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Research Article

Selecting the accurate hydrological method for estimating peak discharge in the Lesti River Catchment Area, Malang Regency, East Java Province, Indonesia

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Abstract

Estimating peak discharge in the catchment poses a challenge for hydrologists due to the potential overflow risks. The present study examined various methods, including Synthetic unit hydrograph, Melchior, and Rational, to determine the peak discharge value in the Lesti River Catchment Area. Accurate hydrological input data is essential for effectively estimating peak discharge and mitigating potential damage or failure. Optimized physical parameters using geographic information systems are critical in generating peak discharge values, emphasizing their importance in the estimation process. The mean absolute percentage error (MAPE) and mean average error (MAE) were used to determine the accurate method for estimating peak discharge. Analysis results showed varied peak discharge values across different methods, and it found that the MAPE values ranged from 15.15% to 7.48% and the MAE values ranged from 1.47% to 0.63%, respectively. The Nakayasu synthetic unit hydrograph obtained the minimum error measure value compared to other methods by 7.48% in MAPE and 0.63% in MAE. Therefore, the MAPE and MAE performance considered that the Nakayasu was closely approximating the observed peak discharge and a relatively accurate method for estimating peak discharge in the Lesti River catchment area.

Keywords: Accurate, Catchment, Estimate, Lesti River, Peak discharge

INTRODUCTION

Estimating peak discharge poses a challenge for hydrologists due to the potential risks of overflow (Barid and Afanda, 2022; Imaaduddiin *et al*., 2022; Suharyanto, 2021). This crucial task involves determining the maximum volume of water flowing through a river or channel during a specific period, usually during extreme weather events such as heavy rainfall or snowmelt (Saadi *et al*., 2021). Accurately predicting peak discharge is vital for designing hydraulic structures, including dams, bridges, culverts, and flood control systems, as it helps ensure that these structures can effectively handle to anticipate water flow and prevent potential damage or failure (Avila and Ávila 2016; Pambudi *et al*., 2021).

Hydrologists and engineers use various methods to estimate peak discharge, considering catchment characteristics, rainfall intensity, topography, land use, morphometrics, and historical flow data (Echeverri-Díaz *et al*. 2022; Tao *et al*. 2019). Due to the hydrologic system's complexity and the catchment's specific characteristic, it is necessary to choose the appropriate method for a particular catchment (Sultan *et al*. 2022;

Gericke and Smithers, 2014). These methods may include statistical analysis of historical records, hydraulic modeling, and empirical equations based on observed relationships between rainfall and streamflow (Echeverri-Díaz *et al*. 2022; Tao *et al*. 2019). Additionally, advancements in technology, such as remote sensing and computer simulations, have provided new tools and techniques to improve the accuracy of peak discharge estimations (Azizian 2019; Seong and Sung 2021).

The peak discharge information results from the hydrologic analysis are needed in planning water structures both in the present and for future planning, assuming the characteristics of the catchment stay the same (Imaaduddiin, Saud, and Santoso 2022). Estimating peak events could be done by hydrologic modeling (Guo *et al*. 2021), and rainfall is the main factor contributing to the cause of peak discharge (Ansori *et al*., 2023) and estimating peak discharge using various hydrological methods through a long data series of peak discharge (>10 years)(Gericke and Smithers 2014). The peak discharge analysis was done using statistical methods.

In the condition that the available data was maximum daily rainfall and river catchment characteristics, the recommended methods were superposition of the instantaneous unit hydrograph (IUH) and Synthetic Unit Hydrograph (SUH), introduced in 1932 by Sherman (Seong and Sung 2021; Shaikh *et al*., 2022). The data required to derive the hydrograph of the measuring unit in the catchment under review are automatic rain data and discharge recordings at specific observation points, known as observed peak discharge (Shaikh *et al*., 2022). However, synthetic peak hydrograph analysis was not available when the rainfall data was required to compile the hydrograph of the units of size Calculated peak discharge using synthetic unit hydrograph methods commonly used in Indonesia include the Snyder-SCS, Snyder-Alexeyev, Nakayasu SUH, GAMA-1, DPMA-IOH, and HSS-αβγ methods (Ansori *et al*., 2023; Natakusumah *et al*., 2011). The other way to estimate peak discharge was Rational, Melchior, Weduwen, and Hasper, known as lumped methods (Ansori *et al*., 2023; Bout and Jetten, 2018; Moges *et al*. 2021; Unami, 2023; Pambudi and Moersidik 2019). Due to various forms, there was an opportunity to employ a calculated process similar to the characteristics of Java Island, especially in East Java (Februanto *et al*., 2021; Pambudi and Moersidik 2019; Roestamy and Fulazzaky 2021). The research was conducted to analyze an ideal and appropriate model from a variety of methods of peak discharge that approximate the catchment characteristics (Boothroyd *et al*., 2023; Metselaar, 2023; Salvadore *et al*., 2015).

This research analyzed and identified an appropriate catchment in East Java Province, Indonesia, to accomplish this aim. Considering the numerous available catchments, the Brantas River Catchment is the largest river in East Java Province, covers nine regencies and six cities with a population of 18,6 million people, which is 43 percent of the population of East Java Province. One of the upstream catchments of Brantas River was the Lesti River in Malang Regency (Februanto *et al*., 2021). The Lesti River has an outlet in the Sengguruh dam, which served as a cofferdam for the Sutami weir. The Sutami weir has a crucial role in flood control, irrigation water supply, and significant supply of most of the hydroelectricity in East Java Province (Roestamy and Fulazzaky, 2021; Legono *et al*., 2021). However, erosion hazard levels were observed in 2021 due to the Lesti River contributing to erosion at 153,868 tons ha/year (exceeding the tolerable erosion rate of 30 (ton ha/year) (Pambudi and Moersidik ,2019; Pambudi *et al*., 2021). The annual increasing trend of decline and the continued land use/cover changes of the Lesti River are critical factors in selecting this Upper Lesti River Catchment (ULRC) as the study location (Bekti *et al*. 2018; Pambudi and Moersidik 2019; Pambudi, Moersidik, and Karuniasa 2021).

