JOURNAL OF WATER AND LAND DEVELOPMENT
e-ISSN 2083-4535
Polish Academy of Sciences (PAN) Institute of Technology and Life Sciences – National Research Institute (ITP – PIB)

JOURNAL OF WATER AND LAND DEVELOPMENT
DOI: 10.24425/jwld.2021.138160
2021, No. 50 (VI–IX): 56–63

The best synthetic unit hydrograph for peak discharge analysis Case: The Bengawan Solo River, section Dengkeng–Pusur

Nova D. Sirait ✉, Sobriyah, Rintis Hadiani, Cahyono Ikhsan

Sebelas Maret University, Faculty of Engineering, Ir. Sutami Street 36A, Solo, 57126, Center of Java, Indonesia

RECEIVED 31.05.2020 REVIEWED 01.07.2020 ACCEPTED 22.10.2020

Abstract: This paper aims to analyse the flood discharge based on the Synthetic Unit Hydrograph (SUH), using the Soil Conservation Service method (SCS), the SUH of Nakayasu method, and the SUH of Gama I method.
Modelling formed the basis of the research conducted on the Bengawan Solo River, Indonesia. The embankment construction on the Dengkeng–Pusur Section was designed as a method of flood control in 1988. The problem was that around its location are densely populated cities, industrial areas, and agricultural areas. In order to measure the risk of embankment failure and water structure planning in general, it is necessary to analyse the maximum flood discharge. There are several methods for analysing maximum flood discharge, so finding a suitable method is essential due to the lack of measuring tools to calculate flood discharge in some areas. The calculation is compared with the observation data at the Serenan AWLR station, which is in the Dengkeng–Pusur section. The observation rainfall data was covered a 20 year period (1999–2018). According to the method used, the analysis is based on series data on four rainfall stations, the watershed characteristics, and other parameters. Furthermore, the maximum flood discharge from the calculation is compared with the observational data at the Serenan station. The result shows that the best SUH is Gama I method compared to the observation maximum flood discharge in AWLR Serenan Station, with an 8.0% error. The other method, the SUH Nakayasu method with a 16.6% error, and the SUH SCS method with a 39.5% error.

Keywords: Bengawan Solo River, maximum flood discharge, the SUH of SCS, the SUH of Nakayasu, the SUH of Gama I

INTRODUCTION

The Bengawan Solo River is the longest river in Java (600 km) and has an important role both socially and economically. One of the Bengawan Solo River problems is flooding which has an impact on the loss of life and property, especially in the downstream area. Major flooding occurred in 2007, resulting in loss of life and property, especially in the downstream area of Solo [Lasminto *et al.* 2016], with the value of losses reaching 200 million US dollars [The World Bank 2010]. To mitigate flood and inundation damage, the government has carried out the construction of reservoirs, embankments, revetments, and channel widening and excavation in several locations [BBWS Bengawan Solo 2015].

Specifically, in the Dengkeng–Pusur section, which is part of the upstream Bengawan Solo River, construction of the embankment along 1.8 km was carried out between 1988–1994. The construction took into consideration that densely populated cities such as Sukoharjo and Klaten and industrial and agricultural areas could be potentially affected by the Bengawan Solo River flood. The embankments are built on either side of the river. In addition to the embankment construction, channel widening, and excavation and revetment was also carried out to increase the river's capacity from the original 400 $m^3 \cdot s^{-1}$ to 1,240 $m^3 \cdot s^{-1}$, which had ten year return period [JICA 2002].

Over time, the Bengawan Solo River faced problems related to watershed management, including; flooding due to the channel capacity being unable to accommodate discharge, especially during the rainy season; high flow coefficient due to land conversion to settlement; additionally illegal logging resulting in small water absorption capacity [BBWS 2010]. In line with this, several studies have shown that changes in land use affect the peak flood discharge, such as research conducted by Cornelissen *et al.* [2013], Maryono [2013], LIU *et al.* [2014], and Deepak *et al.* [2017] Likewise, climate change also influences the peak flood discharge as conducted by Suripin and Kurniani [2016], Knighton *et al.* [2017], Parandin *et al.* [2019].

To determine whether the embankment can control the existing maximum flood discharge, it is necessary to analyse the maximum flood discharge possible. This information is helpful in the context of disaster mitigation and reducing the impact of disaster risk.

The design of flood discharge is carried out using a unit hydrograph that transforms rainfall into streamflow. The unit hydrograph of a watershed is defined as a direct runoff hydrograph (DRH) resulting from one in (usually taken as 1 cm in SI units) excess rainfall generated uniformly over the drainage area at a constant rate for the duration [Chow *et al.* 1988]. The unit hydrograph uses rainfall data and discharges records at the control point. However, in practice, the available hydrological data is of inadequate quality due to errors such as false errors related to recording data, systemic errors related to measuring conditions, and random errors related to monitoring and measurement activities [WMO 2009].

