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ORIGINAL RESEARCH ARTICLE

Estimation of peak current as a basis for sustainable watershed conservation using the number-curve land conservation

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ABSTRACT

BACKGROUND AND OBJECTIVES: Peak flow in watershed is important in designing and controlling soil erosion, as well as assessing the potential water yield. It also serves as a basis for assessing and managing the risk of environmental damage. However, there is no accurate information on peak flow to ensure sustainable management and conservation of Wuno Sub-Watershed in Palu Watershed which serves as a buffer for the capital of Central Sulawesi Province. Therefore, this study aimed to assess and determine the potential runoff and peak flows in watershed using soil conservation service-curve number.
METHODS: Soil conservation service-curve number method was calculated to analyze rainfall from runoff as a function of cumulative rainfall, land use, soil type, and humidity. This method was developed by the United States Soil Conservation Service in 1972 and applied in this study with due consideration for several variables, including (a) land use classification and intensity for settlements, rice fields, plantations, rivers, etc., (b) basic physical conditions of the area such as rainfall and hydrology, as well as (c) classes of soil hydrology significantly influencing carbon-nitrogen value.
FINDINGS: The result showed that carbón-nitrogen values for all types of land use or cover were in normal conditions from 5 to 25 years. Moreover, carbón-nitroGen range was observed to have significantly large quantitative consequences on direct runoff. The trend showed the need for precision and effectiveness in planning watershed management and conservation. Soil conservation service also had a positive influence on land use, specifically runoff, as observed in carbón-nitrogen values for return periods of 2, 5, 25, and 100 years. However, several other factors were identified to influence land use such as land cover and soil texture.
CONCLUSION: Soil Conservation Service presented an analysis of how land use affected runoff, specifically with a focus on carbon-nitrogen values. Land use was not only affected by carbon-nitrogen values but other factors such as land cover and geomorphometric properties. The trend showed the need for a more comprehensive exploration of soil conservation service-curve number method in accurately predicting runoff patterns in sub-watershed areas to ensure effective and sustainable management and conservation practices.

