Research article

The Influence of Two Different Time of Concentration Equations on the GIUH-based Flood Hydrograph Estimates of Keduang and Temon Sub-Watersheds, Indonesia

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Received: 18 May 2021, Revised: 2 November 2021, Accepted: 20 December 2021

DOI: 10.55003/cast.2022.05.22.001

Keywords

unit hydrograph;

time of concentration;

Ventura;

Kirpich;

GIUH

Abstract

Understanding the rainfall-runoff response on a watershed requires the study of both the observed and synthetic unit hydrographs. The application of a synthetic unit hydrograph for an ungauged watershed is the prospective alternative. Model development to obtain the unit hydrograph without rainfall and runoff data requires information on the physical characteristics of the watershed and its geomorphological parameters. This paper presents the results of a study on the application of the Geomorphological Instantaneous Unit Hydrograph (GIUH) model in which the time of concentration equations of Kirpich and Ventura were used as a comparison. The study objects are the Keduang and Temon Sub-watersheds of the Upper Bengawan Solo River, Indonesia. The study utilized the sub-watershed characteristic data obtained from the satellite data of ASTER Global DEM V3, which was then processed with the Watershed Modeling System and ArcMap. The results show that in the Keduang Sub-watershed, the Ventura equation gave results closer to the observed unit hydrograph than the Kirpich equation. In the Keduang Sub-watershed, the differences between the two times of concentration on the triangular parameters were significant, i.e. 77.13%, 337.57%, and 338.20% for peak discharge, peak time, and base time, respectively. On the other hand, in Temon Sub-watershed, the differences were 33.88%, 28.63%, and 25.09% for peak discharge, peak time, and base time, respectively. In terms of the GIUH-based flood hydrograph estimation, the results show that the utilization of the Ventura equation generally led to better estimates (closer to the observed flood hydrograph) than that of Kirpich equation.

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1. Introduction

Study on the rainfall-runoff behavior requires information on the observed flow hydrograph at the control point of the watershed. However, not all watersheds have enough rainfall and flow data due to the relatively high field monitoring equipment prices. Watersheds that do not have hydrological stations are referred to as ungauged watersheds. The establishment of an experimental watershed may be a very effective way to study the hydrological characteristics of the watersheds [1]. Identifying the rainfall-runoff response in a watershed may be carried out by analyzing the unit hydrographs, i.e. the observed and synthetic unit hydrographs. In ungauged watersheds, the use of synthetic unit hydrographs is an alternative.

There were several works related to GIUH model developments, and among of them were those carried out by Azizian [1], Chen *et al*. [2] and Sulistyowati *et al*. [3]. Azizian [1] recommended both Kirpich and Ventura time of concentration equations whereas Chen *et al*. [2] and Sulistyowati *et al*. [3] only utilized the Kirpich time of concentration equation.

Most of the developed T_c are based on the two different approaches [1]. In the first approach, T_c is the time needed for water to travel from hydraulically most distant point to the catchment's outlet. The hydraulically most distant point is the longest travel time to the watershed outlet, but not the longest flow distance to the outlet. Equations that are based on this approach depend on geomorphological characteristics such as flow path length, flow path slope, catchment area, rainfall attributes and land cover-related-coefficient (e.g., Manning's roughness coefficient, curved number, and retardance factors). In the second approach, *Tc* is the time distance between the end of effective rainfall and the inflection point of the hydrograph's falling limb.

There are many formulas for *Tc* that utilize the first approach including Kirpich and Ventura. The Kirpich time of concentration is more widely used than that of Ventura due to basin size considerations [1, 3-5] because of the Kirpich equation is more suitable for relatively small catchment areas (0.004-0.453 km^2). The Ventura time of concentration was developed for rural basins in Italy; however, it is considered suitable for application in tropical climates and relatively large catchment areas.

The SCS-CN method is a popular empirical approach for the estimation of direct runoff for a given rainfall event from small agricultural, forest, and urban watersheds and can incorporate a number of watershed runoff producing characteristics: soil type, land cover and practice, hydrologic condition, and antecedent moisture condition. Due to its low input data requirements and its implementation within GIS, such as the Geomorphological Instantaneous Unit Hydrograph (GIUH), its combination with SCS-CN was used to further develop the flood hydrograph model [6]. The SCS method generally produces a very large peak discharge, so that if this method is used without calibration, it can lead to over-design.