The design of flood discharge requires analysis of the synthetic unit hydrograph (SUH). Synthetic unit hydrograph procedures are used to develop unit hydrographs for other locations in the stream in the same watershed or nearby watersheds of a similar character. According to Chow *et al.* [1988], there are three types of synthetic unit hydrographs: (1) those relating hydrograph characteristics (peak flow rate, base time, etc.) to watershed characteristics (Gray method; Snyder method), (2) those based on a dimensionless unit hydrograph (SCS method), and (3) those based on models of watershed storage (Clark method). Synthetic unit hydrographs can also be developed using genetic algorithms such as those conducted by Rai *et al.* [2009] and Sarkar *et al.* [2010]. In Indonesia, the synthetic unit hydrograph generally used are Soil Conservation Service (SCS) method, Nakayasu method, and Gama I method, referring to many studies [Ariyani, Riadhi 2019; Junia *et al.* 2015; Kristianto *et al.* 2019; Margini *et al.* 2017; Marthina *et al.* 2014].

In this study, three methods are used to analyse the Bengawan Solo River flood discharge in the Dengkeng–Pusur section and compare which method results are the closest analysis of the flood discharge from field observations. Analysis of flood discharge from field observations will use water level data recorded at the Serenan Automatic Water Level Recording (AWLR) station on the Bengawan Solo River. The length of the Bengawan Solo River from upstream to the Serenan AWLR station is about 37 km, and the area of the Bengawan Solo watershed as the study location is 951.35 km^2 [BBWS 2019], as seen as Figure 1. Calculation of flood discharge of the Bengawan Solo River in the Dengkeng–Pusur section also calculates the maximum flood discharge released from the Gajah Mungur Multipurpose Dam, located upstream of the study site at 400 m^3·s^{-1} according to the Gajah Mungkur Reservoir Operation Pattern [PUPR 1997].

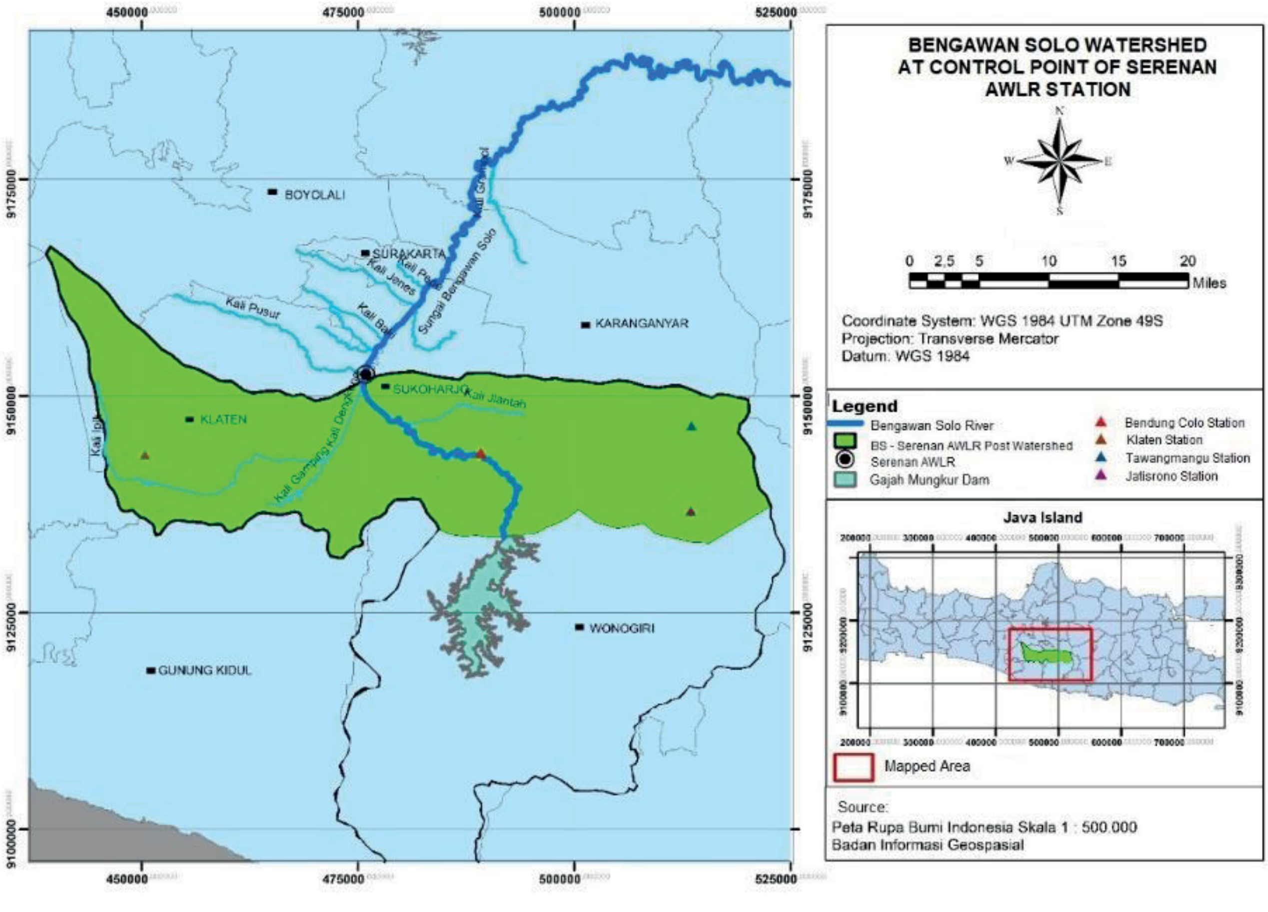

Fig. 1. Study location; source: own elaboration based on Indonesia topographic map

MATERIAL AND METHODS

RESEARCH DATA

This research uses water level data at the Serenan AWLR station from 1998 to 2018, topographical data and watershed characteristics, and rainfall data from 1998 to 2018. Furthermore, this data is used to analyse flood discharge with three synthetic unit hydrograph methods, i.e. the Soil Conservation Service method, the Nakayasu method, and the Gama I method. Besides the flood discharge, a calculation was also carried out based on the water level recorded at the Serenan. The data used are presented in Figure 2.