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INTRODUCTION

The monitoring of peak flow is a parameter directly related to the level of forest and land cover (LC) and serves as one of the efforts to identify the health of watershed (Shih *et al.,* 2022). Peak flow occurs when rainfall intensity exceeds the capacity of infiltration, interception, and evaporation. According to previous studies, the rapid urbanization of some forested watersheds leads to increased peak and reduced low flow due to a significantly diminished soil infiltration capacity (Ridwan *et al.,* 2024; Kan *et al*., 2020; Cheng *et al*., 2002). Moreover, the most important part of the hydrological cycle balance is peak flow (Allan *et al*., 2020) and the concept has been explained as the portion of rainfall that flows over the surface towards the outlet. The present development of peak flow is associated with the changes in some forests and land covers leading to infiltration and surface runoff (Ren *et al*., 2020; Walage *et al.,* 2020). Some important aspects of runoff normally considered in the design of control structures include peak flow, volume, and spread. It is important to state that peak flow is normally influenced by some factors associated with watershed characteristics while the rate and volume of runoff are often affected by the duration, intensity, and distribution of rainfall. Studies also showed that the influence of watershed on surface runoff was determined by factors such as the shape and size of watershed, topography, geology, and land use (LU) conditions (Akhbar *et al*., 2023; Naharuddin *et al*., 2021; Astuti *et al*., 2019). Most of the methods to forecast runoff often neglect and replace certain factors with some assumptions in order to simplify the calculation process. For example, the rational method is normally applied to estimate the magnitude of peak discharge or flow (Zeng *et al*., 2020). It is considered relatively easy to use and more suitable for watershed with small size, less than 300 hectares (ha) (Naharuddin *et al*., 2021). Meanwhile, the Wuno Sub-Watershed exceeds 300 ha, specifically 19,191.94 ha, and this shows the appropriate method to estimate peak flow in the area is the United States Soil Conservation Service (SCS) which relates watershed characteristics, such as soil, vegetation, and land use, to curve number (CN) (Thong *et al.,* 2019). Soil conservation curve number (SCN-CN) has been widely used globally to estimate runoff (Im *et al*., 2020; Lian *et al*., 2020) and for other hydrological applications due to its simplicity (Verma *et al.,* 2021). However, the scarcity of reliable rainfall-runoff recording data is a serious problem in the hydrological analysis of watershed. This shows that the sustainable management of available water in the area is only possible through the application of SCN-CN. The method can provide good information regarding rainfall-runoff and other hydrological determinants influencing influence water resources, specifically water savings (Ibrahim-Bathis, 2016). Since the inception, SCS-CN method has been adopted for different areas, land uses, and climate conditions, including those in Indonesia (Pramono and Basuki, 2019; Devianti *et al.,* 2019). Another method to accurately predict runoff and peak current needed to manage, conserve, and develop watershed is geographic information systems (GIS) based on spatial data (Satheeshkumar *et al.,* 2017). It has been successfully applied in several hydrological conditions due to the simplicity and robustness, easy accessibility to environmental input features, appropriate documentation, and consideration of several factors influencing runoff formation which are consolidated into a single parameter (Soulis, 2021). Peak flow has also been identified to be influenced by runoff coefficients while flood discharge is generally related to climate change (Meresa, 2020) and activities considered not to be environmentally friendly (Sebastian et al., 2019; Surya *et al*., 2020). For example, the changes in land use from primary and secondary forests to cultivated areas can result in high peak flow, leading to a continuous increase in the frequency of flood (Penna *et al*., 2021; Ewane and Lee, 2020). The phenomenon often affects the nature and components of ecosystems by causing environmental problems, specifically in relation to the hydrological elements (Hasan *et al.*, 2020). These problems can be resolved through the application of SCN-CN based on GIS (Alataway, 2023).The Wuno Sub-Watershed is believed to have a strategic value because the area is in the upper part of Palu River, which flows in the year. The sub-watershed serves both protective and preservative functions by regulating water resources for the entire watershed, specifically Palu River that flows and divides Palu City, leading to the consideration for sustainable conservation. However, the carrying capacity changes frequently due to flood and landslides caused by uncontrolled land use without adhering to soil and water conservation principles. A previous study showed speedy degradation of forest and land due to encroachment, primarily in the upstream areas (Naharuddin *et al*., 2020). This led to flood disasters, a reduction in the quality of watershed environment (Gashaw, 2015), as well as a decrease in soil quality and infiltration capacity (Abebaw, 2019). The problems showed the need to manage peak flow in river basins through appropriate estimation as a basic part of conservation (Chalise *et al*., 2019). Therefore, this study aimed to assess and determine potential runoff and peak flow using SCS-CN in 2022 towards ensuring sustainable management and conservation of watershed. The focus was on Wuno Sub-Watershed, administratively located in Sigi Regency, Central Sulawesi, Indonesia performed in 2022.

MATERIALS AND METHODS

Area and time

This study was conducted in Wuno Sub-Watershed, administratively located in Sigi Regency, Central Sulawesi, with coordinates approximately 119°59'17.86" East Longitude (EL) and 1°4'59.91" South Latitude (SL), at an average elevation of 220 meters (m) above sea level (ASL), as presented in Fig. 1. The duration was from April to November 2022 with the study partitioned into two phases. The first phase was the collection of basic physical data such as rainfall, hydrological, and land use conditions of the study area. Meanwhile, the second phase focused on the collection of soil texture data from different land uses and subsequent analysis of the samples at the laboratories in the Faculty of Agriculture and Forestry of Tadulako University.