This study focuses on the unit hydrograph mentioned earlier; two Sub-watersheds were selected, i.e. the Keduang and Temon Sub-watersheds. Both Sub-watersheds lay at the watershed of Wonogiri Reservoir, Central Java, Indonesia (see Figure 1). The Wonogiri Reservoir was built as a flood control installation for the Upper Bengawan Solo River and functioned reducing the flood peak from 4000 m^3/s into 400 m^3/s [7, 8]. The watershed area of Wonogiri Reservoir is approximately 1,260 km^2. Besides flood control, the reservoir also functions to irrigate 23,600 ha of rice fields and to generate up to 12.4 MW of energy. The Wonogiri Reservoir was planned to have a service lifetime of 100 years, was built over the period of 1976-1981, and began to operate in 1982. The Wonogiri Reservoir has ten Sub-watersheds; two of them are the Keduang and Temon Sub-watersheds, as shown in Figure 2 [9, 10]. The above Sub-watersheds contribute significantly to the functioning of the reservoir. For example, they play vital roles in the control of high flow of water and sediment. Analysis of data obtained from the Keduang and Temon Sub-watersheds may facilitate the assessment of the sensitivity of applying different dynamic parameter velocities to the estimation of synthetic unit hydrographs using the Geomorphological Instantaneous Unit Hydrograph (GIUH) method.