FREQUENCY ANALYSIS

Frequency analysis is merely a procedure for estimating the frequency of occurrence or probability of occurrence of past and/ or future events [HAAN 1977]. The frequency analysis of hydrologic data is to relate the magnitude of extreme events to their frequency of occurrence through the use of probability distributions. The hydrologic data analysed are assumed to be independent and identically distributed, and the hydrologic system producing them (e.g. a storm rainfall system) is considered stochastic, space-independent, and time-independent [CHOW *et al.* 1988]. In this study, the analysis of rainfall data is intended to determine the amount of return period of rainfall.

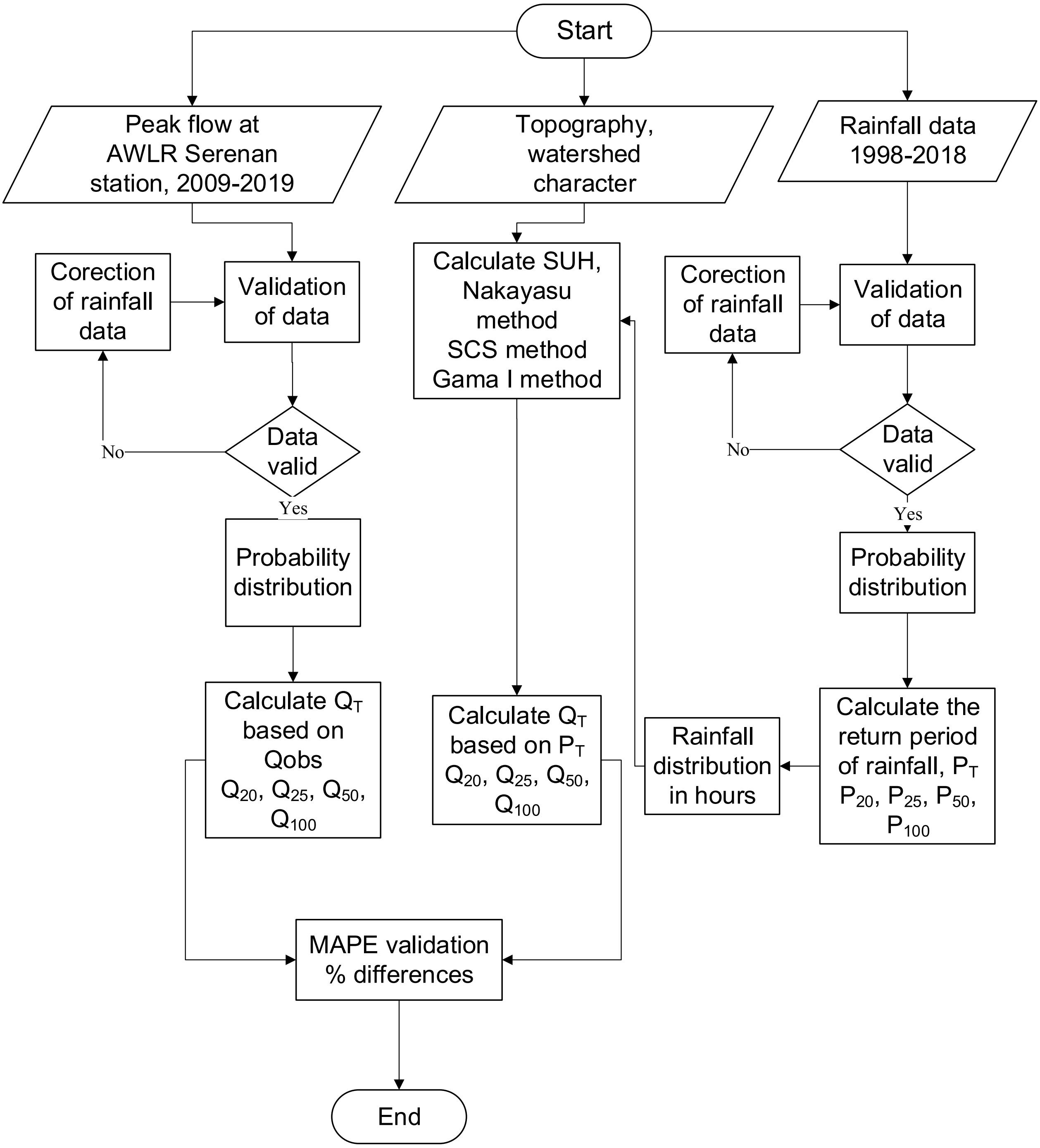

Fig. 2. Research flow diagram; source: own elaboration

This analysis includes several calculation stages, i.e. calculation of rainfall in the catchment area (CA) and then analysis of rainfall frequency and intensity curves. A rainfall probability distribution can be determined by calculating statistical parameters such as mean values, standard deviations, coefficient of variation, and skewness coefficients from existing data and followed by statistical tests. The statistical formulas determine the type of probability distribution as Equations (1)–(4).