The Wuno Sub-Watershed was generally observed from to have a very steep slope class which accounted for 60 percent (%) and covered an area of 14,139 ha. This was followed by flat and steep slopes with 3,890 (17%) and 1,056 ha (4%). Land use was observed to be mainly for primary dryland forest, secondary dryland forest, mixed gardens, fields, grasslands, shrublands, and settlements. Moreover, mixed gardens consisted of coconut and cocoa. It was also observed that land

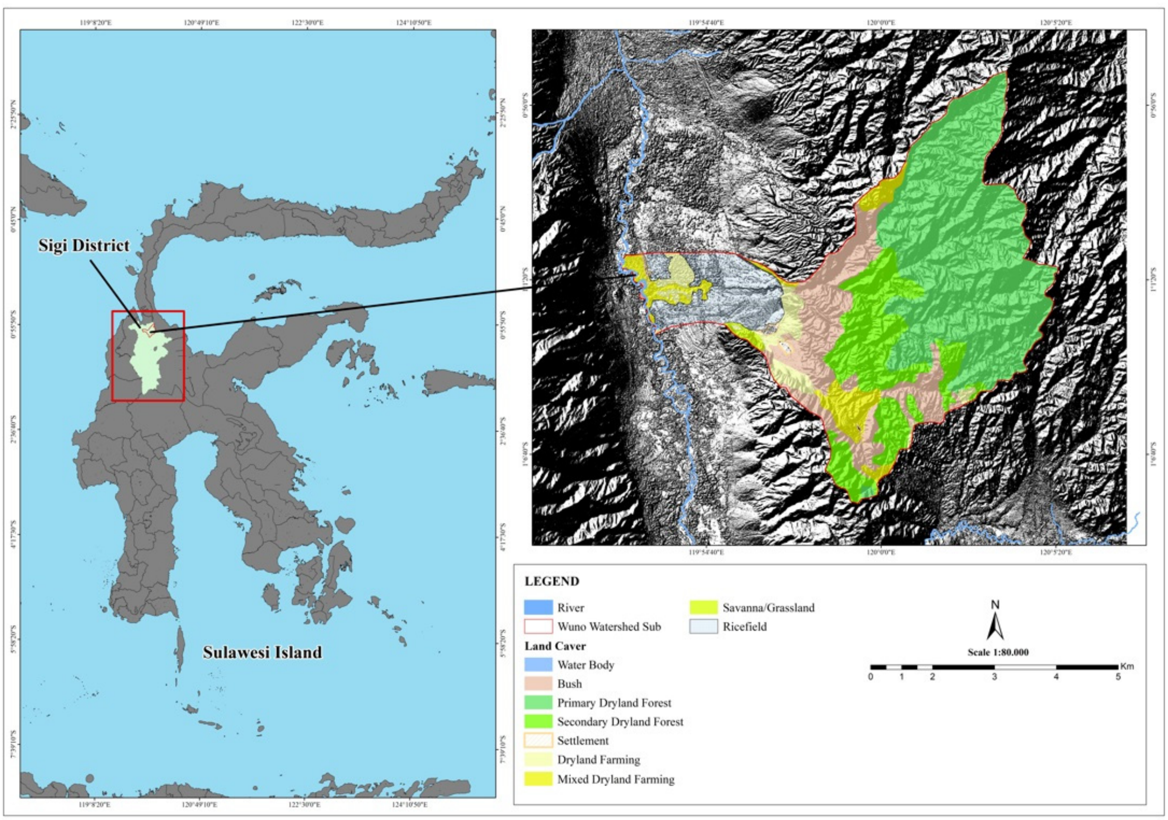

Fig. 1: Geographical description of the study area in Sigi Regency, Central Sulawesi, Indonesia

area with the highest percentage was primary dryland forest, accounting for 38.29%, while the lowest was mixed gardens with 0.53%.

Methods

This study was conducted by collecting primary data on soil texture related to different land uses and the physical condition of the area. Moreover, secondary data on rainfall for the last 10 years, 2012 to 2021, were collected from the Global Atmosphere Watch (GAW) Lore Lindu Bariri as well as the Meteorological, Climatological, and Geophysical (MCG) Agency of Indonesia. Digital elevation model (DEM) map with a resolution of 8m x 8m was also obtained from the National digital elevation model (NDEM) as required for the data. Furthermore, land use and soil type map data were obtained from Palu Poso Watershed Management (PPWM) Office and processed using GIS. These showed that several variables were used in the analysis, such as (a) land use classification and intensity for settlements, rice fields, plantations, rivers, etc., (b) basic physical conditions of the area, including rainfall and hydrology conditions, as well as (c) soil hydrology classes with significant influence on CN values.