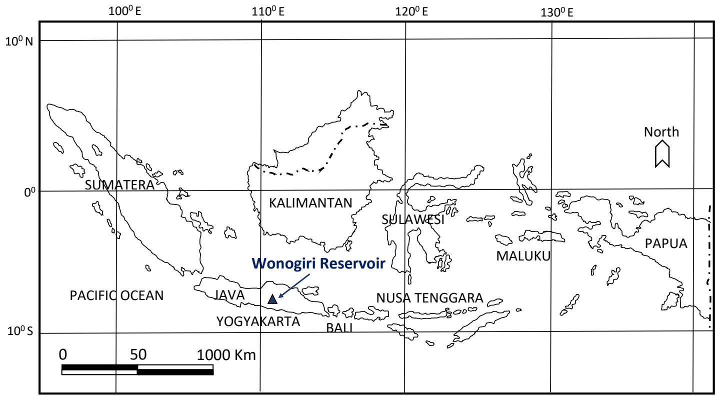


Figure 1. Location Map of Wonogiri Reservoir, Central Java, Indonesia

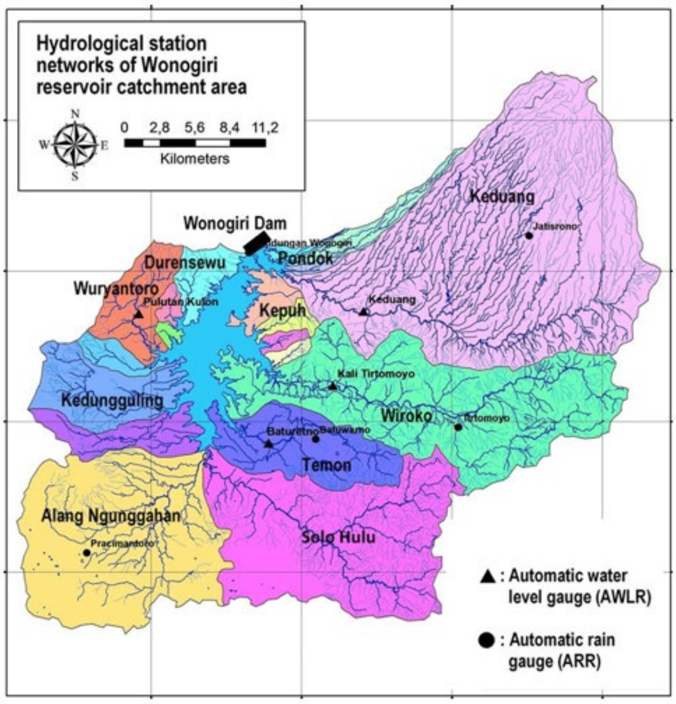


Figure 2. Location map of Keduang and Temon Sub-watersheds

2. Materials and Methods

The study utilized various materials such as study objects, related hydrological characteristics, hydrological-related software, and the Geographical Information System (GIS)-associated software. The study objects are the two Sub-watersheds of Wonogiri Reservoir watershed, the Keduang and Temon Sub-watersheds. The catchment modeling utilized a basic map obtained from the Advanced Spaceborne Thermal Emission and Reflection (ASTER) Global Digital Elevation Modelling (DEM) Version 3 at 30m grid cell resolution. The determination of the physical parameters of the Sub-watersheds studies utilized Watershed Modeling System (WMS) Version 10.1 64-Bit dan ArcMap Version 10.3. The catchment delineation process used the minimum threshold of an accumulation from DEM at the optimal conditions of the drainage patterns, without any calibration and verification of the catchment delineation results. The analysis of the dynamic velocity parameters utilized the combination of the time concentration equation according to Kirpich (and/or Ventura) and the velocity equation [11, 12]. The derivation of the instantaneous unit hydrograph into the unit hydrograph utilized the S-Curve method.

2.1 Watersheds and their physical parameters

This study was focused on the selected Sub-watersheds, i.e. the Keduang and Temon Sub-watersheds. A watershed is an area that consists of a stream pattern surrounded by lines of the highest location. A sub-watershed is an area in which all the land and water would contribute runoff to a specific location termed as a control point. The sub-watershed is a topographical border with a particular control point at the downstream of the river under consideration. It could be a hydrometrical station such as a discharge monitoring station. Sub-watershed morphology includes physical parameters such as boundary, shape, river flow pattern, land use and other sub-watershed conditions. Rainfall conditions are characterized by intensity and duration of a specific rainfall event and are considered the most critical factors affecting sub-watershed conditions. Such rainfall conditions can further determine the particular pattern of runoff conditions, i.e. the unit hydrograph [13]. There should be a correlation between the rainfall and runoff at a sub-watershed. The unit hydrograph information can be very useful for estimating discharge at a control point, even when the flow data is not available. Shirmeen [13] introduced the unit hydrograph concept that has been widely used to translate the rainfall information into the runoff information at specific watersheds. A unit hydrograph is defined as a direct runoff (without base flow) that occurs at the watershed outlet resulting from one unit depth of rainfall that takes place over the whole watershed area with constant intensity and over a specific duration. A simple method of flood hydrograph estimation utilizes the unit hydrograph method, and this method is generally accurate.

2.2 Instantaneous Unit Hydrograph (IUH)

When the duration of the effective rainfall becomes shorter, the resulted unit hydrograph will become an impulse response function that lasts in a considerably short time and is called an Instantaneous Unit Hydrograph (IUH). In other words, the effective rainfall in a catchment forms an IUH within zero time duration. However, such an assumption is only a concept and does not represent the condition in actual practice. Even so, this concept is helpful since the resulted IUH does not usually consider the rainfall duration. The IUH can be interrelated with the geomorphological conditions of a watershed [11, 12].

2.3 Geomorphological Instantaneous Unit Hydrograph (GIUH)

Geomorphological Instantaneous Unit Hydrograph (GIUH) is defined as a probability density function that describes the travel time of effective rainfall at a watershed that flows along with the hydraulics network until the outlet of the watershed. Rodriguez-Iturbe introduced the GIUH concept in 1979 and it was further developed by Gupta *et al*. in 1980 [14]. The model is aimed at deriving a density function based on the geomorphological parameters of the watershed [15]. This model combines the geomorphological characteristic of a watershed and its corresponding response due to rainfall events [14, 16, 17]. Rodriguez-Iturbe and Valdez [11] assumed that the instantaneous unit hydrograph has a triangle form consisting of peak discharge (q_p), peak time (t_p), and base time (t_b) [4, 18, 19]. The triangular parameter of GIUH is illustrated in Figure 3, whereas the equations are written as follows:

$$q_p = \frac{1.31 \times {R_L}^{0.43} \times V}{L_\Omega} \qquad (1)$$

$$t_p = 0.44 \times \frac{L_\Omega}{V} \times \left(\frac{R_B}{R_A}\right)^{0.55} \times R_L{}^{-0.38} \tag{2}$$

$$t_b = \frac{2}{q_p} \tag{3}$$

where:

q_p = peak discharge (hour^{-1})
t_p, t_b = peak time (hours), base time (hours)
L_Ω = river length with the highest order in the watershed (km)
V = dynamic parameter velocity (m/s)
R_A, R_B, R_L = area ratio, bifurcation ratio and length ratio, respectivelly.

