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Determining an optimal run-off coefficient method for estimating peak discharge in the Lesti River catchment

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Abstract: The run-off coefficients provide vital hydrological data used for river discharge forecasts and flood risk management. Selecting an appropriate method to determine this coefficient is essential for accurately estimating peak discharge. This study compared the effectiveness of the Hassing, Cook, and U.S. Forest Service methods integrating GIS in estimating run-off coefficients in the Lesti River catchment area from 2013 to 2019. The findings revealed that the run-off coefficient was determined to be 0.188–0.243 using the U.S. Forest Service method, 0.194–0.213 using the Hassing method, and 0.466–0.480 using the Cook method. These results showed a rapid increase in the run-off coefficient within the Lesti River catchment area, signifying a heightened susceptibility to flooding. This is particularly concerning as the Lesti River is a primary tributary to the Brantas River. The comparison of estimated versus observed peak discharge emphasised the superiority of the runoff coefficient associated with the Hassing method over alternative methodologies when utilised as input data for peak discharge estimation. This was evident by the notable measurement error values of 11% for *MAPE* and 0.58 for *MAE*. The Hassing method emerged as the most appropriate and reliable for reflecting run-off characteristics in the Lesti River catchment area. Additionally, it proved to be the most accurate for estimating run-off coefficients in the Nakayasu process for peak discharge estimation. Consequently, applying the Hassing method offers a viable strategy for effectively mitigating flood risks in the Lesti catchment area.

Keywords: catchment area, Cook method, Hassing method, run-off coefficient, U.S. Forest Service method

INTRODUCTION

The run-off coefficient significantly contributes to hydrological processes and considerably impacts river discharge forecasts and flood risk management (D'Alberto and Lucianetti, 2019). Determining the run-off coefficient was a critical task for engineers and hydrologists when designing stormwater management systems and estimating the peak discharge from a storm event in a specific area. The run-off coefficient represents the proportion of water that flows over the surface due to rainfall compared to the total amount of rain received over a period (Machado, Cardoso and Mortene, 2022). The run-off coefficient is an essential tool that provides information on rainfall patterns and how the physical characteristics of a catchment affect the amount of water that turns into surface run-off. It emphasises that the run-off coefficient is influenced by rainfall and catchment characteristics (Almeida *et al.*, 2022).

The run-off coefficient reflects the combined impact of various catchment conditions in the study (Suharyanto, Devia and Wijatmiko, 2021). It may vary based on the physical characteristics of the catchment (Baiamonte, 2020). Physical factors, including soil type, slope, land use, land cover, and drainage density, significantly influence run-off processes (Yan *et al.*, 2020). Various methods for physically based and spatially distributed numerical models have been widely formulated and applied to indicate the run-off coefficient. Due to these methods, ready-to-use tables and equations are often used when dealing with limited data (Dharmayasa *et al.*, 2022). This research used the Cook, Hassing, and U.S Forest service methods to estimate run-off coefficients. These methods applied ready-to-used tables to estimate run off coefficients (Saidah, Wirahman and Hidayaturrohmi, 2023).

The run-off coefficient ready-to-use table is crucial in identifying primary factors influencing the run-off coefficient. Given the numerous methods, it was possible to employ an appropriate method that matches the characteristics of the catchment in East Java (Februanto, Limantara and Fidari, 2021). The study was conducted to analyse an accurate and appropriate method for determining the run-off coefficient by comparing three types of run-off coefficient methods with estimated peak discharge and observed peak discharge (Boothroyd *et al.*, 2023). The study applied the run-off coefficient of the Hassing, the U.S. Forest Service, and the Cook methods as input to estimate the peak discharge in a catchment using the Nakayasu and Rational methods. The comparison of observed and estimated peak discharge suggests that validation of run-off coefficient methods is necessary. Therefore, the level of accuracy in validation would be indicated by the quality of its measurement error (Abdulwahd *et al.*, 2020).

The Brantas River provides significant ecological and economic support for more than 20 mln people across nine regencies and six cities (Roestamy and Fulazzaky, 2021). However, the Brantas River faces increasing challenges such as deforestation, erosion, flooding, and contamination (Pambudi, Moersidik and Karuniasa, 2021). The run-off and the land-use changes of the Lesti River have contributed to the increasing erosion rate in the Brantas River annually (Pambudi and Moersidik, 2019). The run-off coefficient represents the catchment conditions. An accurate run-off coefficient, as crucial hydrological input data, is vital for accurately estimating the peak discharge in the Lesti River and reducing the risk of flood and erosion hazards. This study aimed to identify the most accurate run-off coefficient method, integrated with GIS and Remote Sensing approaches, for application in the Lesti River.

MATERIALS AND METHODS

STUDY SITE

The study was conducted in the Lesti River Catchment, Malang Regency, East Java Province, Indonesia. The location coordinates are between 7°40'S and 7°55'S and between 112°10'E to 112°25'E (UTM zone 49S). As shown in Figure 1, the study location is part of the upstream Brantas catchment, with an outlet at the Sengguruh Dam.

DATA COLLECTION

During the study period, rainfall intensity and hourly discharge data were gathered from the Automatic Water Level Recorder (AWLR) spanning 2013 to 2019. The calculation of peak discharge in the ULRC incorporated maximum daily rainfall data spanning from 2000 to 2021, obtained from three manual rain gauge stations and one stream gauge at the Tawangrejeni AWLR station. This data was utilised as measured peak discharge data for the years 2006 to 2020, as detailed in Table 1.

