Curve Number Estimation for Ungauged Watershed in Semi-Arid Region

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Abstract

The Benanain Watershed is located in East Nusa Tenggara with an area of 3,181 km^2 and is divided into 29 sub-watersheds. The East Nusa Tenggara itself is an eastern region of Indonesia with a unique climate condition called semi-arid. The high rainfall intensity occurring in short duration results in large surface runoff and erosion. Floods and erosion in semi-arid areas due to sensitive soils to drought and heavy rainfall extremely. This paper presents the application of the Soil Conservation Services-Curve Number (SCS-CN) real-flood flows through a digital map of soil type, land use, topography, and the heterogeneity of physical condition, especially for ungauged watersheds. The method used is an approach empirical to estimate runoff from the relationship between rainfall, land use, and soil hydrology groups. This watershed has a large area that must analyze every sub-watershed. The land-use of the Benanain watershed is secondary dryland forest by 44.26% and the hydrological soil group on the B group classification with medium to high absorption potential by 46.502% from the total area. The curve number value of the Benanain Watershed ranges from 56.54 to 73.90, where the mean CN value of 65.32. The rainfall (mm) for the 29 sub-watersheds in the Benanain Watershed has decreased by about 74.65% when being surface runoff or only 25.35% of water becomes surface runoff. The relationship between rainfall depth and CN is classified as standard response and trend line (flat slope) equilibrium occurs when rainfall depth value of 56.71 mm and CN is close to 66.30. The high variability of intense rainfall between the rainy season and the dry season had a significant influence on the curve number value in a large watershed area. Further analysis will be more accurate if it is supported by long rainfall data and observation runoff data as a control.

Keywords: SCS-CN Method; Soil Type; Land Use; Standard Response.

1. Introduction

A semi-arid region is an area that receives lower rainfall compared to potential evapotranspiration. This semi-arid region covers 31% of the world's [1]. The climate in East Nusa Tenggara (NTT) is of type D with the rainy season (average of monthly rainfall > 200 mm) that occurred between 3-4 months [2]. The characteristic of semi-arid regions is the evapotranspiration is much greater than precipitation, and the intensity of rainfall is very high during the rainy season. High-intensity rainfall variability during the rainy season and dry season causes enormous erosion [3, 4]. The land surface temperature affected land use, land cover, vegetated areas, water resources, etc. [5]. East Nusa Tenggara which has semi-arid conditions, is of course also affected by the land surface temperature.

The large volume of rainfall exceeds the soil infiltration capacity resulting in a large of runoff and erosion. These extreme climatic conditions often lead to misinterpretation of rainfall data, especially in East Nusa Tenggara. That is because the rainfall does not spread evenly throughout the year [6]. The geographical form as thought watershed shape also has a big influence on rainfall. Large local storms can shed a large part of annual rain in just a few days or hours. That causes the river to experience massive flooding every year.

Flood modeling design is inseparable from the rainfall-runoff relationship, and one method that can use is the Natural Resources Conservation Service Curve Number (NRCS-CN). The advantage of this method was can used in areas where flood hydrograph data or automatic recording of water levels are not available; however, rainfall recording data are available [7]. Also, this NRCS-CN model selection be affected by several factors, such as: (1) a familiar model is used over the years around the world, (2) very efficient, (3) the required data input generally available, and (4) this model connecting runoff to soil type, land use and control practices [8].

NRCS-CN has several main elements in the rainfall-runoff process, such as watershed boundaries, rainfall, hydrological abstraction, and runoff [9]. Determination of curve number for watersheds characteristics that do not have flood hydrograph data and water level reservoir also can be seen from the watershed, namely soil type, land use, conditions hydrology, and antecedent moisture condition (AMC). NRCS-CN water loss method and the NRCS unit hydrograph also used to determine hydrologic soil groups from the Harmonized World Soil Database (HWSD) map. In this method, the runoff thickness or rainfall is a function of the total rainfall thickness and reflection parameter of the number of runoff curves called Curve Number [10].

Soil Conservation Services and Curve Number (SCS–CN) technique, also known as the Natural Resources Conservation Service Curve Number (NRCS-CN) is one of the simplest, and well-documented conceptual methods to predict rainfall-runoff. The SCS-CN model application was to estimate runoff from small watersheds and runoff processes typical of a watershed-based on a remote sensing geo-information [11]. The determination of the correction curve number value has been done in an oval watershed using the HEC-HMS model and influencing factors such as soil properties, geological formation, and land use [12].