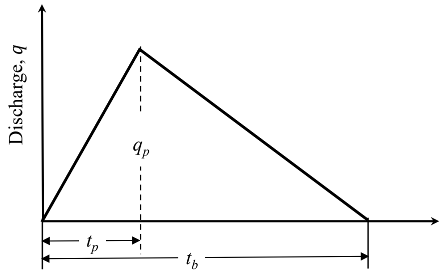


Figure 3. Illustration of the triangular shape of GIUH

2.3.1 Stream orders and Horton ratios

The determination of the river orders may be carried out through the watershed's establishment. The main river order in the watershed is the river with the highest order where the most upstream part of the river receives the water then flows downstream towards the watershed outlet. The downstream channel meets another channel forming the highest order; hence, the first order of the river is defined as the channel that receives the water directly from the upstream, and this river does not have any branch. The meeting point of the two rivers with first order would form the channel with second order. Therefore, that river with the highest order will receive a greater volume of water than rivers of other orders. When two second-order rivers meet each other, similarly, they form a river with third order and so on. This process follows the Horton-Strahler scheme [20, 21]. Horton Ratios are the ratios that are utilized to characterize the river system within a watershed. The Horton Ratios are beneficial to describe the characteristics of the watershed. The Horton Ratios consists of the area ratio (R_A), bifurcation ratio (R_B), and length ratio (R_L). The area ratio R_A is the average area of the watershed. The bifurcation ratio (R_B) is the ratio of the number of the river reach. The length ratio R_L is the river length over the entire river's entire length within the watershed. The formulas to calculate the Horton Ratios are written as follows:

$$R_A = \frac{A_{(i+1)}}{A_i} \tag{4}$$

$$R_B = \frac{N_i}{N_{(i+1)}} \tag{5}$$

$$R_L = \frac{L_{(i+1)}}{L_i} \tag{6}$$

where:

A_i = average area of sub-watershed contributing to the river with the order I; I = 1,2,3… Ω (Ω is the highest order of river within the watershed)
N_i = number of rivers with the order i
L_i = average length of the river with the order i

2.3.2 Dynamic parameter velocity

The accuracy of the IUH estimation using the GIUH model depends on utilizing values of dynamic parameter velocity [22]. It is assumed that a model that has better statistical parameter values would perform better (compared to that of the observed values). The assumption is then utilized to examine the performance of the flood hydrograph as calculated by utilization of two different time of concentration equations, i.e. the Kirpich and Ventura equations. The dynamic parameter velocity of the watershed can be calculated using the combination of the time of concentration (t_c) equation and the velocity (V) equations. Many empirical equations may be utilized to determine the time of concentration-time [1, 5, 23]. The time of concentration equations according to Kirpich and Ventura is shown in equations (7) and (8), respectively.

$$t_{c-Kirpich} = 0.01947 \times L^{0.77} \times S^{-0.385} \tag{7}$$

$$t_{c-Ventura} = 4 \times A^{0.5} \times L^{0.50} \times H^{-0.50} \tag{8}$$

where: t_c = time of concentration (h)
A = area of the watershed (km^2)
H = elevation difference between ends of main waterline (m)
L = length of mean waterline (km)
S = mean steepness (ratio between mean full H and the length of the river)

The time of concentration *tc* is a function of dynamic parameter velocity and is written as follows:

$$t_c = \frac{1}{60} \times \left(\frac{L}{V}\right) \tag{9}$$

Where t_c is the time of concentration (min), L is length of waterline (m), and V is dynamic parameter velocity (m/s).

Substitution of equation (9) into equations (7) and (8) gives the dynamic parameter velocity of Kirpich and Ventura as written in equations (10) and (11), respectively.

$$V_{Kirpich} = 0.8562 \times L^{0.23} \times S^{0.385} \tag{10}$$

$$V_{Ventura} = \frac{5 \times L^{0.5} \times H^{0.5}}{72 \times A^{0.5}} \tag{11}$$

2.3.3 Flood hydrograph estimation using GIUH

The SCS-CN method has been developed since 1972 by the *Soil Coservation Services*. The effective rainfall is calculated using the following equations:

$$P_e = \frac{(P - I_a)^2}{P - I_a + S} \tag{12}$$

$$I_a = \boldsymbol{\lambda}\, \boldsymbol{S} \tag{13}$$

$$S = \left(\frac{1000}{CN} - 10\right) \times 25.4 \tag{14}$$

where:
P_e = effective rainfall (mm)
P = rainfall (mm)