As previously highlighted, the ULRC's water discharge significantly contributes to the Brantas River water discharge (Pambudi and Moersidik 2019; Legono *et al*. 2021). Therefore, numerous hydrologists conducted research to estimate the peak discharge calculation of the ULRC, and the results have shown various values (Ansori *et al*., 2023; Natakusumah *et al*., 2011). Despite the availability of sophisticated methods, estimating the peak discharge of ULRC is challenging due to the inherent uncertainty and complexity of natural hydrological systems (Gericke and Smithers 2014; Kim and Jeong, 2021). Optimized physical parameters play a major role in generating varied peak discharge values, emphasizing their importance in the estimation process.

The accurate hydrological input data is essential for effectively estimating peak discharge in the Lesti River and mitigating potential damage or failure. The accuracy of estimation was influenced by various factors, including the availability and quality of data, the scale of analysis, the assumptions made in the estimation methods, and probability distributions. Therefore, this paper examines various methods, including SUH, Melchior, and the Rational method, to determine the varied peak discharge values in the Lesti River (Februanto *et al*., 2021; Pambudi *et al*., 2021; Roestamy and Fulazzaky 2021). The main objective of this study is to analyze the most relatively accurate method for peak discharge estimation. Selecting an accurate peak discharge method by comparing observed and calculated peak discharge.

MATERIALS AND METHODS

Study site

The study site is in the ULRC connected to the Brantas River (Roestamy and Fulazzaky 2021; Pambudi *et al*., 2021). The coordinates' locations were 7°40'-7°55' S and 112°10'-112°25' E. The automatic water level recorder (AWLR) location of the ULRC was 112°41'4.8", 8°13'49.3" in the village of Tawangrejeni, Turen district area.

The ULRC area is located in Malang Regency of East Java Province, Indonesia. The study area is Lesti River catchment, one of the upstream of Brantas catchment with outlet in Sengguruh Dam (Fig.1). There were three rainfall stations of ULRC and the location is shown in Table 1.

Catchment delineation

The delineation was conducted using a 30-m digital elevation model (DEM) in the watershed modeling system (WMS) (Abdulwahd *et al*., 2020; Yang and Cao, 2021). Then, the flow direction and accumulation were determined, and the river network was defined synthetically (Yang and Cao, 2021). The outlet of the catchment was determined, and the parameters were calculated . The topographic maps, scaling 1:25, were used to analyze the physical characteristics of the catchment, such as catchment boundary, area, slope, and length of the main river (Gaurav and Singh, 2022).

Observed peak discharge data

The hourly discharge data were collected from the AWLR for 2006-2020 when the study was conducted, known as observed discharge (Shaikh *et al*., 2022; Winter *et al*. 2019; Kilonzo, 2022). The maximum observed discharge data was chosen as peak discharge, known as $Q_{p\ obs}$.

Daily rainfall data

The data period varied depending on the rainfall station data and the quality of usable data for acceptable analysis. The oldest data were from 2000, while a few stations started operation in 2004 (Kilonzo, 2022). The usable data were determined after validating the rainfall and discharge data. In this case, statistics has an important role in helping to select and evaluate data as the usage of inferential statistics. Statistics provided tools and methods to find structure and to provide deeper data. The data were screened through scatter plots and outliers (95 percentile<data<5 percentile) (Kilonzo, 2022).

The peak discharge was analyzed using maximum daily rainfall data across the ULRC. In principle, the methodology used in this study includes catchment delineation, rainfall data analysis, and validation analysis. The diagram of the methodology used is shown in Fig. 2.

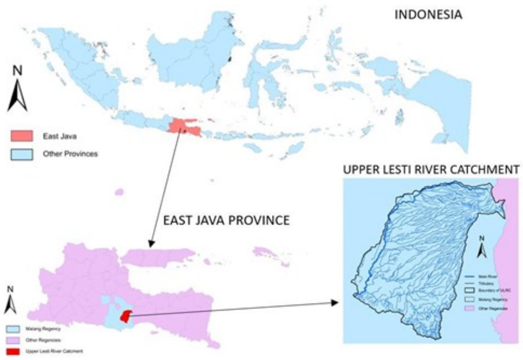

Fig. 1. *Study site in ULRC of Malang Regency of East Java Province*

Table 1. Location of rainfall station

No.	Station Name	Coordinates	
		latitude	longitude
1.	Poncokusumo	112°48'43.52"	8°03'04.09"
2.	Dampit	112°48'47.05"	8°16'05.23"
3.	Wajak	112°44'02.00"	8°06'15.09"

Rainfall intensity

The average maximum rainfall intensity in the ULRC was analyzed for each year. The 15 years (2006-2020) data recorded by rainfall stations were used. The Thiessen polygon method was used to determine the average rainfall intensity in the catchment. The data was converted into hourly rainfall intensities to analyze the peak discharge after determining daily-rainfall intensities (Suharyanto, 2021). The hourly rainfall intensity analysis results can be used as input data to analyze the discharge. The Mononobe was used to assess maximum rainfall intensity (mm hr-1). The Mononobe equation is derived in equation 1

$$R_t = \frac{R_{24}}{T}\left(\frac{T}{t}\right)^{\frac{2}{3}} \qquad \text{Eq. 1}$$

Where Rt is hourly intensity [mm hr^{-1}], R_{24} is daily rainfall [mm day^{-1}], T is the duration of rainfall (equal to 24 hr. for daily rainfall), and t is the actual rainfall duration [hr].