SCS-CN method was applied for calculations based on the assumption that rainfall leading to runoff was a function of cumulative rainfall, land use/land cover, soil type, and humidity. The method was developed by the United States SCS in 1972 (Sentosa *et al.*, 2021; Song *et al.*, 2021) and the magnitude of CN values was used to determine the potential runoff from a specific rainfall. The criterion was that larger CN values represented greater potential for rainwater to become runoff (Nageswara, 2020; Karunanidhi *et al.*, 2020). The use of SCS-CN method was considered appropriate to determine the actual hydrological conditions of watershed through the variations in runoff containment parameters as a basis for estimating peak currents in the context of conservation (Song *et al.*, 2021). The method has been widely used to simulate excess rainfall from the process of rain events, plan water resource management in watershed, and prepare environmental impact assessments due to the simplicity (Shi *et al.*, 2009; Soulis, 2021). The results from the simulation were validated using field rainfall and other environmental data to ensure greater confidence and reliability. The same procedure was applied to the estimation of CN values in Wuno Sub-Watersehed. This was based on some important steps to validate CN values through the conversion into a numerical value to be used as input in a pre-defined approach to determine direct watershed runoff.

Data analysis

Rainfall intensity was calculated based on Mononobe method using Eq. 1 (Priambodo *et al.*, 2019; Kistiawan and Irawan, 2023).

$$I = \frac{R24}{24}\left[\frac{24}{t}\right] \quad (1)$$

Where, I = rainfall intensity (mm/hour), R= maximum rainfall in 24 hours (mm), t= rainfall duration (hours). Meanwhile, CN values for watershed consisting of several types of soil and land use were calculated using Eq. 2 (Walega *et al.*, 2020).

$$CN = \frac{\sum Ai\,CNi}{\sum Ai} \quad (2)$$

Where, CN = Potential water overflow, i = index of river basin division based on uniformity of land use and soil type, CNi = CN for subdivision i, and Ai = drainage area in subsection i.

Peak discharge was calculated based on SCS method using the following Eq. 3 (Bahrami *et al.*, 2019; Shi and Wang, 2020).

$$Qp = \frac{(P-0.2S)^2}{P+0.8S} \quad (3)$$

Where, Qp = peak discharge (mm), P = Rainfall (mm), and S = difference between rainfall and runoff (mm).

RESULTS AND DISCUSSION

Rain intensity and rainfall

Rain intensity is the amount of rain in a certain unit of time. Maximum rainfall intensity was determined for the return periods of 2, 5, 25, and 100 years using Mononobe formula, as shown in Fig. 2.

The results showed that the highest and lowest rainfall intensity was 51.398 mm/hour and 59.29 mm/hour in the 100-year and 2-year return periods respectively. It was also observed that maximum rainfall was recorded to be 993.23 mm and 639.45