I_a = initial abstraction (mm)
S = maximum potential retention (mm)
λ = coefficient of initial abstraction
CN = curve number, as a function of watershed characteristics

To increase the SCS-CN performance, previous research suggested using the λ at 0.05 [6]. The direct runoff hydrograph can be calculated using the following equation:

$$Q_n = \sum_{m=1}^{n} P_m \times U_{n-m+1} \tag{15}$$

Q_n is the direct runoff discharge at hours n; P_m is an effective rainfall at hours m, and U is the ordinate of the unit hydrograph. The resulting unit hydrograph obtained from the GIUH method is then compared with the observed ones, and the discrepancies are examined.

2.3.4. The Nash model

The Nash model is based on the concept of routing of the instantaneous inflow through a cascade of linear reservoirs with equal storage coefficients. The Nash model can be expressed as follows [24]:

$$u(t) = \frac{1}{k\Gamma(n)}\left(\frac{t}{k}\right)^{n-1}\exp\left(-\frac{t}{k}\right) \tag{16}$$

where $u(t)$ is the ordinate of the IUH (h^{-1}), t is the sampling time interval (h), n and k are parameters of the Nash model, in which n is the number of linear reservoirs, and k is the storage coefficient (h). The complete shape of GIUH can be obtained by linking the q_p and t_p of GIUH with the scale (k) and shape (n) parameters of the Nash model, where q_p is the peak flow (h^{-1}), t_p is the time to peak (h). Further analysis of q_p and t_p will form the following equation:

$$q_p * t_p = \frac{(n-1)}{\Gamma(n)}\exp[-(n-1)] * (n-1)^{n-1} \tag{17}$$

where

$$t_p = k(n-1) \tag{18}$$

Another relationship of q_p and t_p that considers the geomorphology characteristic is written as the following equation [25]:

$$q_p * t_p = 0.5764\left[{R_B}/{R_A}\right]^{0.55} {R_L}^{0.05} \tag{19}$$

Further substitution of equations (19) to (17) will form the following equation:

$$\frac{(n-1)}{\Gamma(n)} exp[-(n-1)](n-1)^{n-1} = 0.5764\left[{R_B}/{R_A}\right]^{0.55} {R_L}^{0.05} \tag{20}$$

Iteration of equation (20) will give n values, and substitution of n value into equation (18) will give k values.

2.3.5. The *RME* and *RSME*

The relative mean error (*RME*) differences between values obtained from the model or simulation and the actual or observed values according to the following equations [3]:

$$RME = \frac{1}{n}\sum_{i=1}^{n} RE_i \tag{21}$$

$$REi = \frac{|Q_{obs} - Q_{cal}|}{Q_{obs}} \times 100 \tag{22}$$

where

RE_i = percentage of relative error of each event i
Q_{obs} = observed peak of flood hydrograph
Q_{cal} = calculated peak of flood hydrograph
n = number of events

The root mean square error (*RMSE*) is one of the commonly used error index statistics to measure the differences between values obtained from the model or simulation and the actual observed values [3, 25]. The *RMSE* is calculated using the following equation:

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n} {SE_i}^2} \tag{23}$$

$$SE_i = \left(Q_{obs} - Q_{cal}\right)^2 \tag{24}$$

where

SEi = square of relative error of each event i
Q_{obs} = observed peak of flood hydrograph
Q_{cal} = calculated peak of flood hydrograph
n = number of events

Lower the values of *RME* and *RMSE* indicate better model performance.

3. Results and Discussion

3.1 Keduang and Temon watersheds

The watershed of Wonogiri Reservoir consists of several Sub-watersheds, as shown in Figure 2. Through the WMS Software application to analyze the DEM data from ASTER, the areas of the Keduang and Temon Sub-watersheds were found to be 362.56 and 46.29 km^2, respectively. A previous study [3] showed that the Keduang and Temon Sub-watershed areas were 360.73 and 68.08 km^2, respectively. These differences arose presumably due to the difference of control points used in both Keduang and Temon Rivers. Further analysis of the Keduang and Temon Sub-watersheds using the ArcMap resulted in the value of the Sub-watersheds physical parameters, i.e., the river order length first-order river and the area of the Sub-watersheds. Table 1 shows the physical parameter of the sub-watersheds including the river order and the area of the Keduang and Temon Sub-watersheds.