Calculated peak discharge

The calculated peak discharge, known as Qpcal, was carried out using the SUH and lumped method. The SUH used in this study was Natakusumah *et al.* (2011). The SUH described the physical characteristics of the catchment and the rainfall intensity. The catchment's physical features include the area of the catchment (A), length of the river (L), and the surface runoff coefficient (C) (Ansori *et al*., 2023; Natakusumah *et al*., 2011; Suharyanto *et al*., 2021). The hourly rainfall intensity was used as input data to analyze SUH discharge.

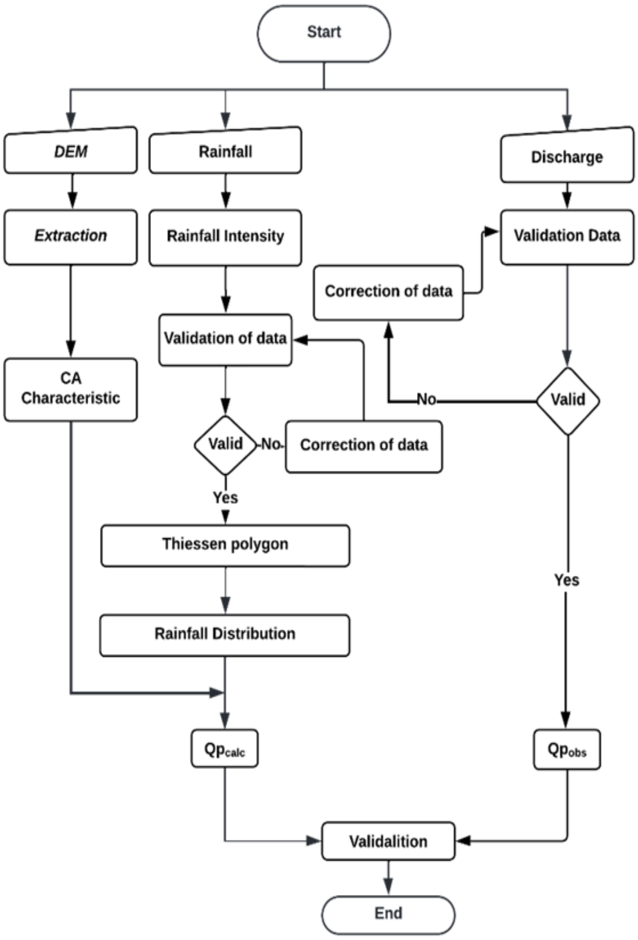

Fig. 2. *Flow diagram of the study method*

Nakayasu SUH

Nakayasu SUH was used to analyzed peak discharge analyses. The formula of Nakayasu SUH can be expressed as follows (Suharyanto *et al*., 2021):

$$Q_p = \frac{1}{6}\left(\frac{A\ x\ R_e}{0.3\ x\ T_p + T_{0.3}}\right) \qquad \text{Eq. 2}$$

$$T_p = T_g + 0.8\ T_r \qquad \text{Eq. 3}$$

$$t_g = 0.4 + 0.058, L \quad > 15\ km, L < 15\ km \qquad \text{Eq. 4}$$

$$T_g = 0.21L^{0.7} \qquad \text{Eq. 5}$$

$$T_{0.3} = \alpha t_g \qquad \text{Eq. 6}$$

Rising lamb (0 < t <Tp)

$$Q_t = Q_p \frac{t^{2.4}}{T_p} \qquad \text{Eq. 7}$$

Decreasing limb ($0 \leq t \leq (T_p+T_{0.3})$)

$$Q_t = Q_p 0.3^{\frac{(t-T_p)}{T_{0.3}}} \qquad \text{Eq. 8}$$

On Decreasing limb

$(T_p+T_{0.3}) \leq t \leq (T_p+T_{0.3}+1.5T_{0.3})$

$$Q_t = Q_p 0.3^{\frac{(t-T_p)+(0.5T_{0.3})}{1.5T_{0.3}}} \qquad \text{Eq. 9}$$

On Decreasing limb

$t > (T_p+T_{0.3}+1.5T_{0.3})$

$$Q_t = Q_p 0.3^{\frac{(t-T_p)+(1.5T_{0.3})}{2T_{0.3}}} \qquad \text{Eq. 10}$$

Qp is peak discharge (m^3sec^{-1}), Re is effective rainfall (mm), A is catchment (km^2), Tp is time to peak [hr], $T_{0.3}$ is the time required from the maximum peak discharge to 30% of the peak discharge, tg is concentration time, Tr is the unit time of rainfall (hr), α is catchment characteristic coefficient, L is main river length (km), tg is time lag (hr). The typical Nakayasu SUH is illustrated in Fig. 3.

To apply the Nakayasu SUH, A, and L were analyzed using the topographic map generated by the GIS (Guo *et al*. 2021; Ansori *et al*., 2023).