The SCS-CN application in the Temef watershed shows that the soil hydrological group affects the flood water level [13]. The effect of river morphometric parameters on the potential for runoff in an ungauged river using satellite imagery, topographic maps, and rainfall data combined with geospatial techniques have been done by the previous [14]. The CN value can be used for comparative studies of the impact of urbanization and forest fires and their combined effect on the runoff response [15]. Estimating the curve number value use the SCS-CN method has been carried out by previous researchers because of its simplicity and practical design [18-20]. At present, many researchers use the GIS and Remote Sensing techniques to explore and analyze the curve number method in a small watershed [16, 17, 21]. The CN values also could be verified using a rainfall simulator confirmed by the statistical tests [22, 23].

This study aims to determine a Curve Number (CN) value based on a hydrogeological map diversified to the hydrologic soil group map and check its applicability to the ungauged watershed such as in the Benanain Watershed. The characteristics of the Benanain watershed have very extreme fluctuation discharge, which indicates that the watershed is experiencing critical damage. Soil physical properties and land cover characteristics in semi-arid areas affect the value of curve numbers such as the Benanain watershed.

2. Research Methodology

2.1. Soil Conservation Service-Curve Number (SCS-CN) Method

The Soil Conservation Services (SCS) method was developed from rainfall observation over many years and has involved many agricultural areas in the United States. This method attempts to relate watershed characteristics such as soil, vegetation, and land use with the curve number (CN), which shows the potential flow for a particular rainfall.

The CN method has based on the relationship between the infiltration of each soil type and the amount of rainfall that falls every time it rains. The CN values range between 1 and 100 that is a function of runoff resulting from soil types, land use, hydrological conditions, and antecedent moisture condition [10, 16].

The form of the equation is:

$$Q = \frac{(P-I_a)^2}{P-I_a+S} \tag{1}$$

Where Q = direct runoff (mm), P = rainfall depth/precipitation (mm), I_a = initial abstraction (Initial loss), and S = the water maximum retention potential by the soil, which a big part because of infiltration (mm).

The definition of initial loss is part of the rainfall used to wet the soil surface include plants, trash, and vacant land before the infiltration happened. For impermeable surface or cement coated, the initial loss is the amount needed to moisten the surface before water accumulates and becomes runoff. For forest land cover, lose initial is usually taken

5.1 - 13 mm needed to wet the surface. Total this is rarely measured, and the SCS assumes that the initial loss is approaching 0.2 times the maximum soil moisture retention or S.

Woodward et al. use 307 watersheds scattered in America, which has more than 20 flood events [24]. The results indicated a λ value of about 0.05 gives a better fit to the data and would be more appropriate for using the runoff simulations. That λ is not constant from watershed to watershed, and the assumption of λ = 0.20 is unusually high.

In determining the depth of excess rainfall or surface runoff, the correlation between I_a and S values shown as follows [7, 17]:

$$I_a = \lambda \cdot S \tag{2}$$

$$I_a = 0.2 \, S \tag{3}$$

Based on Equation 3, the value of runoff depth (mm) is used in the following formula [20, 25]:

$$Q = \frac{(P - I_a)^2}{(P + 0.8 \, S)} \quad \text{for} \quad P \geq 0.2 \tag{4}$$

$$Q = 0 \quad \text{for} \quad P \leq 0.2 \, S \tag{5}$$

The maximum retention (S), and characteristics of the watershed associated with the intermediate parameter, namely Curve Number (CN).

$$S = \frac{25400 - 254 \, CN}{CN} \tag{6}$$

Where CN (Curve Number) is a representation of potential runoff from the land cover – soil complex characteristics [10]. For watersheds with sub-watersheds that have a different land type and land cover, then CN composite values are determined based on:

$$CN = \frac{CN_1 A_1 + CN_2 A_2 + \cdots + CN_i A_i + CN_n A_n}{\sum_{i=1}^{n} A_i} \tag{7}$$

Where CN_i is the CN value in the sub-watershed i, A_i is the area in sub-watershed i, and n is the number sub-watershed. A combination of a hydrologic soil group, land use, and treatment class can be shown in Table 1 [8].

To estimate the curve number from rainfall-runoff data for S as a function of precipitation and depth runoff (Q) forms the equation [25]:

$$S = 5 \left(P + 2Q - \sqrt{(4Q^2 + 5 \, P \, Q)} \right) \tag{8}$$

The strong relationship between CN and rainfall depth occurred when Equations 5 and 7 are used to calculate values of CN from observed rainfall depth and runoff depth. The CN method is often used as a transformation of design rainfall depth to design runoff depth for a given return period [25]. To determine the curve number for rainfall depth and runoff depth has been applied for an ungauged watershed in the Benanain River.