The physical characteristics of the Keduang and Temon sub-watershed are described as follows [26]. The slopes of Keduang and Temon Sub-watersheds range from 0-0.03 (21%); 0.03-0.08 (26%); 0.08-0.15 (20%); 0.15-0.25 (11%); over 0.25 (22%) and 0-0.03 (33%); 0.03-0.08 (9%); 0.08-0.15 (10%); 0.15-0.25 (15%); over 0.25 (24%). The entire area of the Keduang and Temon Sub-watersheds have the average slopes of 0.194 and 0.184, respectively. The soils distributed in the Wonogiri watershed are classified following the old Indonesian classification system into four soil types: Mediteran (Soil Taxonomy: Alfisols), Litosol (Inceptisols), Latosol

Table 1. Physical parameters of the Keduang and Temon Sub-watersheds

Sub-watershed and river order	Physical parameters				
	Number of reaches (N)	Length (L, km)	Average length (km)	Area (A, km^2)	Average area (km^2)
Keduang					
Order 1	161	257.978	1.602	221.495	1.376
Order 2	38	130.861	3.444	228.704	6.019
Order 3	9	88.271	9.808	236.310	26.257
Order 4	2	20.856	10.428	270.722	135.361
Order 5	1	7.566	7.566	362.566	362.566
Temon					
Order 1	127	66.901	0.440	40.791	0.321
Order 2	28	25.665	0.917	49.207	1.757
Order 3	4	9.997	2.494	52.275	13.059
Order 4	1	9.967	9.967	56.841	56.841

(Alfisols) and Grumusol (Vertisols) [26]. The Keduang Sub-watershed is dominated by Mediteran and Litosol, whereas the Temon Sub-watershed comprises Grumusol only. Over at least the last two decades, the land use of Keduang and Temon Sub-watersheds has remained unchanged. The land uses in Wonogiri watershed (including the Keduang and Temon sub-watershed) have been classified into the land use categories: i) paddy field, ii) home settlement, iii) upland field, iv) orchard/plantation, v) forest, vi) state forest, and vii) others. Among the categories, paddy field occupies the largest share followed by upland field and home settlement. The upland field and parts of home settlement areas are extensively used for dry land farming.

3.2 GIUH-based unit hydrographs of Keduang and Temon Sub-watersheds

The results of the Keduang and Temon Sub-watersheds physical parameter analysis using the WMS and ArcMap were then analyzed to obtain the unit hydrographs. The analysis utilized the GIUH through the process of calculation of the Horton Ratio, dynamic parameter velocity (V), peak discharge (q_p), peak time (t_p), and base time (t_b). Further utilization of the physical parameters of the Keduang and Temon Sub-watersheds from Table 1 gave the values of the Horton Ratios for both Sub-watersheds (see the summary in Table 2).

Table 2. Horton Ratios of the Keduang and Temon Sub-watersheds

Horton Ratios	Suggested values	Keduang sub-watershed	Temon sub-watershed
R_A	3-6	4.163	5.774
R_B	3-5	3.709	5.196
R_L	1.5-3.5	1.523	2.818

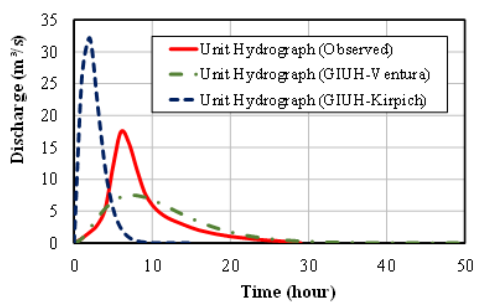
It is seen from Table 2 that only the value of R_B found to be slightly higher than the suggested value. Such conditions would be of interest for further research evaluation of the physical parameter value and their relationship with the watershed characteristics. In this study, the dynamic parameter velocities (V) were calculated using the time of concentration equations according to Ventura and Kirpich as written in equations (11) and (10), respectively. The results of the calculations showed that the time of concentrations for the Keduang were 0.359 and 1.58 min for the Ventura and Kirpich equations, respectively, whereas the Temon sub-watershed were 1.064 and 1.5 min for the Ventura and Kirpich equations, respectively. The different times of concentration may affect the limb of the unit hydrograph and hence also the time to peak and flood peak hydrographs. Moreover, the time to peak and flood peak hydrographs may also depend on the geomorphological characteristic of the basin. The triangular parameter of the