Snyder SUH

The synthetics unit hydrograph of Snyder was determined by elements including Qp (m^3sec^{-1}), Tb (hr), tp (hr), and tr (hr). These elements are related to A, which is the area of catchment (km^2), and L, which is the length of the main river (km). Using these elements, Snyder developed a synthetic unit hydrograph model as follows:

$$Q_p = \frac{C_p A}{t_p} \qquad \text{Eq. 11}$$

$$t_p = C_t(LL_t)^{0.3} \qquad \text{Eq. 12}$$

$$Q_p = \frac{C_p\ A}{t_p} \qquad \text{Eq. 13}$$

$$\mathbf{T = 3 + \frac{t_p}{8}} \qquad \text{Eq. 14}$$

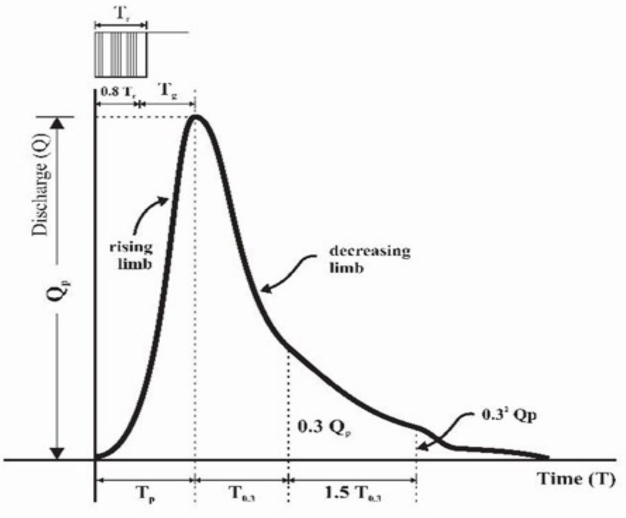

Fig. 3. *Schematic of The Nakayasu SUH* Source : (Suharyanto, 2021)

$$t_D = \frac{t_p}{5.5} \qquad \text{Eq. 15}$$

$$t_{pR} = t_p + 0.25(t_r - t_D) \qquad \text{Eq. 16}$$

$$Q_{pR} = Q_p \frac{t_p}{t_{pR}} \qquad \text{Eq. 17}$$

$$W_{50} = \frac{0.23\, A^{1.08}}{Q_{pR}{}^{1.08}} \qquad \text{Eq. 18}$$

$$W_{75} = \frac{0.13\, A^{1.08}}{Q_{pR}{}^{1.08}} \qquad \text{Eq. 19}$$

Where: tp is time lag (hr), Qp is peak discharge ($m^3 sec^{-1}$), Tb is base time (hr), Q_{pR} is unit discharge per unit area (m^3 $sec^{-1} km^{-2}$); tr is effective rain duration (hr), C_t and C_p are coefficients that depend on the units and characteristics of the catchment (Boothroyd *et al.* 2023). The coefficients Ct and Cp values need to be determined empirically because they vary between regions. In the metric system, Ct ranges from 0.75 to 3.00, while Cp ranges from 0.90 to 1.40 (Ansori *et al.*, 2023; Labdul and Alitu 2021; Shaikh *et al.*, 2022). The typical Snyder SUH is illustrated in Fig. 4.

Snyder developed a model to calculate the peak discharge and the time required to reach the peak of a single hydrograph. Therefore, to obtain the entire hydrograph curve, it takes time to calculate its parameters. Due to expedite this process, the Alexejev formula is provided, which gives the form of the unit hydrograph. The Alexejev equation is as follows (Barid and Afanda, 2022; Labdul and Alitu, 2021):

$$Q = f(t) \qquad \text{Eq. 20}$$

$$Y = \frac{Q}{Q_p} \qquad \text{Eq. 21}$$

$$X = \frac{t}{T_p} \qquad \text{Eq. 22}$$

$$Y = 10^{a\frac{(1-x)^2}{x}} \qquad \text{Eq. 23}$$

$$\lambda = \frac{Q_p\, T_p}{h\, A} \qquad \text{Eq. 24}$$

$$a = 1.32\,\lambda^2 + 0.15\lambda + 0.045 \qquad \text{Eq. 25}$$

Analysis of Lumped method

The Lumped method is generally applied at a single point or within a specific region to analyze the hydrologic processes (Y,u 2015). The lumped method has taken the capability to estimate runoff in areas ungauged stations within the catchment, predict the consequences of land use changing (Baiamonte, 2020; Brirhet and Benaabidate, 2016). Considering the spatial variability of rainfall and physical characteristics within a catchment using distributed modeling obtained an appropriate method. However, recent studies have indicated that distributed modeling approaches un-consistently to analyze the catchment (Moges *et al.*, 2021; Yang and Cao, 2021).

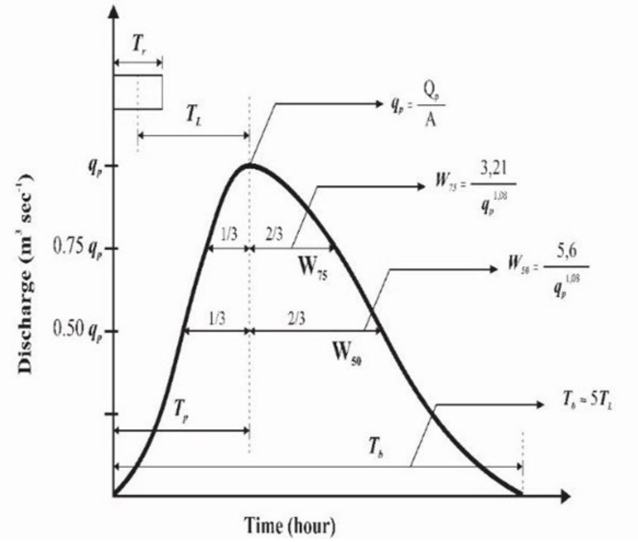

Fig. 4. *Schematic of the Snyder* SUH Source: (Suharyanto *et al*., 2021)

Melchior method

The Melchior method is used with the following formula (Natakusumah *et al*., 2011; Ansori *et al*., 2023):

$$Q_n = \alpha\ x\ \beta\ x\ q\ x\ A\ x\ \frac{R_n}{200} \qquad \text{Eq. 26}$$

Where Qn is peak discharge for period-n ($m^3 sec^{-1}$) α is the runoff of coefficient, β is coefficient of reduction, q is maximum rainfall (mm), A is area of catchment (km^2), and $\frac{R_n}{200}$ is maximum rainfall data (mm)

Rational method

The Rational method used the following formula (Al-Amri, Ewea, and Elfeki, 2022; Baiamonte, 2020):

$$Q_p = 0.278\ x\ C\ x\ I\ x\ A \qquad \text{Eq. 27}$$

Where Qp is peak discharge (m^3 sec^{-1}), C is the runoff of coefficient (dimensionless), I is intensity ($mm\ hr^{-1}$), and A is the area of the catchment (km^2). This method assumes that the rainfall intensity remains consistent throughout the rainfall and uniformly distributed across the entire catchment.

