung	1.594	6.390	0.009	2.306	stable
4.	Temas	2.256	6.390	0.190	2.306	stable
5.	Pendem	5.573	6.390	0.506	2.306	stable
6.	Karangploso	3.041	6.390	-0.020	2.306	stable
7.	Singosari	5.367	6.390	-0.056	2.306	stable
8.	Blimbing	1.778	6.390	0.066	2.306	stable
9.	Kedungkandang	4.262	6.390	0.144	2.306	stable
10.	Jabung	2.691	6.390	0.001	2.306	stable
11.	Tumpang	5.318	6.390	0.171	2.306	stable

Source: own study

3.5 Persistence test

The persistence test is carried out for knowing the data are come from the random sample or not and independent or not. Random data means as the data have the same probability to be selected, however, independent data means the data is not depended on the time, the selected data, the event of the other data in the same population. The persistence test of the rainfall data for Tinjumoyo station is presented as in the Table 8. However, the persistence test for the other stations is analyzed by the same way and the recapitulation is presented as in the Table 9.

Table 8 The persistence test of rainfall for Tinjumoyo station

No	Year	X (mm)	Rt	di	di^2
1.	2006	1,264	5	-	-
2.	2007	1,558	8	3	9
3.	2008	1,949	3	-5	25
4.	2009	1,605	7	4	16
5.	2010	2,818	6	-1	1
6.	2011	1,748	9	3	9
7.	2012	1,842	4	-5	25
8.	2013	2,542	2	-2	4
9.	2014	1,737	10	8	64
10.	2015	1,433	1	-9	81
Jumlah			234		
m			9		
Persistence test			Conclusion		
$KS = 1 - \frac{6\sum_{i=1}^{n}(di)^2}{m^3 - m}$ = -0.950; $t = KS\left[\frac{m-2}{1-KS^2}\right]^{\frac{1}{2}}$ =-8.050; Two tailed test: 2.5%; t table = 2.365; dk = 7			-8.050 < 2.365; Ho is accepted; Data is random		

Source: own study

Note:

X = rainfall data (mm)

Rt = ranking of hydrological variable in the periodic series

di = the difference between the rank of X_i and X_{i-1}

di^2 = number of quadratic (*di*)

KS = correlation coefficient of Spearman series

m = number of data

t = analyses value of *t* test

Table 8 Recapitulation of the persistence test result

No	Rainfall station	The persistence test (t calculated < t table)		Test result
		t calculated	t table	
1.	Tinjumoyo	-8.050	2.365	random
2.	Ngaglik	-2.028	2.365	random
3.	Ngulung	-4.986	2.365	random
4.	Temas	-0.493	2.365	random
5.	Pendem	-3.078	2.365	random
6.	Karangploso	-1.632	2.365	random
7.	Singosari	-6,642	2.365	random
8.	Blimbing	-0.782	2.365	random
9.	Kedungkandang	-2.476	2.365	random
10.	Jabung	-3.245	2.365	random
11.	Tumpang	-11.009	2.365	random

Source: own study

3.6 Outliers test

Before carrying out the distribution analysis, the yearly rainfall has to be evaluated by abnormality test. This evaluation is used for knowing the maximum and minimum data is feasible or not to be used for analysis [13] . Table 9 and Figure 3 presents the analysis of outliers test for the rainfall data in the Tinjumoyo station.

Table 9 Analysis of outliers test for the rainfall in the Tinjumoyo station

No	X (mm)	Log X	$(\text{Log X} - \text{Log X}_{\text{rerata}})^2$	$(\text{Log X} - \text{Log X}_{\text{rerata}})^3$
1.	2,818	3.450	0.0380568	0.0074242
2.	2,542	3,405	0.0225949	0.0033964
3.	1,949	3.290	0.0012217	0.0000427
4.	1,842	3.265	0.0001088	0.0000011
5.	1,748	3.243	0.0001517	-0.0000019
6.	1,737	3.240	0.0002268	-0.0000034
7.	1,605	3,205	0.0024388	-0.0001204
8.	1,558	3.193	0.0038803	-0.0002417

9.	1,433	3.156	0.0097246	-0.0009590
10.	1,264	3.102	0.0234434	-0.0035895
∑	=	32.549	0.1018478	0.0059485
Log X_{mean}	=	3.255	Upper limit (YH) = 3,4714465 Lower limit (YL) = 3.0382725	
Sd	=	0.106		
Cs	=	0.686		
Ka	=	2.036	XH = 2,991.0550928 XL = 1,092.1254115	

Source: own study

Note:

X = rainfall data (mm)

n = number of data data

YH = upper limit

YL = lower limit

XH = maximum rainfall after the outliers detection (mm)

XL = minimum rainfall after the outliers detection (mm)