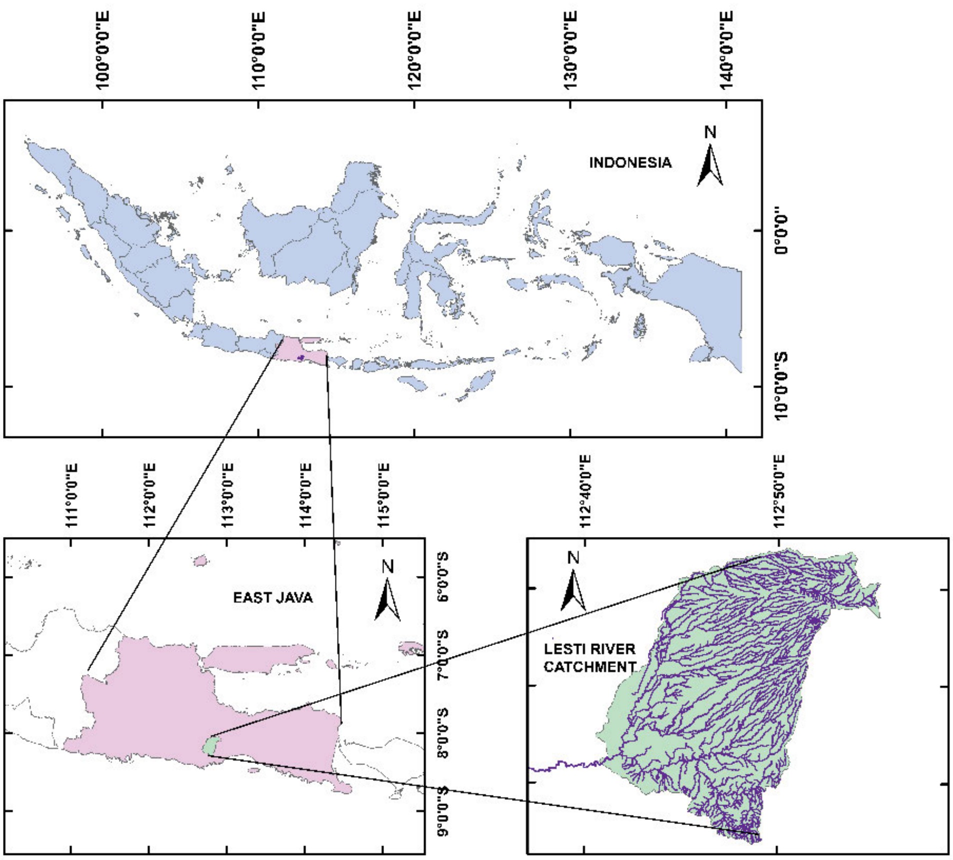

Fig. 1. Study site; source: own elaboration

Table 1. Location of manual rain gauge and AWLR station

No.	Station	Coordinates	
		latitude (S)	longitude (E)
1	Poncokusumo	8°03'04.09"	112°48'43.52"
2	Dampit	8°16'05.23"	112°48'47.05"
3	Wajak	8°06'15.09"	112°44"02.00"
4	Tawang Rejeni	8°13'49.30"	112°41'04.80"

Source: own elaboration.

The availability of data varied depending on the installation date of the rain gauges and the quality of data suitable for analysis. Operations at some stations commenced in 2004, with all rainfall stations providing data up to 2020. The selection and evaluation of maximum annual rainfall data involved statistical methods. The probability distribution function (PDF) delineates all potential values that a random variable could take within a specified range. It outlines the sample space and probabilities associated with values ranging from the minimum to the maximum.

The analysis of peak discharge utilised maximum daily rainfall data throughout the Lesti River Catchment, referred to as regional rainfall and measured in mm per day. Perum Jasa Tirta (PJT) supervised the management of historical rainfall and discharge data. This study employed a statistical approach to select daily rainfall data.

These digital elevation models (DEMs) are based on the WGS84 Geoid model and were enhanced using a filtering technique to improve accuracy and quality (Phan, Kuch and Lehnert, 2020; Suprayogi *et al*., 2022). The DEMs were utilised to generate maps depicting drainage density and land slope. For the identification of land use and land cover (LULC), Landsat 8 imagery was employed (Saddique, Mahmood and Bernhofer, 2020). The delineation of watershed boundaries and the extraction of morphometric parameters were carried out using various DEMs. The delineation process involved converting the contour maps from Rupa Bumi Indonesia (RBI) to DEMs using GIS software, with the delineation procedure outlined in Table 2. The flow direction and accumulation in the watershed were determined synthetically using GIS. The soil type was derived using the soil map of the Food and Agriculture Organization (FAO).

Table 2. Map index and name of maps

No.	No. map index	Name of map
1	1607-414	Sumber Manjing Wetan
2	1607-423	Gamping
3	1607-432	Turen
4	1607-441	Tlogosari
5	1607-434	Bululawang
6	1607-443	Tumpang
7	1607-444	Ranupane

Source: BIG (2023).

METHODS

In this study, the Hassing, Cook, and U.S. Forest Service methods were employed to ascertain the run-off coefficient within the Lesti River catchment. The run-off coefficient obtained from each method served as input data for estimating peak discharge and was then compared with observed peak discharge values. The appropriate and reliable run-off coefficient was measured using mean absolute percentage error (*MAPE*) and mean absolute error (*MAE*).