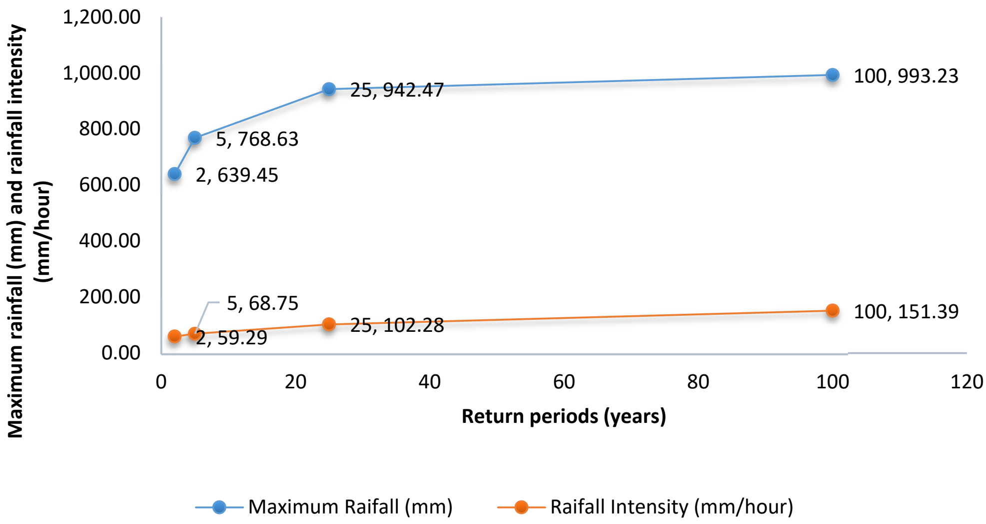

Fig. 2: Maximum rainfall and rainfall intensity for return periods of 2, 5, 25, and 100 years

Table 1: CN values for Wuno Sub-Watershed

Land Use (LU)/Land Cover (LC)	A (Km^2)	CN
Shrubs	30.28	19.2
Primary Forest	106.35	5
Secondary Forest	47.51	5
Settlement	2.54	24
Dryland farming	10.67	18.3
Mixed Shrub Dry Land Farming	14.63	18.3
Savanna	1.47	25
Ricefield	22.1	15
Total	235.55	129.8

mm. Moreover, SCS method was used to determine peak discharge hydrograph based on stated guidelines (Aziz *et al*., 2020). The value was found to be 84.97 cubic meters per second (m^3/s) over 2 years with a maximum rainfall of 639.45 mm, while 264.84 m^3/s was anticipated to recur or occur in a 100-year timeframe which was approximately 300% increase, as presented in Table 3. In some cases, the values contradicted the results obtained for forested areas in a previous study (Bera *et al*., 2021). This showed that rainfall intensity did not have a significant influence on the strong increase in peak discharge. Furthermore, the measurement of rainfall intensity per hour and minute did not have practical value in predicting peak discharge volume from forested areas. The trend showed that rainfall intensity had a limited role in forming peak discharge in river basin compared to the estimated value. This could be because flooding was observed to be influenced by other geomorphometric characteristics despite the existence of good forest cover (Narendra *et al*., 2024).

Settlement land was observed to have the highest CN values, 24, and this was inversely proportional to primary and secondary forests with 5.0 each, as presented in Table 1. The low CN values in primary forest with 106.35 ha (50%) and secondary forest with 47.51 ha (20.2%) in Fig. 3 compared to other land use were associated with the existence of good infiltration. This could also be associated with the fact that the forest serves as a water system regulator in addition to several other functions, thereby showing an interrelation and interconnection between forest and water. Moreover, the existence of forest depends on the good circulation of water which ensures the