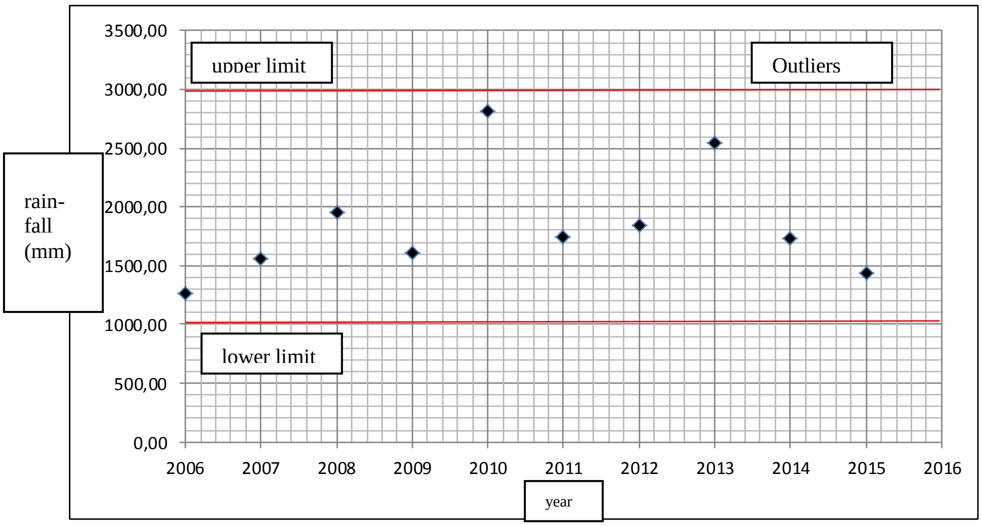

Figure 3 Outliers test of rainfall data in Tinjumoyo station

Based on the steps of evaluation analysis for the absence of tendency test, stationer test, persistence test, and outliers test, the recapitulation of evaluation is presented as in the Table 10 for all recorders (stations)

Table 10 Recapitulation of rainfall data filtering in the upstream Brantas watershed

Station	Test				
	Absence of tendency	Stationer		Persistence	Outliers
		F test	t test		
Tinjumoyo	Ho accepted	Ho accepted	Ho accepted	Ho accepted	X_H= 2,961.005 mm X_L = 1,092.125 mm
	No absence of tendency	Data variant is stationer/ homogeny	Data variant is stationer/ homogeny	Data is random	Data is feasible
Ngaglik	Ho accepted	Ho accepted	Ho accepted	Ho accepted	X_H= 2,774.9865108 mm X_L = 874.1259414 mm
	No absence of tendency	Data variant is stationer/ homogeny	Data variant is stationer/ homogeny	Data is random	Data is feasible
Ngujung	Ho accepted	Ho accepted	Ho accepted	Ho accepted	X_H= 3,288.4741543 mm X_L = 956.4618850 mm
	No absence of tendency	Data variant is stationer/ homogeny	Data variant is stationer/ homogeny	Data is random	Data is feasible
Temas	Ho accepted	Ho accepted	Ho accepted	Ho accepted	X_H= 2,574.5352441mm X_L = 988.3045287 mm
	No absence of tendency	Data Variant is stationer/ homogeny	Data variant is stationer/ homogeny	Data is random	Data is feasible
Pendem	Ho accepted	Ho accepted	Ho accepted	Ho accepted	X_H= 2,447.47020911mm X_L = 1,059.5309214 mm
	No absence of tendency	Data variant is stationer/ homogeny	Data variant is stationer/ homogeny	Data is random	Data is feasible
Karangploso	Ho accepted	Ho accepted	Ho accepted	Ho accepted	X_H= 3,572.9222464 mm X_L = 791.4875385 mm
	No absence of tendency	Data variant is stationer/ homogeny	Data variant is stationer/ homogeny	Data is random	Data is feasible
Singosari	Ho accepted	Ho accepted	Ho accepted	Ho accepted	X_H= 5,884.9234527 mm X_L = 597.1745115 mm
	No absence of tendency	Data variant is stationer/ homogeny	Data variant is stationer/ homogeny	Data is random	Data is feasible
Blimbing	Ho accepted	Ho accepted	Ho accepted	Ho accepted	X_H= 3,904.7935616 mm

					X_L = 1,171.6828185 mm
	No absence of tendency	Data variant is stationer/ homogeny	Data variant is stationer/ homogeny	Data is random	Data is feasible
Kedung kandang	Ho accepted	Ho accepted	Ho accepted	Ho accepted	X_H= 3,198.7644658 mm X_L = 1,106.2553945mm
	No absence of tendency	Data variant is stationer/ homogeny	Data variant is stationer/ homogeny	Data is random	Data feasible
Jabung	Ho accepted	Ho accepted	Ho accepted	Ho accepted	X_H= 3,866.3857155 mm X_L = 1,107.4204384 mm
	No absence of tendency	Data variant is stationer/ homogeny	Data variant is stationer/ homogeny	Data is random	Data is feasible
Tumpang	Ho accepted	Ho accepted	Ho accepted	Ho accepted	X_H= 3,488.9099807mm X_L = 1,469.2126188mm
	No absence of tendency	Data variant stationer/ homogeny	Data variant stationer/ homogeny	Data is random	Data is feasible

Source: own study

4. CONCLUSION

Hydrological analysis evaluation is enhanced when conducting a multi-objective analysis. This study presents a unified framework for proper interpretation of statistical evaluation performance in a statistically rigorous way and for the evaluation of other effects such as bias, outliers and repeated data. As shown in this work, when the goodness-of-fit evaluation is based on a single indicator, the value is affected by other factors (outliers, model bias, repeated data). A comprehensive procedure for evaluating statistical evaluation performance is proposed and tested here that can serve as a useful guidance and less subjective tool for the hydrological analyst.

Based on the statistical analysis as above which is including the absence of tendency test, the stationer test, the persistence test, and the outliers test, it can be concluded that the rainfall data from 2006 until 2015 in the upstream Brantas watershed, all of the record can be used for supporting the hydrological analysis. In additional, the test result indicates that all of the rainfall record are in the normal limitation so there is no data has to be deleted.

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