The run-off coefficient of the Hassing method

The Hassing method provided three variables (C_t, C_s, and C_v) in the ready-to-use table. The C value of a river catchment is obtained by the total value of the slope variable (C_t), the soil permeability (C_s), and the vegetation and land cover variable (C_v). Each variable is classified into four categories with its score, as listed in Table 3.

Table 3. The run-off coefficient using the Hassing method

Slope		Soil		Vegetation	
Class of slope	C_t	class of soil	C_s	class of vegetation	C_v
Very flat (<1%)	0.03	sand and gravel	0.04	forest	0.04
Undulating (1–10%)	0.08	sandy clays	0.08	farmland	0.11
Hilly (10–20%)	0.16	clay and loam	0.16	grassland	0.21
Mountainous (>20%)	0.26	sheetrock	0.26	no vegetation	0.28

Explanations: C_t = the total value of the slope variable, C_s = the permeability of soil, C_v = the vegetation and land cover variable.
Source: Hassing (2005), modified.

The run-off coefficient (C) value is following formula (Hassing, 2005):

$$C = C_t + C_s + C_v \tag{1}$$

The run-off coefficient of the U.S Forest Service method

Asdak (2020) provided a ready-to-use table of the U.S. Forest Service method, as listed in Table 4.

Table 4. The run-off coefficient of the U.S. Forest Service method

Land use	Run-off coefficient
Business	
Downtown areas	0.70–0.95
Neighbourhood areas	0.50–0.70
Residential	
Single-family area	0.30–0.50
Multi-units, detached	0.40–0.60
Multi-units, attached	0.60–0.75
Suburban	0.25–0.40
Industrial	
Light areas	0.50–0.80
Heavy areas	0.60–0.90

cont. Tab. 4

Land use	Run-off coefficient
Parks, cemeteries	0.10–0.25
Playgrounds	0.20–0.35
Railroad yard area	0.10–0.35
Lawn	
Sandy soil, flat, 2%	0.05–0.10
Sandy soil, avg, 2–7%	0.10–0.15
Sandy soil, steep, 7%	0.15–0.20
Heavy soil, flat, 2%	0.13–0.17
Sandy soil, avg, 2–7%	0.18–0.22
Sandy soil, vertical, 7%	0.25–0.35
Agricultural land	
Bare packed soil:	
– smooth	0.30–0.60
– rough	0.20–0.50
Cultivated rows:	
– heavy soil, no crop	0.30–0.60
– heavy soil, with crop	0.10–0.25
– sandy soil, no crop	0.20–0.40
– sandy soil, with crop	0.10–0.25
Pasture:	
– heavy soil	0.15–0.45
– sandy soil	0.05–0.25
– woodlands	0.05–0.25
Street	
Asphaltic	0.70–0.95
Concrete	0.60–0.90
Brick	0.70–0.85
Unimproved areas	0.10–0.30
Drives and walks	0.75–0.85
Roofs	0.75–0.95

Source: Asdak (2020), modified.

The run-off coefficient of the Cook method

The run-off coefficient can be determined using the Cook method, which provides four parameters, adopting techniques recommended (Auliyani and Nugrahanto, 2020). Each parameter, including slope, infiltration, land cover, and drainage density, is categorised into four groups and allocated scores based on the condition (low, average, high, and extreme), as depicted in Table 5. The condition range of the parameters determines the scoring for each category and is frequently used to compute the run-off coefficient. Equation (2) was used to determine the drainage density.

$$D_d = \frac{L}{A_d} \tag{2}$$

where: D_d = drainage density (km·km^{-2}), L = total length of all rivers (km), A_d = area of the drainage basin (km^2).

The cumulative run-off coefficient for each parameter was determined through the Equation (3) (Dharmayasa *et al.*, 2022).

$$C = \frac{\sum_{i=1}^{n=4}[(S_{t_n} \cdot A_{t_n}) + (S_{s_n} \cdot A_{s_n}) + (S_{d_n} \cdot A_{d_n}) + (S_{v_n} \cdot A_{v_n})]}{100} \tag{3}$$

where: C = run-off coefficient catchment's composite (Saddique *et al.*, 2020), S_{s_n}, S_{d_n}, S_{v_n} = parameters of slope, soil, drainage density and land use land cover assigned with score, respectively, A_{t_n}, A_{s_n}, A_{d_n}, A_{v_n} = ratio of slope area, the ratio of the infiltration rate area, the drainage density area, and the ratio of each land cover area to the total size of the catchment, respectively (Dharmayasa *et al.*, 2022).