Peak discharge validation

It is important to understand that there is no such thing as the best approach or method. The level of accuracy would be indicated by the quality of the application of the method (Abdulwahd *et al.,* 2020). Many measures such as MAPE, MAE, and MASE are used to indicate the accuracy of estimated methods that have been previously recommended for use, and several authors

Table 2. Runoff coefficient

Land cover	C	Land cover	C
Business Lawns		Lawn. Sandy Soil	
Downtown	0.70-0.95	Flat. 2%	0.05-0.10
Neighborhoods	0.50-0.70	Average. 2% -7%	0.10-0.15
Residential		Steep. >7%	0.15-0.20
Single-family	0.30-0.50	Lawn. Heavy Soil	
Multi Units. detached	0.40-0.60	Flat. 2%	0.17-0.17
Multi Units. attached	0.60-0.75	Average. 2% -7%	0.18-0.22
Residential (suburban)	0.25-0.40	Steep. >7%	0.25-0.35
Light	0.50-0.80	Agriculture Area	
Heavy	0.60-0.90	Open Land	
Parks. Cemeteries	0.10-0.25	Flat	0.30-0.60
Playground	0.20-0.35	Rough	0.20-0.50
Railroad yard	0.20-0.35	Cultivated Area	
Unimproved	0.10-0.30	Heavy Soil. No Vegetation	0.30-0.60
Pavements		Heavy Soil. Vegetation	0.20-0.50
Asphalt	0.70-0.85	Sandy Soil. No Vegetation	0.20-0.25
Concrete	0.70-0.95	Sandy Soil. Vegetation	0.10-0.25
Stone/Brick	0.70-0.85	Meadow	
Pedestrian	0.75-0.85	Heavy Soil	0.15-0.45
Roofs	0.75-0.95	Sandy Soil	0.05-0.25
		Forest. Vegetation	0.05-0.25
		Bare Land	
		Flat. impervious	0.70-0.90
		Rough	0.50-0.70

Source :Winter *et al*., 2019

have made recommendations about what should be used when comparing the accuracy of estimated methods applied and observed (Goodwin and Lawton, 1999). The accuracy in hydrology methods helped hydrologist to understand how various calculated methods and observations differ. There are two accuracy measures reported in this study:

The Mean Absolute Percentage Error (MAPE) is commonly regarded as the most frequently used measurement for assessing the accuracy of estimations (Armstrong and Collopy, 1992; Goodwin and Lawton, 1999; Ren and Glasure, 2009). This simple measurement is reliable, easy to interpret and support statistical analysis (Khairina *et al*., 2020). The performance of the estimating method is highly accurate estimating if the MAPE value is below 10%, good estimating if the MAPE value is between 10% and 20%, reasonable estimating if the MAPE value is between 20% to 50% and inaccurate estimating if the MAPE value more than 50% (Moges *et al*., 2021; Prayudani *et al*., 2019). The MAPE formula is as follows:

$$MAPE = \frac{\sum_{t=o}^{n}\left|Q_{P_{obs}} - Q_{P_{cal}}\right|}{n} x100\% \qquad \text{Eq. 28}$$

Where: Q_{pobs} is observed peak discharge, Q_{pcal} is calculated peak discharge and n is amount of data

The Mean Average Error (MAE) calculates the mean of the absolute differences between estimated values and actual values (Moges *et al*. 2021; Willmott and Matsuura 2005). In other words, MAE calculates the average absolute error in predictions. The MAE value close to 0 is the better performance of the method (Brirhet and Benaabidate 2016; Moges *et al*., 2021). The MAE formula, can be expressed as follows (Willmott and Matsuura 2005):

$$MAE = \frac{1}{n}\sum_{i=1}^{n}\left|Q_{P_{cal}} - Q_{P_{obs}}\right| \qquad \text{Eq. 29}$$

Where: Q_{Pobs} is observed peak discharge, Q_{Pcal} is calculated peak discharge and n is amount of data.

The four methods were used to analyze the Lesti River flood discharge and compared which method results were the closest analysis of the flood discharge from observations of peak discharge using Mean Absolute Percentage Error (MAPE) and Mean Average Error (MAE).

RESULTS AND DISCUSSION

The characteristic of measure results of ULRC's catchment using the Software (Gaurav Singh & Singh, 2022) showed that the catchment (A) is equal to 395 km^2. The main river length (L) is 29.49 km from upstream to downstream. The catchment's location, topography and shape are shown in Fig. 5.

The elevation of Lesti River is approximately 378-3665 m above mean sea level (MSL). The topographic map of the catchment is shown in Fig. 6.

Rainfall intensity

The maximum daily rainfall intensity data from 2006 to 2020 were selected from rainfall stations (Tarasova *et al*., 2019). The rainfall intensity in the catchment analyzed using the Thiessen polygon is shown in Fig. 7. The observed peak discharged data from 2006-2020 was selected to compare the calculated peak discharged (Qp_{cal}) and the observed peak discharged (Qp_{obs}). The recorded Qp_{obs} data in AWLR was chosen based on the highest Qp_{obs} value. The available data was selected as shown in Table 3. The rainfall data was taken on the dates related to the Qp_{obs} among the three affected stations. The average rainfall intensity and the hourly rainfall intensity was calculated using the obtained data. Based on the rainfall intensity and the catchment characteristics, the Q_{pcal} was calculated using various methods.