Standard deviation

$$s = \left[\frac{\sum_{i=1}^{n}(x_i - \bar{X})^2}{(n-1)}\right]^{0.5} \tag{1}$$

Skewness coefficient

$$C_s = \frac{n}{(n-1)(n-2)s^3}\sum_{i=1}^{n}(x_i - \bar{X})^3 \tag{2}$$

Variant coefficient

$$C_v = \frac{S}{\bar{X}} \tag{3}$$

Curtosis coefficient

$$C_k = \frac{n^2}{(n-1)(n-2)(n-3)s^4}\sum_{i=1}^{n}(x_i - \bar{X})^4 \tag{4}$$

where: n = sum data; $\bar{X}$ = average of rainfall; s = standard deviation; x_i = number of data i.

There are several distribution analyses in hydrology, i.e. normal distribution, log-normal distribution, extreme value type I (Gumbel), and log-Pearson type III. In practice, the actual probability distribution is difficult to know to explain the related phenomena; it is necessary to choose the appropriate distribution type through a statistical approach. The type of distribution analysis is based on statistical parameters in Table 1.

THE SMIRNOV–KOLMOGOROV TEST

The Smirnov–Kolmogorov test is one way to assess whether the selected distribution represents observational data. The data should not be grouped for this test [Haan 1977]. The Smirnov–Kolmogorov test compares the maximum difference between the data plots with the theoretical lines on the probability paper or the maximum Δ value with the possibility of getting a value smaller than the critical value. The value of criticism (Δcr) depends on the amount of data (n) and the degree of failure (α), as can be seen in Table 2.

Table 1. Statistical parameters to determine the type of distribution

Distribution	Condition
Normal	$(\bar{x} \pm s)\cdot 100\% = 68.27\%$
	$(\bar{x} \pm 2s)\cdot 100\% = 95.44\%$
	$C_s \approx 0$
log normal	$C_s = C_v^3 + 3C_vC_s$
	$C_k = C_v + 6C_v^6 + 15C_v^4 + 16C_v^2 + 3$
Gumbel	$C_s = 1.14C_s$
	$C_k = 5.4$
log-Pearson III	not the value above

Source: Triatmodjo [2008].

Table 2. Smirnov–Kolmogorov test on value of criticism (Δcr)

Amount of data n	Δcr values at α			
	0.20	0.10	0.05	0.01
5	0.45	0.51	0.56	0.67
10	0.32	0.37	0.41	0.49
15	0.27	0.30	0.34	0.40
20	0.23	0.26	0.29	0.36
25	0.21	0.24	0.27	0.32
30	0.19	0.22	0.24	0.29
35	0.18	0.20	0.23	0.27
40	0.17	0.19	0.21	0.25
45	0.16	0.18	0.20	0.24
50	0.15	0.17	0.19	0.23
>50	$\frac{1.07}{\sqrt{n}}$	$\frac{1.22}{\sqrt{n}}$	$\frac{1.36}{\sqrt{n}}$	$\frac{1.63}{\sqrt{n}}$

Source: Triatmodjo [2008].

RETURN PERIOD

The return period of discharge analysis requires a return period of rainfall data. The return period is defined as the average elapsed time between the occurrences of an event with a certain magnitude or more significance. The return period can be associated with the probability of exceeding a specific rainfall or discharge value. It means not the event of rainfall or discharge that will recur every time in the return period, but the possibility that it occurs within a certain period [Haan 1977].

RAINFALL DISTRIBUTION

The rainfall distribution model is used to obtain a hyetograph of the return period of rainfall. In this study, the rainfall distribution model uses the rainfall distribution of Tadashi Tanimoto. This model was developed based on the study of rainfall distribution on the island of Java and used an eight-hour rainfall distribution [Triatmodjo 2008].

SYNTHETIC UNIT HYDROGRAPH (SUH) OF SOIL CONSERVATION SERVICE (SCS) METHOD

The dimensionless unit hydrograph used by the SCS was developed by Victor Mockus and was derived based on many unit hydrographs from basins that varied in characteristics such as size and geographic location. The unit hydrographs were averaged, and the final product was dimensionless by considering the ratios of q/q_p (flow/peak flow) on the ordinate axis and t/t_p (time/time to peak) on the abscissa. This final, dimensionless unit hydrograph has a time-to-peak located at approximately 20% of its time base and an inflexion point at 1.7 times the time-to-peak [SCS 1972]. The formula used is:

$$Q_p = q_p \; P_e \; 0.0028 Q_p \tag{5}$$

$$q_p = \frac{A}{T_0 \text{ corrected}} 484 \tag{6}$$

$$T_0\text{corrected} = \frac{T_c}{1.5} \tag{7}$$

$$T_c = 0.06628 L^{0.77} \; S^{0.38} \tag{8}$$

$$T_p = \frac{0.24 T_c}{2} + t_p \tag{9}$$

$$P_e = \frac{(P - 0.2S)^2}{P + 0.8S} \tag{10}$$

$$S = \frac{25400}{CN} - 254 \tag{11}$$

where: Q_p = peak of discharge ($m^3 \cdot s^{-1}$); q_p = high peak discharge (inches); A = cross-section area (m^2); T_0 corrected = correction time of time concentration (h); T_p = up time (h); T_c = time of concentration (h); t_p = lag time (h); P_e = effective rain (mm); P = wet perimeter (mm) S = potential maximum retention (mm); CN = weighted curve number.