The analysis of the run-off coefficient

The run-off coefficient using a ready-to-use table was obtained by combining several physical characteristics of the catchment, including its topography, soil infiltration, vegetation, and surface storage. Each physical feature is classified with different weights. The surface the run-off coefficient was calculated using Equation (4) (Nagy, Szilagyi and Torma, 2022):

$$C = \frac{\sum_{i=1}^{N} C_i A_i}{\sum_{i=1}^{N} A_i} \tag{4}$$

where: C_i = run-off coefficient for land use in the catchment, A_i = area of each land use in the catchment, N = total number

Table 5. The run-off coefficient of the Cook method

Catchment characteristic	Streamflow characteristics							
	extreme (100)		high (75)		normal (50)		low (25)	
	description	score	description	score	description	score	description	score
Slope	steep (>30%)	40	hilly (10–30%)	30	rolling (5–10%)	20	flat (<5%)	10
Infiltration rate	fast, the infiltration rate >2.00 cm·h^{-1} (sandy soil)	5	the average infiltration rate 0.75–2.00 cm·h^{-1} (sandy clay)	10	slow infiltration rate 0.25–0.75 cm·h^{-1} (sandy loam)	15	soil with negligible infiltration (rock layers)	20
Land cover	good to excellent (~50–90% covered by trees)	5	fair (~10–50% covered by trees)	10	poor (~1–10% surrounded by trees)	15	no adequate plant cover or only ground layer (<1%)	20
Drainage density (km km^{-2})	high (>8)	20	normal (3.2–8.0)	15	low (1.6–3.2)	10	very low (1.6–3.2)	5

Source: Asdak (2020b), modified.

of land uses in the catchment, catchment composed of multiple land uses.

Equation (4) should be used to determine C by weighting the C values of each land use.

The analysis of peak discharge

The estimation of peak discharge ($Q_{p\ \mathrm{est}}$) was conducted using the Nakayasu and rational methods (Natakusumah, Hatmoko and Harlan, 2011). The Nakayasu method described the physical characteristics of the catchment and the rainfall intensity. The catchment's physical features include the catchment area (A), length of the river (L), and the run-off coefficient. The hourly rainfall intensity was used as input data to analyse the Nakayasu discharge (Ansori, Lasminto and Kartika, 2023).

The Nakayasu method was used to analyse peak discharge. This method and formulas for calculating the needed parameters are detailed by Suharyanto (2021). The Nakayasu synthetic unit hydrograph is illustrated in Suharyanto, Devia and Wijatmiko (2021).

The rational method was a hydrological method that uses Eq. 15 (Al-Amri, Ewea and Elfeki, 2022):

$$Q_p = C\, i_T\, A \tag{5}$$

The method assumes consistent rainfall intensity throughout the entire catchment, with peak discharge (Q_p) (m^3·s^{-1}), run-off coefficient (C), rainfall intensity at return period T (i_T), (mm·h^{-1}), and catchment area (A) (km^2).

Run-off coefficient validation

The run-off coefficient validation method is crucial for hydrologists to accurately understand catchment run-off coefficients, which are essential for estimating peak discharge (Abdulwahd *et al.*, 2020). The comparison of observed ($Q_{p_{obs}}$) and estimated peak discharge ($Q_{p_{est}}$) suggests that validation of run-off coefficient methods is valuable. The *MAPE* and *MAE* are measurement errors used to indicate the accuracy level of estimated methods (Goodwin and Lawton, 1999). There are two accuracy measures reported in this study.

1. Mean absolute percentage error (*MAPE*) is the widely accepted metric for evaluating estimation precision, as it is reliable, easy to interpret, and supports statistical analysis (Ren and Glasure, 2009). The performance of the estimation method ranges from highly accurate to inaccurate based on the *MAPE* value, with good performance between 10 and 20%, and reasonable performance between 20 and 50% (Moges *et al.*, 2021). The *MAPE* formula is as follows:

$$MAPE = \frac{\sum_{t=0}^{n} \left| Q_{p_{obs}} - Q_{p_{est}} \right|}{n} 100\% \tag{6}$$

where: $Q_{p_{obs}}$ = observed peak discharge, $Q_{p_{est}}$ = calculated peak discharge, n = amount of data.

2. The mean average error (*MAE*) measures the difference between estimated and actual values, with a *MAE* value close to 0 indicating superior method performance. The *MAE* formula is as follows (Moges *et al.*, 2021):

$$MAE = \frac{1}{n} \sum_{i=1}^{n} \left| Q_{p_{est}} - Q_{p_{obs}} \right| \tag{7}$$

where: $Q_{p_{obs}}$ = observed peak discharge, $Q_{p_{est}}$ = calculated peak discharge, n = amount of data.

RESULTS AND DISCUSSION

RESULTS

The run-off coefficient of the Hassing method

The Lesti River catchment's slope map was categorised into four types: very flat (<1%), undulating (1–10%), hilly (10–20%), and mountainous (>20%), as shown in Figure 2. The detailed scoring value and areas of slope condition are listed in Table 6.

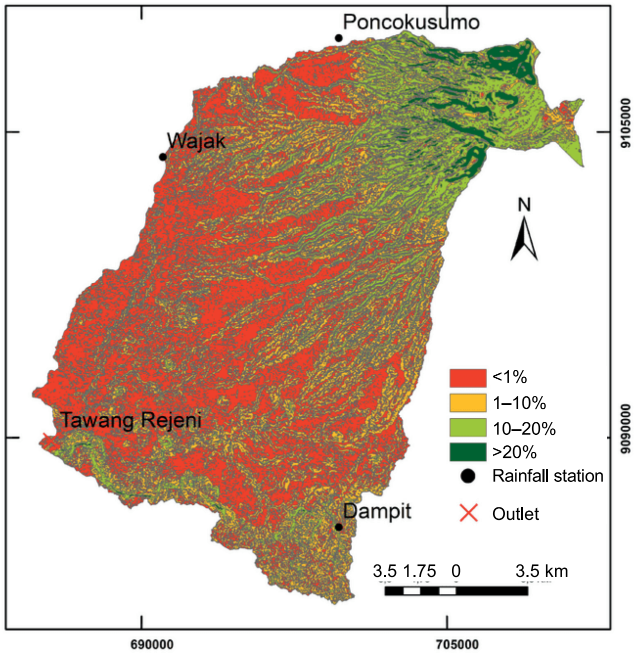

Fig. 2. The slope categorisation of the Hassing method; source: own study

Table 6. Slope characteristic and the total value of the slope variable (C_t) value of the Hassing method