Sub-watersheds is the peak discharge (q_p), the peak time (t_p), and the base time (t_b). The values of the three parameters depends on the values of the dynamic parameter velocity (V). Table 3 presents the triangular parameters of the Keduang and Temon Sub-watersheds. It can be seen from Table 3 that there are some differences in the values of parameters obtained from the different values of time of concentration. In the Keduang sub-watershed, the differences mentioned above are significant, i.e. 77.13%, 337.57%, and 338.20% for q_p, t_p, and t_b, respectively. On the other hand, in the Temon sub-watershed, the discrepancies are 33.88%, 28.63%, and 25.09% for q_p, t_p, and t_b, respectively.

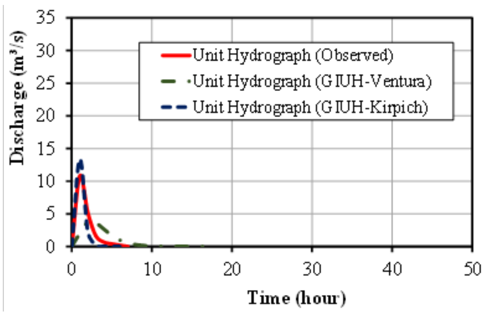
Table 3. Triangular parameters of the Keduang and Temon Sub-watersheds

Sub-watershed	Method of dynamic parameter velocity	Peak discharge (q_p) m^3/s	Peak time (t_p) h	Base time (t_b) h
Keduang	Ventura	0.075	7.395	26.774
	Kirpich	0.328	1.690	6.110
Temon	Ventura	0.245	2.368	8.156
	Kirpich	0.307	1.870	6.510

The determination of unit hydrograph by the method of GIUH requires information on the Instantaneous Unit Hydrograph or IUH and values of constants n and k from the Nash Model [2, 3]. The resulted values of n and k vary depending upon the catchment area and time of concentration. The n and k values are 3.079 and 0.811; 3.077 and 3.561; 3.211 and 0.299; 3.274 and 1.041 for the Keduang-Kirpich, Keduang-Ventura, Temon-Kirpich, Temon-Ventura, respectively. After the IUH obtained from combined analysis of GIUH triangular parameter and NASH Model was determined, the derivation of IUH into UH was carried out utilizing the S-Curve method. The results in the form of the GIUH-based unit hydrograph are shown in Figures 4 a and 4 b for the Keduang and Temon Sub-watersheds, respectively. In addition, the observed flood hydrographs obtained from a previous study [3] are also included in the Figures mentioned above.



(a)



(b)

Figure 4. The GIUH-based and observed unit hydrograph
(a) Keduang sub-watershed, (b) Temon Sub-watershed

It is seen from Figure 4 that in terms of the GIUH-based unit hydrograph, the Kirpich equation for Temon sub-watershed performed better than the Ventura equation (Figure 4b). This was probably due to the two geomorphological characteristics being different. Another reason is due to the rainfall event that took place unevenly over the entire catchment. This is a subject of interest for further research.

3.3 Flood hydrograph of Keduang and Temon Sub-watersheds

The GIUH-based Unit Hydrograph utilizing both Ventura and Kirpich equation of dynamic parameter velocity was then used to estimate the flood hydrograph using several rainfall events. The effective rainfall was calculated utilizing the SCS-CN method, and the results are shown in Figures 5 a and 5 b for the Keduang and Temon Sub-watersheds, respectively. The *CN* values are 71.62 and 83.06 for the Keduang and Temon Sub-watersheds, respectively. The effective rainfall calculation utilizing the above *CN* values were obtained and used to further calculate the flood hydrograph. Finally, the peak of the direct runoff hydrographs (Qp) was examined using the statistical parameters of *RME* and RMSE (see Table 4).

It is seen from Table 4 that the results show better agreement for the utilization of the Ventura than the Kirpich equation of time of concentration. The GIUH-Ventura model results look better as compared with the observation data, however, the *RMSE* is still high. The watershed characteristics such as size and drainage pattern could be the dominant factors affecting the model performance, including its *RSME* value.