SYNTHETIC UNIT HYDROGRAPH (SUH), NAKAYASU METHOD

Dr Nakayasu developed the SUH of the Nakayasu method based on hydrography observations on several rivers in Japan. This method requires several parameters, such as the time to peak from the beginning of the rainfall to the top of the hydrography, the time to the centre of the rainfall to the centre of the hydrography, and the time of the hydrograph [Soemarto 1987].

$$Q_p = \frac{1}{3.6} \frac{A \; R_e}{0.3 T_p + T_{0.3}} \tag{12}$$

$$T_p = tg + 0.8 T_r \tag{13}$$

$$tg = 0.4 + 0.058 \; L \text{ for } L > 15 \; km \tag{14}$$

$$tg = 0.21 \; L^{0.7} \text{ for } L < 15 \; km \tag{15}$$

$$T_{0.3} = \alpha tg \tag{16}$$

$$T_r = 0.5 \; tg \tag{17}$$

where: Q_p = peak of discharge ($m^3 \cdot s^{-1}$), v = flow speed ($m \cdot s^{-1}$); R_e = radius hydraulic (m); T_p = time of peak (h), tg = time base of hydrograph (h); L = length of the longest channel (m); $T_{0.3}$ = time lag (h); T_r = unit time of rainfall (h).

SYNTHETIC UNIT HYDROGRAPH (SUH) OF GAMA I METHOD

The synthetic unit hydrograph of the Gama I method was developed o by Sri Harto based on observations on the 30 hydrological behaviour of the watershed in Java [Harto 2000]. The method proved to be functioning well too for various other regions in Indonesia [Triatmodjo 2008]. Several new watershed parameters were proposed to develop the SUH of Gama I, without ignoring the watershed parameters that have been developed previously. The impact is significant in the process of simulated rainfall to the river flow. The SUH of the Gama I contains four main variables, i.e. time to rise (T_R), peak discharge (Q_p), time base/time to base (T_B), and storage coefficient (K). The equations used are as follows:
Time to rise SUH Gama I (T_R)

$$T_R = 0.43 \left(\frac{L}{100 \; SF} \right)^3 + 1.0665 \; SIM + 1.2775 \tag{18}$$

Peak of discharge (Q_p)

$$Q_p = 0.1836 \; A^{0.5887} {T_R}^{-0.4008} JN^{0.2381} \tag{19}$$

Time base (T_B)

$$T_B = 27.4132 \; {T_R}^{0.1457} S^{-0.0986} SN^{0.7344} RUA^{0.2574,} \tag{20}$$

Recession coefficient (K)

$$K = 0.5617 \; A^{0.1798} \; S^{-0.1446} SF^{-1.0897} D^{0.0452} \tag{21}$$

Base flow (Q_B)

$$Q_B = 0.4715 \; A^{0.6444} D^{0.9430} \tag{22}$$

where: T_R = time to rise SUH Gama I (h); Q_p = peak of discharge ($m^3 \cdot s^{-1}$); T_B = time base (hours); L = length of river (km); K = recession coefficient (km); SF = source factor, the ratio between the number of lengths of river first ordo with the number of river lengths of all ordo; SIM = symmetry factor, the product of the width factor (WF) and the ratio of upstream area (RUA); A = watershed area (km^2); JN = number of river joint; S = slope of watershed; SN = source frequency; RUA = ratio upstream area; D = drainage network density (km).

While the recession side is expressed in the form of an exponential equation shown in the equation below:

$$Q_t = Q_p e^{-T/K} \tag{23}$$

where: Q_t = discharge of each time, after Q_p ($m^3 \cdot s^{-1}$); Q_p = peak discharge ($m^3 \cdot s^{-1}$); T = time to peak (h); K = storage coefficient.

THE MEAN ABSOLUTE PERCENTAGE ERROR

Models and simulations need to be verified and validated, primarily to assess the level of accuracy, which is one indicator of the quality of the application of models and simulations [Balci 2004]. Mean absolute percentage error (*MAPE*) is a simple method for analysing the accuracy of forecasting data with actual data [Makridakis *et al.* 1999]. This method calculates the absolute error in each period divided by the observed value and then averages the absolute percentage error. This method is used to find the best forecasting method and is used in various scientific fields, such as that done by Heriansyah, Hasibuan [2018], Zainun *et al.* [2019], and Margi, Pendawa [2015]. The ability of forecasting models is good if the *MAPE* value is below 10% and good if the *MAPE* value is between 10% and 20% [Lewis 1982]. The *MAPE* formula is as follows:

$$MAPE \ = \frac{\sum_{t=0}^{n} \frac{\left|Y_t - \hat{Y}_t\right|}{Y_t}}{n} \ 100\% \tag{24}$$

where: Y_t = prediction; $\hat{Y}_t$ = actual data; n = amount of data.