Slope characteristics	A (km^2)	S_t
Very flat (<1%)	185.77	5.573
Undulating (1–10%)	140.13	11.210
Hilly (10-20%)	57.11	9.138
Mountainous (>20%)	11.98	3.114
C_t		0.074

Explanation: S_t = parameters of slope assigned score.
Source: own study.

The LULC map was produced by analysing Landsat images from 2013 to 2019. Table 7 and Figure 3 show the area of each land use and land cover (LULC) classification.

The research location has six soil types: Lithosol, Eutric Regosol, Mollic Andosol, Orchid Andosol, Vitric Andosol, and Eutric Fluvisol, as shown in Figure 4 with details of area cover and texture in Table 8. Table 9 shows the Hassing method's run-off coefficient data from 2013 to 2019.

Table 7. The vegetation and land cover variable (C_v) value of the Hassing method in land use and land cover (LULC) classification

LULC classification	Year							
	2013		2015		2017		2019	
	area (km^2)	S_v	area (km^2)	S_v	area (km^2)	S_v	area (km^2)	S_v
Forest	320.22	320.22	320.22	320.22	320.22	320.22	210.43	8.417
Plantation, agriculture	73.77	8.115	89.18	9.810	114.27	12.570	183.65	20.202
Grass	0.97	0.204	0.52	0.109	1.6	0.336	0.336	0.336
Bare soil	0.0081	0.0081	0.0081	0.0081	0.0081	0.0081	0.0081	0.0081
C_v value	0.053		0.056		0.061		0.073	

Explanation: S_v = parameters of land use land cover assigned with score.
Source: own study.