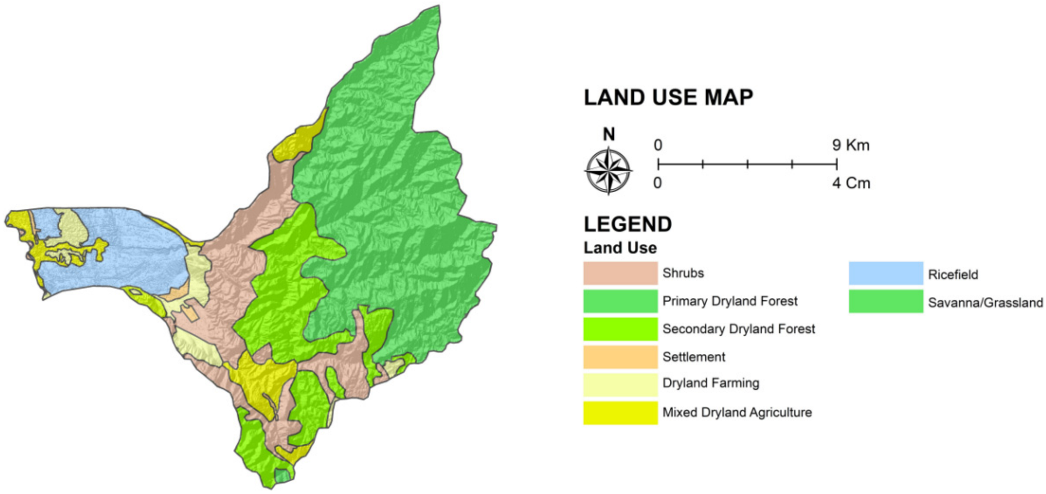

Fig. 3. Land use map of Wuno Sub-Watershed

Table 2: Soil texture for several land uses in Wuno Sub-Watershed

Land use/ land cover	Soil texture			Description
	Sand (%)	Dust (%)	Clay (%)	
Shrubs	14.2	43.6	44.2	Dusty clay
Primary Forest	17.2	41.7	42.3	Clay
Secondary Forest	20.1	44.5	35.3	Dusty clay
Settlement	25.6	37.1	38.1	Dusty clay
Dryland farming	22.6	35.3	43.5	Dusty clay
Mixed shrub dry land farming	46.7	28.5	23.7	Dusty clay
Savanna	23.4	53.6	26.6	Dusty clay
Rice field	10.2	51.6	24.5	Dusty clay

preservation and storage of quality and good quantity of water in the ground. The amount of water stored in soil is very important for the ecosystem sustainability due to the usefulness for living creatures. It is also important to state that runoff directly depends on rainfall, soil type, soil moisture, size and shape of watershed, land cover, and several other factors. Therefore, different thematic layers, soil textures, and land uses were generated in GIS applied to this study.

A higher infiltration rate led to a lower occurrence of erosion and flood which further caused the retention of more water in soil. Al-Ghobari *et al.* (2020) showed that CN values for normal and agricultural conditions ranged between 74 and 93. CN values were observed to have been influenced by land cover and soil texture conditions, as shown in Table 2.

Table 2 shows that the dominant soil texture in Wuno Sub-Watershed is a dusty clay texture with a content percentage of 23.7%-44.2% in all land use or land cover types as also presented in Fig. 4. Texture is very important in determining the hydrological aspects of soil groups. This has led to the classification of soil texture based on the different fractions contained (Kayet *et al.*, 2018). For example, the dusty clay content in land use or land cover mixed shrub dry land farming, savanna, and rice fields is less than 30%, leading to quite high soil expansion power and an increase in runoff (Purdue *et al.*, 2021). The trend showed that there was a need for appropriate soil and water conservation structures as well as sustainability and water-saving mechanisms to control runoff.

The factors identified are required to be considered in designing optimal water harvesting schemes such as micro dams to collect and store surface runoff for irrigation development in Wuno Sub-Watershed. Kassam *et al.* (2014) also reported that the maintenance of soil mulch cover required land