RESULTS AND DISCUSSION

The results of the analysis of the calculation of the maximum flood discharge of the Bengawan Solo River in the Dengkeng–Pusur Section using the Synthetic Unit Hydrograph of the Synthetic Soil Conservation Service method, Nakayasu method, Gama I method and also the results of the analysis of the maximum flood discharge based on analysis of observational data on the AWLR Post of Serenan can be seen in Table 3. In the analysis, each method has taken into account the maximum flood discharge released from the Gajah Mungkur Multipurpose Dam, located upstream of the study site at 400 $m^3 \cdot s^{-1}$ according to the Gajah Mungkur Reservoir Operation Pattern and assumed to be fixed for each flood period recalculation.

Table 3 shows that the synthetic unit hydrograph of the Nakayasu method provides the highest maximum flood discharge compared to the observation maximum flood discharge at the Serenen AWLR station, followed by the Soil Conservation Service method and Gama I method. For example, the maximum flood discharge of the 10-year return period at the Serenen AWLR station is 977.65 $m^3 \cdot s^{-1}$. Meanwhile, the results of the analysis of the Nakayasu method are 1512.97 $m^3 \cdot s^{-1}$. The SCS method is 1087.16 $m^3 \cdot s^{-1}$, and the Gama I method is 881.69 $m^3 \cdot s^{-1}$. A comparison of unit hydrographs of the three methods for flood discharge in the ten year returns period is shown in Figure 3.

The percentage of maximum flood discharge errors of the synthetic unit hydrograph (SUH) of the Soil Conservation Service, Nakayasu method, and Gama I method, compared to the observation maximum flood discharge at the AWLR Serenan Station, use the mean absolute percentage error (*MAPE*) method is shown that the maximum flood discharge of the Bengawan Solo River in the Dengkeng–Pusur Section using the SUH of the Gama I method has the slightest error until 8.0% compared to the observation maximum flood discharge at the Serenen AWLR station, followed by the Soil Conservation Service method of 16.6% and Nakayasu method of 39.5%. In other words, the SUH of the Gama I method is the most accurate error percentage compared to the other two methods.

Table 3. Maximum flood discharge (Q) of each method and flood discharge at Serenan AWLR station

Return period	**Q ($m^3 \cdot s^{-1}$)**			
	SCS method	**Nakayasu method**	**Gama I method**	**Flood discharge at Serenan AWLR station**
2	793.31	1 037.03	681.96	775.77
5	955.15	1 299.17	791.97	905.13
10	1 087.16	1 512.97	881.69	977.65
20	1 213.77	1 718.05	967.74	1 031.04
25	1 285.57	1 834.34	1 044.07	1 058.82
50	1 459.12	2 115.42	1 134.49	1 115.06
100	1 656.59	2 435.27	1 268.71	1 163.37

Source: own study.

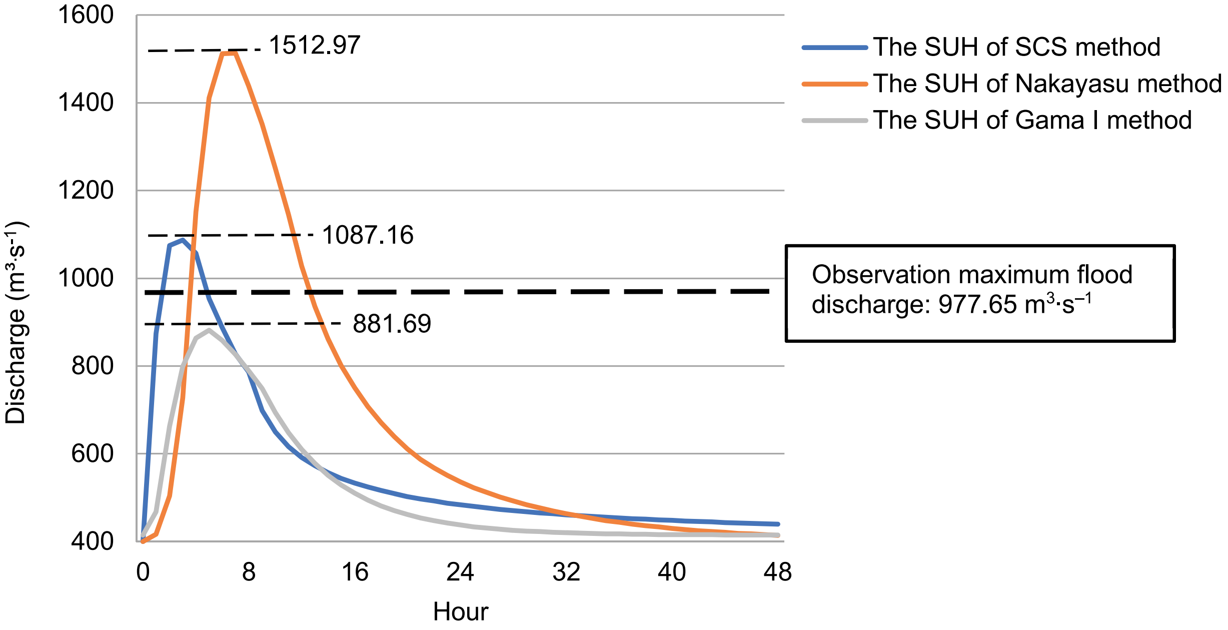

Fig. 3. The synthetic unit hydrograph (SUH) of the three methods for flood discharge in the 10-year return period; source: own study

Table 4. Percentage of maximum flood discharge errors for each method compared to observation maximum flood discharge

Gama I method	SCS method	Nakayasu method
8.0	16.6	39.5

Source: own study

CONCLUSIONS

1. The Gama I method is the best synthetic unit hydrograph to calculate the maximum flood discharge of the Bengawan Solo River in the Dengkeng–Pusur section because the calculation results are closer to the field observation discharge with an error percentage of 8.0%. On the other hand, the calculation of the maximum flood using the synthetic unit hydrograph (SUH) of the Synthetic Soil Conservation Service showed an error percentage of 16.6%, and the SUH of the Nakayasu method showed an error percentage of 39.5%.