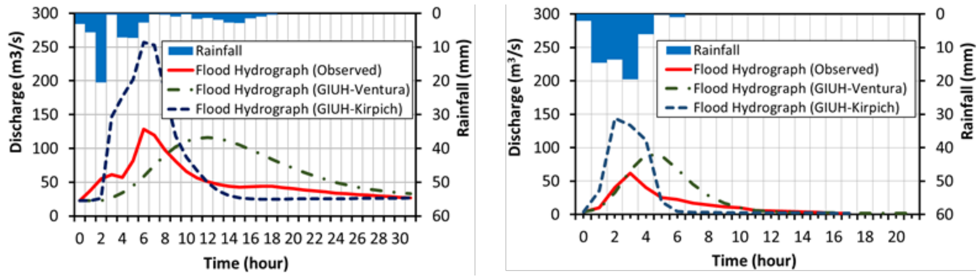
The significant difference between the calculated and observed peak discharge as shown in Figure 4 a is probably due to the physical parameters of the Keduang sub-watershed. An adjustment on the river orders may present more appropriate estimations, and this is a subject of interest for further research. It seems that the number of events in both Keduang and Temon Sub-watersheds were not sufficient to examine either the GIUH or its corresponding flood hydrographs. However, the evaluation of the utilization of two different time of concentrations in the GIUH-based flood hydrograph is considered important in the selection of the better equation of time of concentration.

Due to the limited observed data, the data utilized for the Temon sub-watershed was obtained from 22-23 February 2000. The Temon sub-catchment is a remote area where the geomorphological characteristics have remained relatively unchanged from 2000 until now (2021). It was then anticipated that the observed data in 2000 could be compared with the current prediction. Unfortunately, for this study, to add more observed data in the analysis was not possible. However, for further research, more observed data and its corresponding analysis will be of interest and should be implemented.

Table 4. RME and RMSE of GIUH-based and observed flood hydrograph

Sub-watershed and event	Q_p observed (m^3/s)	Q_p (GIUH-Ventura) (m^3/s)	*RME*	*RMSE*	Q_p (GIUH-Kirpich) (m^3/s)	*RME*	*RMSE*
Keduang, 6-7 March 2019	128.36	116.59	9.34	11.99	256.95	100.18	128.59
Temon, 22-23 February 2000	61.92	89.65	117.32	33.22	143.73	333.51	95.17
Temon, 7 March 2020	19.98	57.91			126.84		

The GIUH-Ventura model results are in reasonable agreement with the observation data, however, the *RMSE* is still too high. It is seen from Table 4 that both *RME* and *RMSE* values are considered too high. This is probably due to the geomorphological characteristics of the basin, particularly the number of river orders and lengths. This needs to be examined in further research.



(a) **(b)**

Figure 5. The GIUH-based and observed flood hydrograph:
(a) Keduang sub-watershed (6-7 March 2019), (b) Temon sub-watershed (22-23 February 2000)

4. Conclusions

The utilization of the river order in the form of accumulation threshold may increase the accuracy of the determination of the watershed physical parameters. In the case of the Keduang and Temon Sub-watersheds, the application of the Ventura approach gave a closer agreement between the analysis and the observed unit hydrograph than the Kirpich equation. However, the utilization of the GIUH-based unit hydrograph to estimate the direct runoff hydrograph seemed to require further evaluation using more rainfall event data. Nevertheless, the technique of analysis used in this study is considered promising, particularly for the ungauged watersheds.

This paper also demonstrates the value of practical application of the method used in the study, particularly concerning the selection of the most appropriate equation of the time of concentration. Moreover, the entire process of analysis to estimate the GIUH-based flood hydrograph utilizing two different equations of time of concentration has shown that the techniques being utilized are practically acceptable. Other statistical tests may be used to evaluate the model, including the Nash-Sutcliffe efficiency (*NSE*), Percent Bias (*PBIAS*), and ratio of the root mean square error to the standard deviation of measured data (*RSR*) [25]. In addition, the evaluation of the outlier data that affects the *RMSE* calculation may only be carried out subject to ample numbers of observed data. Unfortunately, the Keduang sub-watershed had only one event, and the Temon sub-watershed had only two events.

5. Acknowledgments

The authors express their gratitude to the Bengawan Solo River Basin Authority for providing data related to the Keduang and Temon Sub-watersheds. The authors also thank the researchers in the Hydraulics Laboratory, Department of Civil and Environmental Engineering, Universitas Gadjah Mada, for the discussion related to the topic of this study.

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