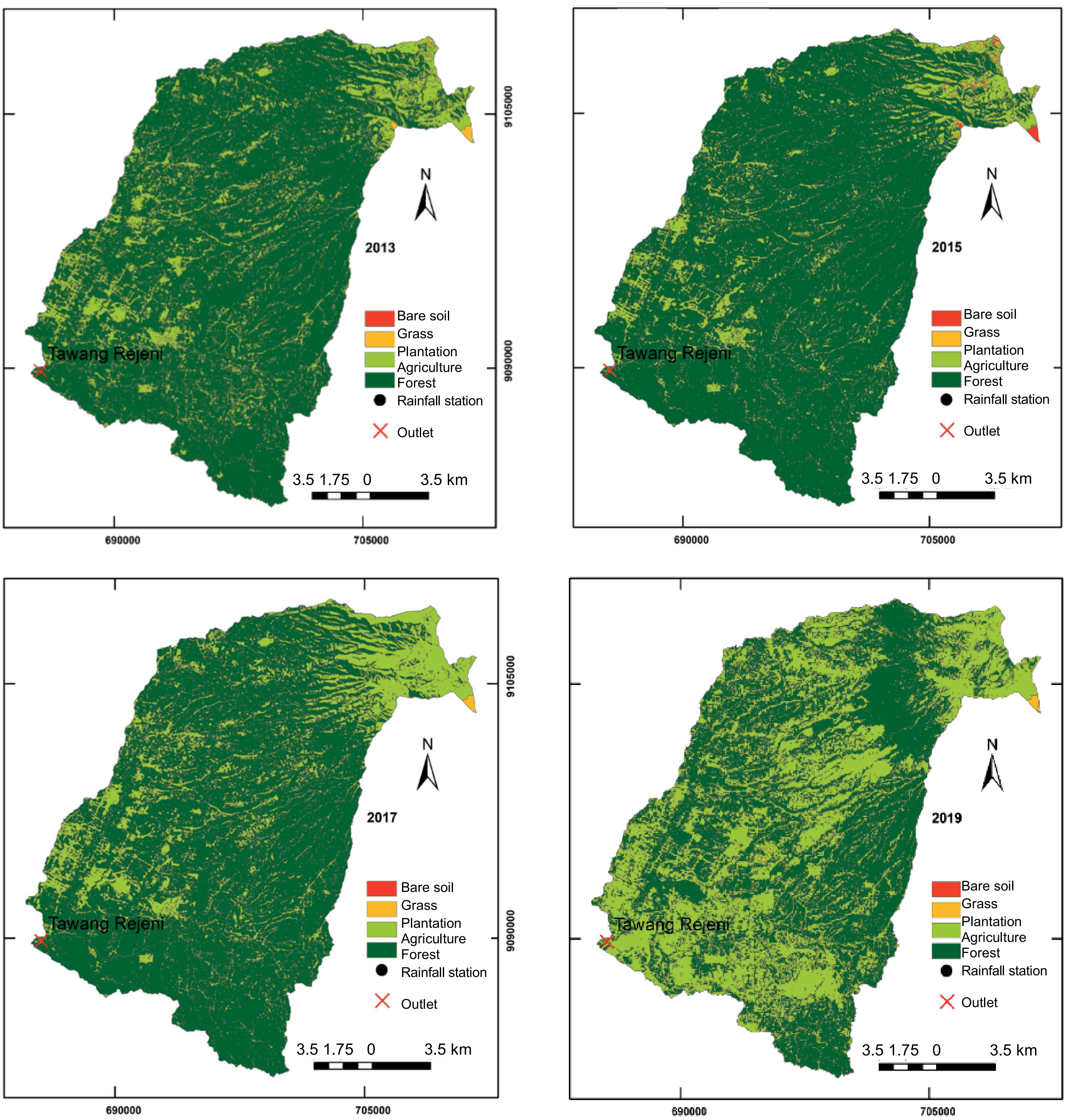

Fig. 3. The land use and land cover map, 2013–2019; source: own study

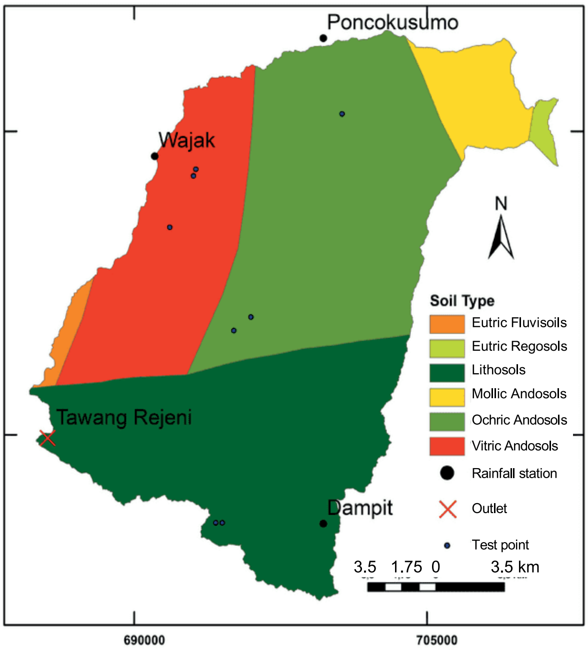

Fig. 4. Soil-type map of the Lesti River catchment; source: own study

Table 8. The soil type and texture

Soil texture	Soil type	Area (km^2)	S_s
Sand and gravel	Lithosol	137.4	5.496
Sandy clays	Eutric Regosol, Mollic Andosol, Orchid Andosol, Vitric Andosol	253.46	20.277
Clay and loam	Eutric Fluvisol	4.14	0.662
Sheetrock	–	0	0
C_s value			0.067

Explanations: S_s = parameters of soil assigned with score, C_s = permeability of soil.
Source: own study.

Table 9. The run-off coefficient results of the Hassing method

Year	Run-off coefficient value			
	C_t	C_s	C_v	C
2013	0.074	0.067	0.053	0.194
2015	0.074	0.067	0.056	0.197
2017	0.074	0.067	0.061	0.202
2019	0.074	0.067	0.073	0.213

Explanations: C_t = total value of the slope variable, C_s = permeability of soil, C_v = vegetation and land cover variable, C = run-off coefficient.
Source: own study.

The run-off coefficient of the U.S Forest Service method

The U.S. Forest Service's method was used to determine the run-off coefficient for the Lesti catchment from 2013–2019, based on its specific characteristics. The study preferred using the average run-off coefficient value, denoted as C_{normal}. Table 10 shows the run-off coefficient value based on the U.S. Forest Service method with C_{low}, C_{normal}, and C_{high}.

Table 10. The run-off coefficient value (C) by the U.S. Forest Service method

Year	Run-off coefficient value		
	C_{low}	C_{normal}	C_{high}
2013	0.078	0.188	0.297
2015	0.084	0.195	0.307
2017	0.094	0.209	0.324
2019	0.120	0.243	0.367

Source: own study.

Catchment characteristics acc. to the Cook method

The Cook method analyses catchment characteristics such as slope, soil, LULC, and drainage density (Mengistu *et al.*, 2022), revealing flat (0–5%), rolling (5–10%), hilly (10–30%), and steep slopes (>30%) in the catchment area (Fig. 5).

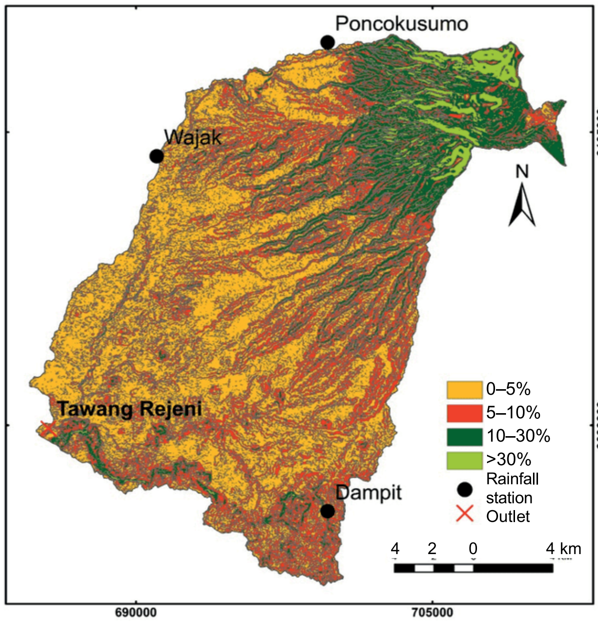

Fig. 5. The Cook method's slope condition maps; source: own study

Table 11 indicates that the Lesti River catchment has the most significant proportion of slopes in the low (0–5%) category, covering an area of 185.772 km^2. Lands with a hilly to steep

Table 11. The total value of the slope variable (C_t) for slope characteristics

Streamflow characteristics	Area (km^2)	Score (%)	S_t
Low	185.772	10	18.577
Normal	140.128	20	28.026
High	57.111	30	17.133
Extreme	11.979	40	4.792
C_t			0.173

Explanation: S_t as in Tab. 6, C_t = total value of the slope variable.
Source: own study.

gradient cause rainfall to descend rapidly, leaving insufficient time for infiltration. The analysis of the run-off coefficient for slope characteristics is listed in Table 11. It showed that the C_t value of the Lesti catchment is 0.173.