2. The synthetic unit hydrograph of the Gama I method is the best applied at the Bengawan Solo River in the Dengkeng–Pusur Section. The method can serve as a verification tool if there is a damaged gauge in the Bengawan Solo River or at other locations that have similar watershed characteristics of the study site.

3. The maximum flood discharge for the ten year return period of the Bengawan Solo River in the Dengkeng–Pusur section based on the analysis of the synthetic unit hydrograph of the Gama I method, Soil Conservation Service method and Nakayasu method varying between 881.69 $m^3 \cdot s^{-1}$ to 1512.97 $m^3 \cdot s^{-1}$ while the design flood discharge of Bengawan Solo River embankment in the Dengkeng–Pusur section of 1,240 $m^3 \cdot s^{-1}$ or are among the calculations of the three methods.

REFERENCES

Ariyani D., Riadhi H. 2019. Perbandingan hasil analisa debit banjir dengan menggunakan metode hidograf satuan sintetis Nakayashu dan Gama I di das Ciherang hulu [Comparison of results of flood discharge analysis using the Nakayashu and Gama I synthetic unit hydrograph method in the Ciherang hulu watershed]. Spirit of Civil Engineering (SPRING) Journal. Vol. 01. Iss. 01 p. 1–7.

Balci O. 2004. Quality assessment, verification, and validation of modeling and simulation applications. Proceedings of the 2004 Winter Simulation Conference. Vol. 1 p. 122–129. DOI 10.1109/WSC.2004.1371309.

BBWS 2010. Pola pengelolaan sumber daya air: wilayah sungai Bengawan Solo [The pattern of water resources management in the Bengawan Solo River Basin]. Surakarta. Balai Besar Wilayah Sungai Bengawan, Ditjen Sumber Daya Air, Kementerian Pekerjaan Umum pp. 18.

BBWS Bengawan Solo 2015. Rencana pengelolaan sumber daya air wilayah sungai Bengawan Solo [Bengawan Solo River basin management plan]. Surakarta. Indonesia pp. 171.

BBWS Bengawan Solo 2019. Laporan hidrologi tahunan wilayah sungai Bengawan Solo [Annual hydrological report of Bengawan Solo river basin]. Surakarta. Indonesia pp. 19.

Chow V.T., Maidment D.R., Mays L.W. 1988. Applied hydrology. McGraw-Hill International Edition. ISBN 0-07-010810-2 pp. 572.

Cornelissen T., Diekkrüger B., Giertz S. 2013. A comparison of hydrological models for assessing the impact of land use and climate change on discharge in a tropical catchment. Journal of Hydrology. Vol. 498 p. 221–236. DOI 10.1016/j.jhydrol.2013.06.016.

Deepak K., Patra D., Mondal A., Kundu S. 2017. Impact of landuse/land cover change on run-off in the catchment of a hydro power project. Applied Water Science. Vol. 7. Iss. 2 p. 787–800. DOI 10.1007/s13201-015-0292-0.

Haan C.T. 1977. Statistical method in hydrology. The Iowa State University Press. Iowa. ISBN 0-8138-1510-X pp. 178.

Harto B.S. 2000. Hidrologi: teori, masalah, penyelesaian [Hydrology, theory-problem-solution]. Yogyakarta. Nafiri Offset. ISBN 979-861-24-1 pp. 389.

Heriansyah E., Hasibuan S. 2018. Implementasi metode peramalan pada permintaan bracket side stand K59A [Implementation of forecasting method on K59A side stand bracket request]. PASTI Jurnal. Vol. 12. No. 2 p. 209–223.

JICA 2002. Upper Solo River improvement project [online]. [Access 31.03.2020]. Available at: https://www.jica.go.jp/english/our_-work/evaluation/oda_loan/post/2002/pdf/057_full.pdf

Junia N., Fauzi M., Suprayogi I. 2015. Kesesuaian model hidrograf satuan sintetik studi kasus sub daerah aliran sungai Siak bagian hulu [The conformity of the synthetic unit hydrograph model case study of the Upper Siak River Basin]. Jom Fteknik. Vol. 2. No. 1 p. 1–9.

Knighton J.O., Degaetano A., Walter M.T. 2017. Hydrologic state influence on riverine flood discharge for a small temperate watershed (Fall Creek, United States): Negative feedbacks on the effects of climate change. Journal of Hydrometeorology. Vol. 18. No. 2 p. 431–449. DOI 10.1175/JHM-D-16-0164.1.