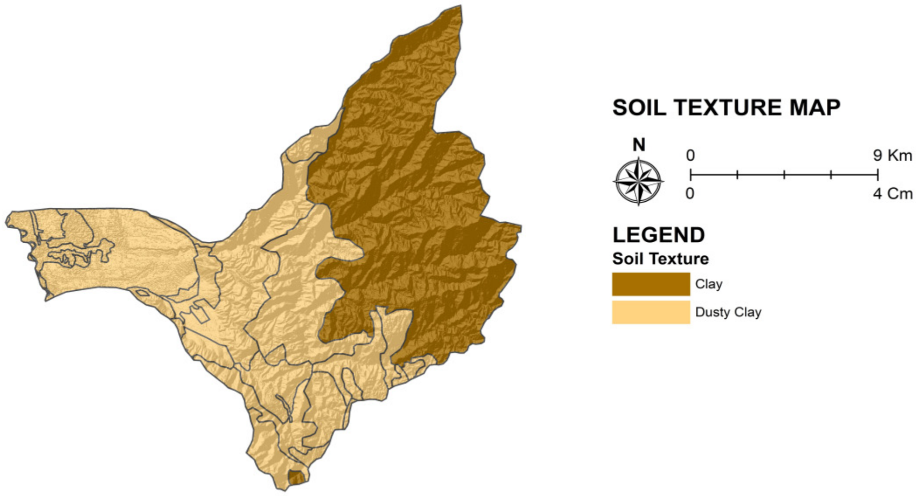

Fig. 4: Soil texture in Wuno Sub-Watershed

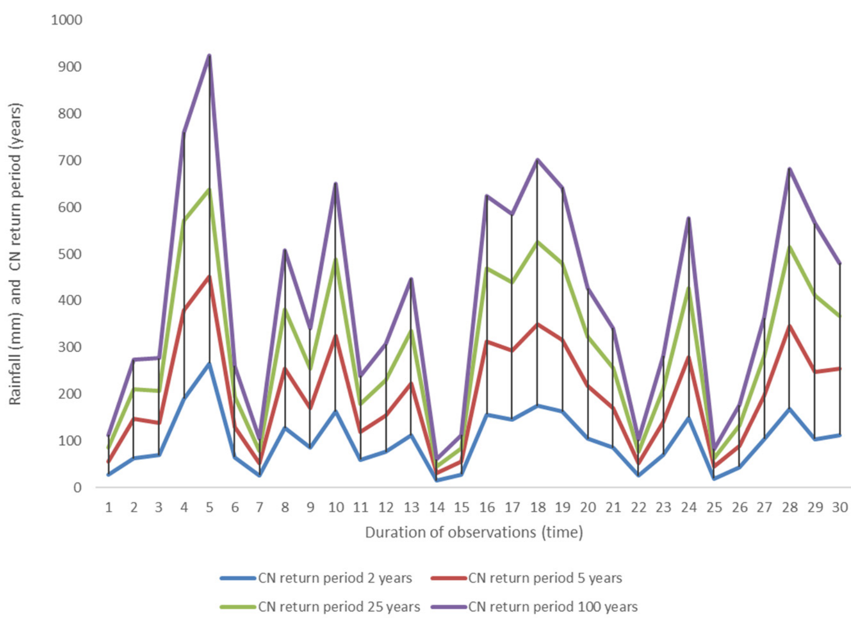

Fig. 5: Potential water runoff for return periods of 2, 5, 25, and 100 years

management practices considered sufficient to meet soil and water conservation objectives. The comparison of CN values for the return periods of 2, 5, 25, and 100 years in Fig. 5 showed a direct proportion between the values and period due to the influence of changes in land use. This showed that the increase in CN values was directly due to the changes in land caused by the rapid rise in the population of each area around watershed. The trend was similar to the observation of Soulis (2021) and Ideawati *et al.* (2015) that an increase in CN values was due to changes in land use and this further led to an increment in peak flow.

Peak discharge was influenced by soil texture, the availability of soil organic matter, the presence of ground vegetation, and other covers as presented in Table 3. Sandy soil was found to have a high infiltration capacity which could reduce peak

Table 3: Peak discharge values using SCS method before and after the change scenario

Return period	rainfall (mm)	difference between rainfall and runoff (mm)	Qp (m^3/s)
2	639.45	1068.92	85.97
5	768.63	2321.23	136.28
25	942.47	4826.16	179.35
100	993.23	3704.33	264.84

discharge on land. Meanwhile, clayey soil had a high water-holding capacity which impeded water flow and reduced infiltration rate. The result was observed to be consistent with the observation of Hidayat *et al*. (2020) that each soil had different absorption capacities, where sandy and clayey soil tended to have high and low infiltration rates, respectively. This is due to the fact the pores in sandy and clayey soil are generally small, hindering the movement of water and air in soil, and resulting in slow infiltration. The occurrence of rain, even at a relatively low amount, can lead to surface runoff and ponding. However, the same soil types having varying densities usually exhibit different infiltration rates, with denser soil generally showing a lower rate.

Table 3 shows an increase in peak discharge during the return periods of 2 to 100 years, correlating positively with the increase in rainfall. Moreover, SCS method considered cumulative rainfall, land use, soil type, and humidity in determining the amount of runoff. This showed that the method was more effective in explaining peak discharge compared to the rational method. The observation is consistent with the report of Kousari *et al.,* (2020) that the most suitable and widely applicable method used in estimating flood hydrograph ordinates in watershed is SCS-CN. The applicability is enhanced by a user-friendly interface, availability of model inputs, and numerous outputs such as peak flood discharge, time to peak, time lag, and flood duration.