Table 3 shows the rainfall intensity of ULRC from 2006 to 2020. The average weighted rainfall over the area was calculated based on the Thiessen polygon. Fig. 7 shows that each polygon area was affected by Wajak, Poncokusumo and Dampit stations by 0.329, 0.287 and 0.384, respectively.

Runoff Coefficient

Seven categories of land cover types in ULRC were classified using Terra-Modis 1B imagery seven (Li *et al*., 2022), as shown in Fig. 8. The land cover types and area of each type are shown in Table 2.

The C value based on land cover is shown in Table 4 (Hidayati *et al*., 2021). The weighted average of the C value ranges from 0.25 (2006-2010), 0.26 (2010-2015) and 0.27 (2016-2020), respectively. The ULRC has variation values of runoff coefficient in time period, indicating that it might be related to changes in land use, soils (layers, porosity), relief (slope, river channel gradient), and precipitation (height, duration and intensity) (Ru *et al*., 2022).

Calculated peak discharge

The calculated annual peak discharge method using Nakayasu SUH, Snyder SUH, Melchior and Rational method applied to the ULRC is shown in Table 5. Analysis results show that the Q_{pcal} showed varied and confident results than Q_{pobs}

Varied peak discharge

This study states varied peak discharge rates of the ULRC among methods. Therefore, it was listed and discussed in the following sections. The calculated peak discharge in the ULRC required accurate data as input for hydrological and morphometric parameters.

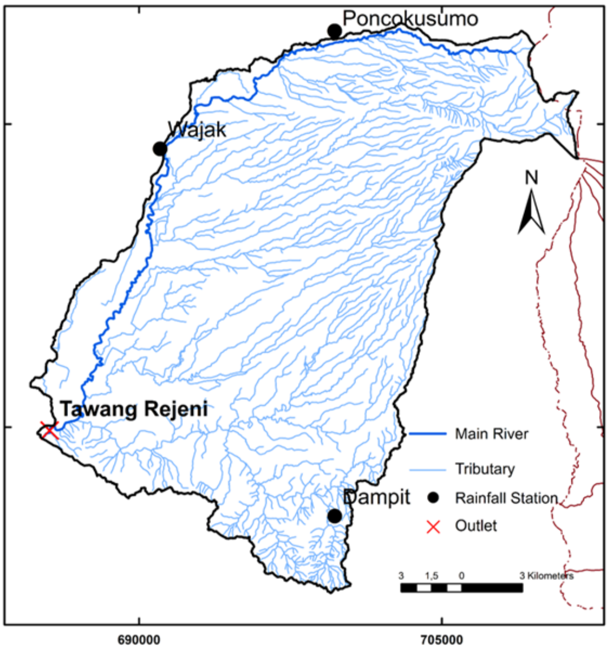

Fig. 5. *Upper Lesti River catchment*

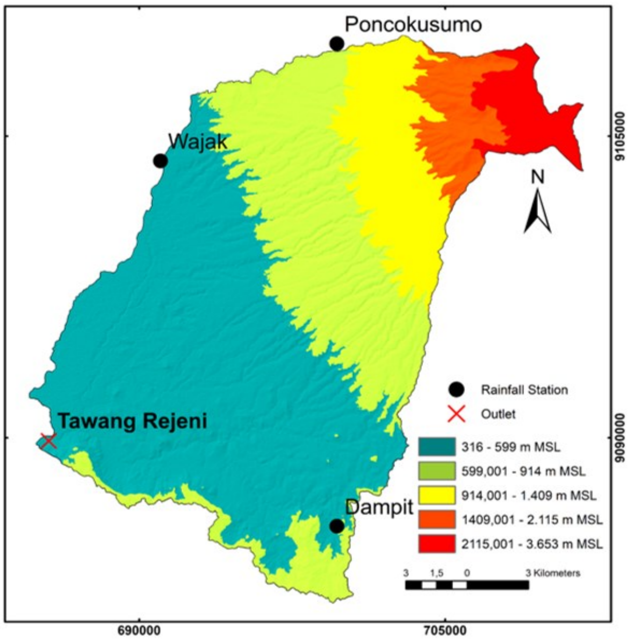

Fig. 6. *Topographic map of the upper Lesti River*

Fig. 7. *Thiessen polygon*

Both assumptions and estimated values can contribute to variations in the results. Additionally, the variability of input data, the accuracy of the model or analysis method, and other factors can also cause variations in the estimated values.Fig. 9 shows the varied values of peak discharge among methods with an observed peak discharge.

It is important to critically evaluate the varied peak discharge value obtained by the assumptions used and the level of uncertainty that may exist in the estimated input values. Uncertainty, as an aspect of estimation, reflects the degree of confidence or reliability associated with estimated values. It acknowledges that inherent limitations, potential errors, or unknown factors can affect the estimation's accuracy or validity. Uncertainty is often expressed in terms of confidence intervals, probability distributions, or qualitative assessments of the likelihood of different outcomes (Moges *et al.*, 2021).

Comparison of methods

It may be argued about the varied peak discharge among methods in ULRC. Each method has unique strengths and limitations, and none can be considered the best fit (Moges *et al.*, 2021). The difference results obtained from various hydrological and physical parameters. This is due to the complexity and high level of uncertainty involved in hydrological systems, which include factors such as future forcing input variables and decision-making in environmental change. The uncertainty input can result from inaccurate measurement, spatial interpolations, assumptions in boundaries, initial conditions, and missing data (Moges *et al.*, 2021). Hydrologists also need to make rational choices regarding the method that is most appropriate for the characteristics of the catchment. The calibration process can result in a relatively accurate method which approaches to ULRC characteristics. This process is used to compare the calculated with the observed method. The comparisons between calculated and observed peak discharge among methods are illustrated in Fig. 10.