Kristianto A.B., Norken I.N., Dharma I.G.B.S., Yekti M.I. 2019. Komparasi model hidrograf satuan terukur dengan hidrograf satuan sintetis (Studi kasus das Tukad Pakerisan) [Comparison of measured unit hydrograph model with synthetic unit hydrograph (Case study of Tukad Pakerisan watershed)]. Jurnal Spectran. Vol. 7. No. 1 p. 21–31.

Lasminto U., Lumantara E., Widyastuti H., Zharin F. 2016. Flood assessment of Bengawan Solo River. Asian Research Publishing Network Journal of Engineering and Applied Sciences. Vol. 11. No. 24 p. 14443–14450.

Lewis C.D. 1982. Industrial and business forecasting methods. Butterworth-Heinemann. London. ISBN 978-0408005593 pp. 143.

Liu J., Wang S., Li D. 2014. The analysis of the impact of land-use change on flood exposure of Wuhan in Yangtze river basin, China. Journal of Water Resource Management. Vol. 28 p. 2507–2522. DOI 10.1007/s11269-014-0623-1.

Makridakis S., Wheelwright S.C., McGee V.E., Bahasa A., Andriyanto U.S., Basith A. 1999. Metode dan aplikasi peramalan [Forecasting methods and applications]. Vol. 1. Jakarta. Binarupa Aksara. Tangerang pp. 143.

Margi K., Pendawa S. 2015. Analisa dan penerapan metode single exponential smoothing untuk prediksi penjualan pada periode tertentu (studi kasus: PT. Media Cemara Kreasi) [Analysis and application of the single exponential smoothing method for prediction of sales in certain periods (case study: PT. Media Cemara Kreasi)]. Proceedings of the 2nd SNATIF in 2015 p. 259–266.

Margini N.F., Nusantara D.A.D., Ansori M.B. 2017. Analisa hidrograf satuan sintetik Nakayasu dan ITB pada sub das Konto, Jawa Timur [The analysis of Nakayasu synthetic unit hydrograph and ITB in Konto sub-watershed, East Java]. Jurnal Teknik Hidroteknik. Vol. 2. No.1 p. 41–45.

Marthina S., Rapar E., Mananoma T., Wuisan E. M., Binilang A. 2014. Analisis debit banjir sungai Tondano menggunakan metode HSS Gama I dan HSS Limantara [Tondano river flood discharge analysis using the HSS of Limama and the HSS of Gama I]. Jurnal Sipil Statik. Vol. 2. No. 1 p. 13–21.

Maryono A. 2013. The landuse change related to the increase of peak discharge of Pengabuan catchment, Jambi, Indonesia. Indonesian Journal of Geography. Vol. 41. Iss. 1 p. 93–101. DOI 10.22146/ijg.18273.

Parandin F., Khoorani A., Bazrafshan O. 2019. The impacts of climate change on maximum daily discharge in the Payab Jamash watershed, Iran. Open Geosciences. Vol. 11. Iss. 1 p. 1035–1045.

PUPR 1997. Operasi dan pemeliharaan bendungan Wonogiri [Wonogiri dam operations and maintenance]. Jakarta. Kementerian Pekerjaan Umum dan Perumahan Rakyat. Departemen Pekerjaan Umum, Direktorat Jenderal Pengairan pp. III-8.

Rai R. K., Sarkar S., Singh V.P. 2009. Evaluation of the adequacy of statistical distribution functions for deriving unit hydrograph. Water Resources Management. Vol. 23. Iss. 5 p. 899–929. DOI 10.1007/s11269-008-9306-0.

Sarkar S., Goel N.K., Mathur B.S. 2010. Performance investigation of Nakagami-*m* distribution to derive flood hydrograph by genetic algorithm optimization approach. Journal of Hydrologic Engineering. Vol. 18. Iss. 8 p. 658–666. DOI 10.1061/(ASCE)HE.1943-5584.0000220.

SCS 1972. National engineering handbook. Section 4. Hydrology. Chapter 21. Design hydrographs. Washington, D.C. U.S. Department of Agriculture, Soil Conservation Service pp. 127.

Soemarto C.D. 1987. Hidrologi teknik [Engineering hydrology]. Penerbit Usaha Nasional. Surabaya. Indonesia. ISBN 975-760-342-9 pp. 513.

Suripin, Kurniani D. 2016. Pengaruh perubahan iklim terhadap hidrograf banjir di kanal banjir timur kota Semarang [The effect of climate change on flood hydrographs in the east flood canal of the city of Semarang]. Jurnal Media Komunikasi Teknik Sipil. Vol. 22. No. 2 p. 119–128.

The World Bank 2010. The rise of Indonesia, policy priorities for 2010 and beyond [online]. [Access 21.04.2020]. Available at: http://documents.worldbank.org/curated/en/

Triatmodjo B. 2008. Hidrologi terapan [Applied hydrology]. Yogyakarta. Beta Offset. ISBN 978-979-8541-40-7 pp. 274.

WMO 2009. Guide to hydrological practices. Vol. 2. Management of water resources and application of hydrological practices. World Meteorological Organization. No. 168. Switzerland. ISBN 978-92-63-10168-6 p. II.5-15-II.5-20.

Zainun N.Y.B., Rahman I., Eftekhari M. 2019. Forecasting low-cost housing demand in Johor Bahru Malaysia using artificial neural networks (ANN). Journal of Mathematics Research. Vol. 2. No. 1 p 14–19. DOI 10.5539/jmr.v2n1p14.