The Cook method's ready-to-use table classifies soil texture based on infiltration rate, reclassifying it based on the class score in Table 12. Soil infiltration is crucial for rainfall absorption and it is influenced by vegetation and soil properties. Directly struck rain reduces macropore volume, moisture, and permeability parameters, determining infiltration rate. According to Ma *et al.* (2020), soil properties that determine infiltration capacity include soil structure, which is significantly affected by water texture and content. In addition, Lallam, Megnounif and Ghenim (2018) suggest that soil texture indicates the relative sizes of soil particles. Soils with smooth surfaces, such as clay, have small pore spaces; hence, the infiltration could be slower as rainfall requires a long time to fill the soil pores. Table 12 shows that the C_s value for the Lesti catchment is 0.083.

Table 12. The C_s for soil characteristics

Streamflow characteristics	Soil type	Area (km^2)	Score (%)	S_s
Low	Lithosol	137.402	5	6.870
Normal	Eutric Regosol, Mollic Andosol, Orchid Andosol, Vitric Andosol	253.456	10	25.346
High	Eutric Fluvisol	4.142	15	0.621
Extreme	–	0	20	0
C_s				0.083

Explanation: S_s as in Tab. 8.

Drainage density is a crucial catchment characteristic, assessing run-off potential by comparing the total area and length of streams and rivers within the catchment (Mahmoud, 2014). The Lesti River catchment has a length of 1049 km, resulting in a drainage density >2.6 km km^{-2}, indicating normal streamflow characteristic. Table 13 shows that the C_d value for the Lesti River catchment is 0.150.

The classification area of LULC is shown in Table 5. The S_v value was obtained by scoring each classification area of LULC, as listed in Table 14. The composite run-off coefficient value for the Lesti River catchment, as determined by the Cook method from 2013 to 2019, is listed in Table 15.

Table 13. The C_d for drainage density characteristics

Streamflow characteristics	Area (km^2)	Score (%)	S_d
Low	0	20	0
Normal	395	15	59.25
High	0	10	0
Extreme	0	5	0
C_d			0.150

Explanation: S_d = the product of area and weight.

DISCUSSION

The run-off coefficient from 2013 to 2019 was determined using tables from the Hassing, the U.S. Forest Service, and the Cook methods (Tab. 16). The study reveals that slope, soil texture, land use and land cover, and drainage density significantly impact the run-off coefficient value of the 395 km^2 catchment area (Miardini and Susanti, 2016).

The Hassing and U.S Forest Service utilised three indicators for determining the run-off coefficient value, while the Cook method employed four, including slope, soil, LULC, and drainage density.

The run-off coefficient was validated by comparing estimated peak discharge ($Q_{p_{est}}$) with observed peak discharge ($Q_{p_{obs}}$) using Nakayasu and Rational methods. The process involved inputting the run off coefficient from Hassing, U.S Forest Service, and Cook methods into the peak discharge estimation process.

The results from the three methods of calculating the run-off coefficient demonstrate their advantages in indicating the increasing values of the run-off coefficient within the Lesti catchment, reflecting the deteriorating condition of the Lesti catchment from 2013 to 2019. Conversely, this study identified the variability in run-off coefficients among the methods as a disadvantage. The run-off coefficient derived from the Hassing method and the U.S. Forest Service method yielded the lowest values, suggesting that the Lesti catchment area is in relatively good condition. However, the run-off coefficient obtained from the Cook method indicated that nearly 50% of the Lesti

Table 14. The vegetation and land cover variable (C_v) value based on land use and land cover characteristics

Streamflow characteristics	Area (km^2)				Score (%)	S_v			
	2013	2015	2017	2019		2013	2015	2017	2019
Low	320.223	305.268	278.480	210.433	5	16.011	15.263	13.924	10.522
Normal	73.766	89.183	114.274	183.649	10	7.377	8.918	11.427	18.365
High	0.972	0.522	1.597	0.863	15	0.146	0.078	0.240	0.129
Extreme	0.008	0.001	0.602	0.013	20	0.002	0.000	0.120	0.003
C_v						0.060	0.061	0.065	0.073

Explanation: S_v as in Tab. 7.
Source: own study.

Table 15. The C composite value of the Cook method (2013–2019)

Year	Run-off coefficient value				
	C_t	C_S	C_d	C_v	C
2013	0.173	0.083	0.150	0.060	0.466
2015	0.173	0.083	0.150	0.061	0.468
2017	0.173	0.083	0.150	0.065	0.472
2019	0.173	0.083	0.150	0.073	0.480

Explanations: C_d = product of area and weight per the total area, C_t, C_s, C_v = as in Tab. 9.
Source: own study.