Based on the results shown in Fig. 10, illustrated the Qp_{cal} values that were determined using the Nakayasu SUH, Snyder SUH, Rational and Melchior method. These methods showed large deviations for the corresponding values determined using Qp_{obs}. It was found that the highest values of calculated peak discharged

Table 3. Rainfall intensity in Lesti River

No.	**Date**	**Rainfall Station (mm)**			**Average (mm day^{-1})**	**Average Rainfall Intensity (mm hr^{-1})**	**$Q_{p\ obs}$ (m^3 sec^{-1})**
		Wajak	**Poncokusumo**	**Dampit**			
1	13/04/2006	41	20	17	25.92	15.29	102.00
2	26/12/2007	105	151	225	164.32	99.67	1485.00
3	09/12/2008	48	45	85	61.35	37.13	444.00
4	02/12/2009	70	80	74	74.41	41.00	360.00
5	08/11/2010	0	9	62	26.41	19.75	119.00
6	04/04/2011	28	12	16	18.79	10.67	73.00
7	20/03/2012	46	13	26	28.84	15.88	131.00
8	15/12/2013	3	2	53	21.92	16.52	737.27
9	09/01/2014	47	32	74	53.06	32.04	527.15
10	26/01/2015	43	5	75	44.38	28.39	187.29
11	31/03/2016	13	2	79	35.20	25.54	215.52
12	01/04/2017	23	55	50	42.57	24.86	154.28
13	06/01/2018	105	20	61	63.68	33.69	266.82
14	19/03/2019	0	36	14	15.72	11.37	89.03
15	14/12/2020	139	57	0	62.04	24.29	316.38

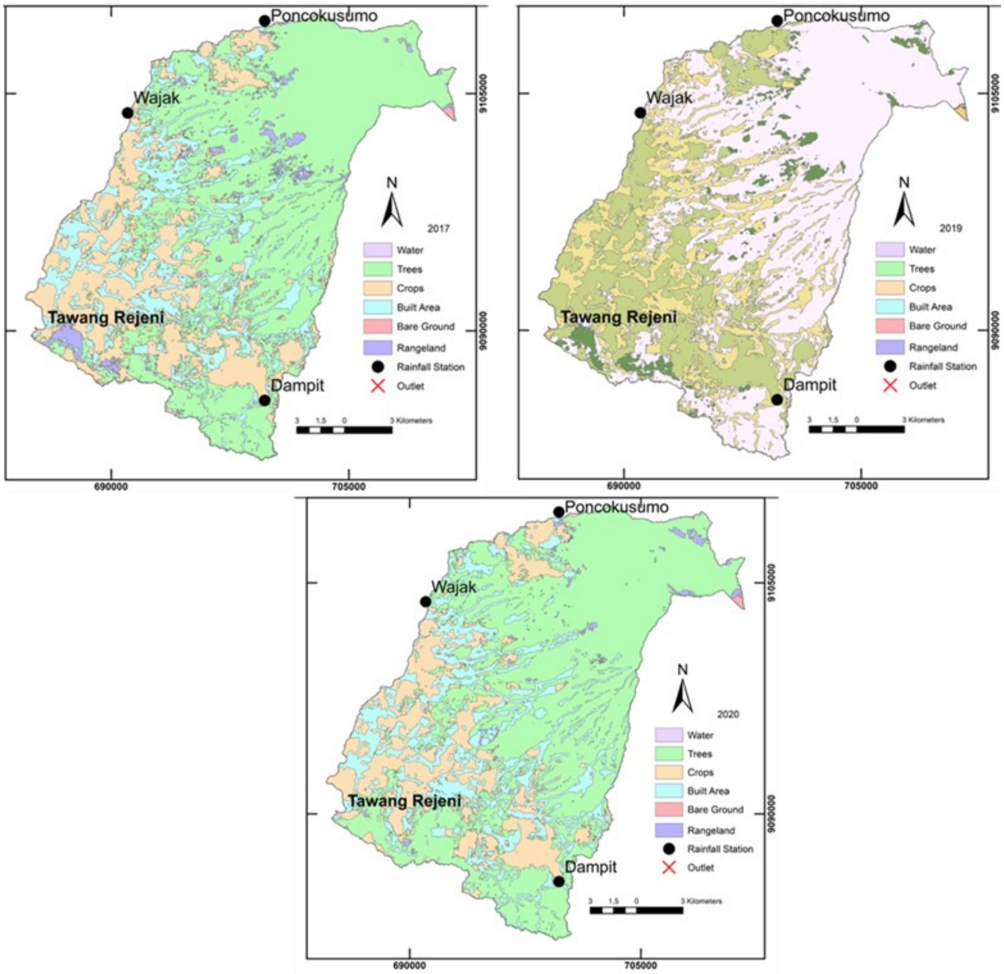

Fig. 8. *Land cover types at the ULRC (a) 2017, (b) 2019, and (c) 2020*

Table 4. Land cover of ULRC

No.	**Land cover categories**	**Area (km^2) 2017**	**Area (km^2) 2019**	**Area (km^2) 2020**
1	Water	0.09	0.04	0.03
2	Forest	223.23	208.13	234.51
3	Paddy	90.67	93.82	78.38
4	Residential	70.45	78.84	77.89
5	Open Land	0.37	0.36	0.36
6	Shrub and Brush	10.03	13.78	3.82
	Total Area	395.00	395.00	395.00

were obtained using the Rational method and the lowest values of calculated peak discharged were obtained using the Snyder SUH method. The Nakayasu SUH method is shown slightly close to observed peak discharge but has significant bias inconsistent peak discharge. Indeed, the Nakayasu SUH method was relatively closer to observed peak discharge than other methods.