CONCLUSION

In conclusion, the application of SCS-CN to the return periods of 2, 5, 25, and 100 years showed an increasing peak discharge due to the reduction in land area with corresponding land cover. Peak discharge was directly proportional to the rainfall intensity value, runoff coefficient value, and area of the rain catchment area. This showed that an increase in these factors led to a higher peak discharge. Moreover, a peak discharge of 264.84 m^3/s and a maximum rainfall of 942.47 mm was expected to recur within a period of 100 years which was approximately a 300% increase from the values recorded in 25 years. Moreover, runoff volume was estimated through some supporting parameters such as type of land cover, soil hydrology group, and soil texture conditions. It was also discovered that CN was related to the magnitude of the difference between rainfall and surface runoff. CN values recorded in all areas of Wuno Sub-Watershed were found to be in the normal range of 5 to 25 for all types of land use or land cover. Furthermore, SCS was used to provide an overview of the influence of land use on runoff based on CN values. It was observed that the value was not determined solely based on land use but on the existence of some other factors such as land cover. The data obtained for land use showed the increase in peak discharge was influenced by a reduction in land cover. This indicated that a reduction in CN could lead to an increment in surface runoff and peak discharge. SCS-CN method was also observed to have a better performance in high rainfall-runoff or high CN events. The trend is due to the fact that infiltration capacity (IC) is the main explanatory variable for runoff production (or CN) in the study sample plots because it shows the expected inverse relationship between CN and IC. The phenomenon showed that CN values could be determined based on these characteristics using SCS method. However, several limitations were identified in the implementation of the method such as the lack of a slope factor, non-consideration of rainfall duration, and absence of guidance regarding previous moisture conditions. The limitations showed that the application of SCS-CN needed further attention in estimating the runoff picture in sub-watershed areas for sustainable management and conservation purposes. This was despite the ability of SCS-CN to estimate surface runoff, specifically when there was insufficient hydrological information.

Practitioners and policymakers are required to mandate the estimation of peak current in order to sustain water resources. Further study is also needed on other sub-watersheds in Palu Watershed by developing flow modeling in the water catchment area using GIS-based SCS-CN method to have complete comprehensive data.

AUTHOR CONTRIBUTIONS

Naharuddin was the corresponding author and provided instructions to other authors in analyzing and summarizing the test results, including advice on techniques and methods. Rukmi researched and collected primary and secondary data. S.D. Massiri participated in collecting rainfall data from Global Atmosphere Watch and Meteorology, Climatology, and Geophysics (MCG). B. Toknok collected all data, analyzed the results, and drew conclusions. Akhbar sharpened the background and recommended improvements, specifically on DEM data and peak discharge. I.N. Korja contributed to the data analysis and manuscript correction and also examined the discussion more sharply.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interest regarding the publication of this manuscript. The ethical issues including plagiarism, informed consent, misconduct, data fabrication or falsification, double publication or submission, and redundancy were completely observed by the authors.

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ABBREVIATIONS

%	Percent
A	Area
Ai	Drainage area
ASL	Above sea level
CN	Curve number
DEM	Digital elevation model
EL	East Longitude
Eq.	Equation
GAW	Global Atmosphere Watch
GIS	Geographic information system
ha	Hectare
I	Rainfall intensity
IC	Infiltration capacity
kg	Kilogram
km	Kilometer
km^2	Square kilometers
LC	Land cover
LU	Land use
M	Meters
m/s	Meter per second (velocity unit)
m^2	Meter square
m^3	Cubic metre
m^3/s	cubic meter per second

MCG	Meteorology, climatology and geophysics
mm	Millimeter
NDEM	National digital elevation model
P	Rainfall
PPWM	Palu Poso watershed management
Qp	Peak discharge
R	Maximum rainfall
S	Second
S	Difference between rainfall and runoff
SCN-CN	Soil conservation curve number
SCS	Soil conservation service
SL	South Latitude
T	Rainfall duration

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