Table 16. The comparison value among the run-off coefficient method

Method	Run-off coefficient	Run-off coefficient value			
		2013	2015	2017	2019
Hassing	C_1	0.194	0.197	0.202	0.213
U.S. Forest Service	C_2	0.188	0.195	0.209	0.243
Cook	C_3	0.466	0.468	0.472	0.480

Source: own study.

catchment area is in poor condition. Therefore, the run-off coefficient should be validated to find the appropriate and reliable method. In this study, it was validated by comparing estimated peak discharge ($Q_{p_{est}}$) with observed peak discharge ($Q_{p_{obs}}$), using Nakayasu and rational methods by inputting run-off coefficient of the Hassing, U.S Forest Service, and Cook methods into the peak discharge estimation process as listed in Table 17. The *MAPE* and *MAE* results, used as error measures in this validation method, indicate the accuracy levels of the run-off coefficient methods, as presented in Table 18.

The findings revealed a rapid increase in the run-off coefficient within the Lesti River catchment, indicating increased susceptibility to flooding. This poses a significant concern, given that the Lesti River serves as a primary tributary to the Brantas River. Moreover, comparative analysis demonstrated that the Hassing method yielded more effective results, with a measurement error value of 11%, and *MAE* of 0.58. These results indicate that the Hassing method's run-off coefficient is an appropriate and reliable input for estimating peak discharge ($Q_{p_{est}}$) in the Nakayasu process (Iqbal *et al*., 2023). It also indicates that the Hassing method accurately reflects the run-off characteristics of the Lesti River catchment. Therefore, utilising the Hassing method emerges as a practical approach for effectively mitigating flood risks.

It is important to critically evaluate the varied runoff coefficient value obtained by 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 there are inherent limitations, potential errors, or unknown factors that can affect the accuracy or validity of the estimation. Uncertainty is often expressed in terms of confidence intervals, probability distributions, or qualitative assessments of the likelihood of different outcomes (Moges *et al*., 2021).

The differing results obtained from various hydrological and physical parameters are 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 in input can result from inaccurate measurement, spatial interpolations, assumptions in boundary and initial conditions, and missing data (Moges *et al*., 2021).

It is also important for hydrologists to make rational choices regarding the method that is most appropriate for the characteristics of the catchment. The validation process can identify a relatively accurate method that aligns with the Lesti River catchment characteristics. This process is used to compare the estimating method with the observed method.

Table 17. The peak discharge estimation using run-off coefficient C_1, C_2, and C_3 determined acc. to Hassing, U.S. Forest, and Cook methods, respectively

Year	$Q_{p_{obs}}$ ($m^3 s^{-1}$)	I_{max} (mm h^{-1})	$Q_{p_{est}}$ ($m^3 s^{-1}$) estimated using method					
			Nakayasu			rational		
			C_1	C_2	C_3	C_1	C_2	C_3
2013	737.27	16.52	155.18	140.26	427.50	351.93	341.02	1039.39
2015	187.29	28.39	183.32	170.22	501.94	614.15	607.89	1792.49
2017	154.28	24.86	179.51	173.69	480.35	551.43	570.51	1577.78
2019	89.03	11.37	158.93	256.95	410.97	265.94	303.40	732.89

Source: own study.

Table 18. The accuracy level of the run-off coefficient C_1, C_2, and C_3 determined acc. to Hassing, U.S. Forest, and Cook methods, respectively

Measurement error	Nakayasu			Rational		
	C_1	C_2	C_3	C_1	C_2	C_3
MAPE	11.00	18.20	48.94	49.93	49.31	158.99
MAE	0.58	0.69	1.09	1.25	1.24	3.40

Explanations: *MAPE* = mean absolute percentage error, *MAE* = mean absolute error.
Source: own study.

CONCLUSIONS

The analysis of the run-off coefficient in the Lesti River catchment from 2013 to 2019 utilised the Hassing, U.S. Forest Service, and Cook methods. To identify influential catchment characteristics affecting the run-off coefficient, such as slope, soil type, and land use and land cover (LULC), digital spatial data and GIS technologies were employed.

These findings carry important implications for water resources management in the Lesti River catchment. The results showed that run-off coefficient in Lesti River catchment tends to increase rapidly in the studied period. This indicates an increased vulnerability to flooding, which is particularly concerning due to the Lesti River's role as one of the major tributaries of the Brantas River. The appropriate method for estimating the run-off coefficient would be an effective tool for decision makers to mitigate flood risk.

Uncertainty is an essential aspect of estimating the run-off coefficient, acknowledging inherent limitations, potential errors, or unknown factors affecting the accuracy or validity of estimations. Hydrologists must make informed decisions regarding the most appropriate method aligned with catchment characteristics. Validation processes can help selecting relatively accurate methods that align closely with the characteristics of the Lesti River catchment.

According to the findings with an 11% mean absolute percentage error, the Hassing method emerged as more appropriate than the U.S. Forest Service and Cook methods for estimating peak discharge in the Nakayasu method when calculating the run-off coefficient. Additionally, the Hassing method proved reliable for determining peak discharge in the Nakayasu process, with a mean absolute error analysis yielding a result of 0.58. These results underline that the Hassing method is an appropriate and reliable choice for estimating the peak discharge in the Lesti River catchment.

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CONFLICT OF INTERESTS

All authors declare that they have no conflict of interests.

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