Performance of the Calibrated method

The selected method presented relative accuracy in estimating peak discharge and indicated an approach similar to characteristics of the catchment.

The need to validate the peak discharge method of ULRC should be emphasised. The performance of methods was validated by using error measures. The measured values are shown in Table 6.

The performance of the Nakayasu SUH and Snyder SUH methods in the ULRC can be assessed based on their error measurement values. The MAPE values listed in Table 6 indicate that the Nakayasu SUH and Snyder SUH methods are highly accurate in estimating peak discharge. The Melchior and Rational methods were in good estimation performance. Therefore, the MAE value also indicates that Nakayasu SUH's performance is considered relatively accurate in estimating the peak discharge method. The analysis showed that the Nakayasu SUH value was closely aligned with the observed peak discharge and represented a relatively accurate method which approaches the ULRC characteristics.

Conclusion

The present study analyzed peak discharge in ULRC using the Nakayasu SUH, Snyder SUH, Melchior and Rational method. The same physical parameters, including the area of the catchment (A) of 395 km^2,

Table 5. Annual observed and calculated peak discharge in Lesti River

No.	Year	Qpobs (m^3sec^{-1})	Qpcal (m^3sec^{-1})			
			Rasional	Nakayasu	Snyder	Melchior
1	2006	102.00	419.75	346.74	325.28	473.41
2	2007	1485.00	2736.28	894.09	281.63	412.10
3	2008	444.00	1019.26	271.45	179.41	377.00
4	2009	360.00	1125.67	268.22	198.14	416.37
5	2010	119.00	542.17	303.97	395.43	550.54
6	2011	73.00	304.63	172.18	365.80	285.36
7	2012	131.00	453.38	277.87	307.00	645.13
8	2013	737.27	471.63	354.25	229.82	167.74
9	2014	527.15	914.75	393.13	154.82	325.34
10	2015	187.29	810.52	236.94	237.18	588.26
11	2016	215.52	757.19	393.07	123.41	459.32
12	2017	154.28	737.02	406.19	198.12	482.42
13	2018	266.82	998.80	518.50	162.78	342.07
14	2019	89.03	337.11	511.39	366.55	337.38
15	2020	316.38	720.17	373.86	117.37	246.65

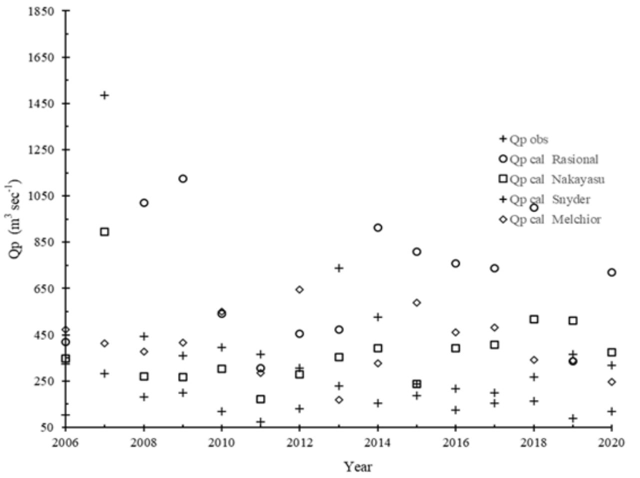

Fig. 9. Annual peak discharge of $Q_{p\ obs}$, $Q_{p\ cal\ Rational}$, $Q_{p\ cal\ Nakayasu}$, $Q_{p\ cal\ Snyder}$, and $Q_{p\ cal\ Melchior}$

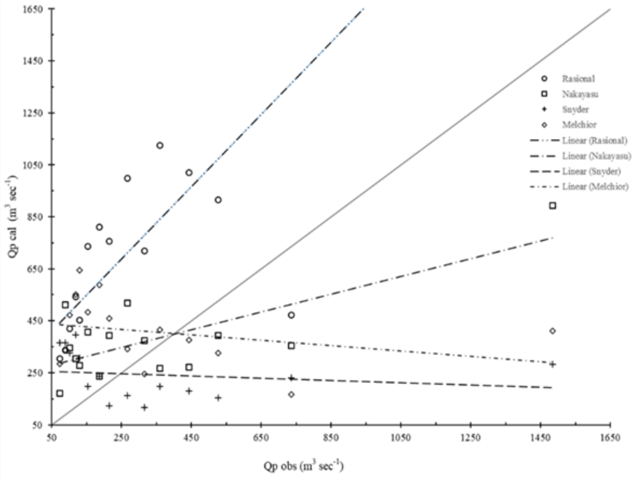

Fig. 10. *Comparisons for the Qp_{obs} versus Qp_{cal}*

length of river (L) of 29.5 km and dimensionless runoff coefficient (C) ranged from 0.25-0.27 identified using GIS and obtained varied results of peak discharge. Each method has unique strengths and limitations; none can be determined universally superior. In selecting an appropriate method for ULRC characteristics, it emphasised comparing and validating the calculated peak discharge result among methods. Based on the results, it argued in comparison that the calculated peak discharge of Nakayasu SUH method was slightly close to the observed peak discharge. The performance of methods also validated by using error measurement showed that the Nakayasu SUH method has a highly accurate estimate of peak discharge in Lesti River. Based on the performance, the Nakayasu SUH method was considered relatively accurate in providing the estimated peak discharge value of the Lesti River.

Table 6. Error measure values

Error measure	MAPE (%)	MAE (%)
Rational	15.15	1.47
Nakayasu SUH	7.48	0.63
Snyder SUH	8.10	0.82
Melchior	11.10	0.93

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Conflict of interest

The authors declare that they have no conflict of interest.

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