Table 1. CN value based on land use

No.	Land Covering	A	B	C	D
1	Airport	79	86	90	92
2	Marshy Bush	100	100	100	100
3	Primary Dryland Forest	25	55	70	77
4	Secondary Dryland Forest	25	55	70	77
5	Primary Mangrove Forest	100	100	100	100
6	Secondary Mangrove Forest	100	100	100	100
7	Primary Swamp Forest	100	100	100	100
8	Secondary Swamp Forest	100	100	100	100
9	Perennial Forest	25	55	70	77
10	Habitation	79	86	90	92
11	Plantation	62	71	78	81
12	Mining	62	71	78	81
13	Dryland farming	51	67	76	80
4	Dry Land and Shrub Farming	51	67	76	80
15	Swamp	100	100	100	100

No.	Land Covering	A	B	C	D
16	Savana	30	58	71	78
17	Rice fields	59	70	78	81
18	Shrubs	29	57	70	77
19	Pond	59	70	78	81
20	Open Land	30	58	71	78
21	Transmigration	59	74	82	86
22	Body of Water	100	100	100	100

Soil Conservation Services (SCS) has developed a soil classification system based on soil properties and classified it into four hydrological soil groups (Table 2).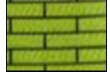 Soil Conservation Services has developed a soil classification system based on soil properties and classified it into four hydrological soil groups (Table 2). It is ranging from soil type A (very absorb water), B (potency absorbs moderately water), C (potency absorbs less water), and D (potency absorbs the least water). The definitions for each soil group adjusted by looking at the similarities to the potential surface runoff under the same weather conditions and land use.

Table 2. Hydrologic soil group classification

Land Group	Information	Infiltration Rate (mm/hr)
A	The smallest running water potential. Including deep sand soil with elements of dust and clay. High infiltration rate.	8-12
B	Water potential. Small runoff, sandy soil shallower than A. fine to medium texture, medium infiltration rate.	4-8
C	Medium runoff water potential. Shallow soil and contains enough clay. Medium to smooth texture. Low infiltration rate.	1-4
D	High Runoff Water Potential, mostly clayey, shallow, with an impermeable layer near the soil surface. Very low infiltration.	0-1

The depth and hydraulic conductivity of any water-impermeable layer and the depth to any high-water table, it used to determine the correct hydrologic soil group for the soil. Hydraulic conductivity is a quantitative measure of the ease with which water transmits through soil pores depending on the rock permeability. Lithological composition of rocks and permeability conditions to give qualitative information on the soil permeability, the occurrence of groundwater, and productivity of aquifers. It provides an overview of the depth of the aquifer (Table 3). Therefore, these two parameters are interrelated and linear relationship (the increases the hydraulic conductivity, the greater the permeability).

Table 3. Lithological composition of rocks and permeability conditions

No.	Figure	Lithological and Permeabilities	Aquifers
1		Pillow lava, generally low permeability	(Fissures and Porous) of Poor productivity Regions without exploitable: groundwater and regions without exploitable groundwater
2		The alluvium is composed of sands, gravels, cobbles, clays, and mud. Moderate to high permeability in coarse materials; low permeability in fine materials.	Aquifers in which flow is intergranular: Extensive, productive aquifer (Aquifer of moderate transmissivity; water table generally above or near the surface; wells yield generally more than 5 1/sec)
3		Sandy marl interbedded with sandstone, conglomerate, and dacitic tuff. Generally low to moderate permeability.	(Fissures and Porous) of Poor productivity Regions without exploitable: Poorly productive aquifers of local importance
4		Predominantly consist of massive limestone and calcilutite. Low to moderate permeability, depends on the degree of fissuration.	Aquifers in which flow is through fissures, fractures, and channels: Moderately productive aquifers.
5		Generally, coralline limestone, locally karstified. Permeability varies, depends on the karstified degree.	Aquifers in which flow is through fissures, fractures, and channels: Moderately productive aquifers.

Soil permeability was determined using the conversion of hydrogeological maps through to the Hydrological Soil Group maps [7] are shown in Table 4 and Table 5.

Table 4. Transfer of hydrogeological map to HSG for deep groundwater, more than 100 cm

Permeability				
Very High	**High**	**Moderate**	**Low**	**Very Low**
A				
		B		
			C	
				D

Table 5. Transfer of the hydrogeological map to HSG for shallow groundwater, less than 100 cm

Permeability				
Very High	**High**	**Moderate**	**Low**	**Very Low**
A				
	B			
		C		
				D

2.2. Study Area and Data Used

Benanain River is the main river of the Benanain Watershed which has an area of 3,182 km^2, where the Benanain River flows across four districts, namely Malaka District, Belu District, North Central Timor District, and South-Central Timor District. It is located at approximately 124°11'45.64" - 125°07'31.22" E and 8° 56'33.21" - 9° 58'34.60" S (Figure 1).
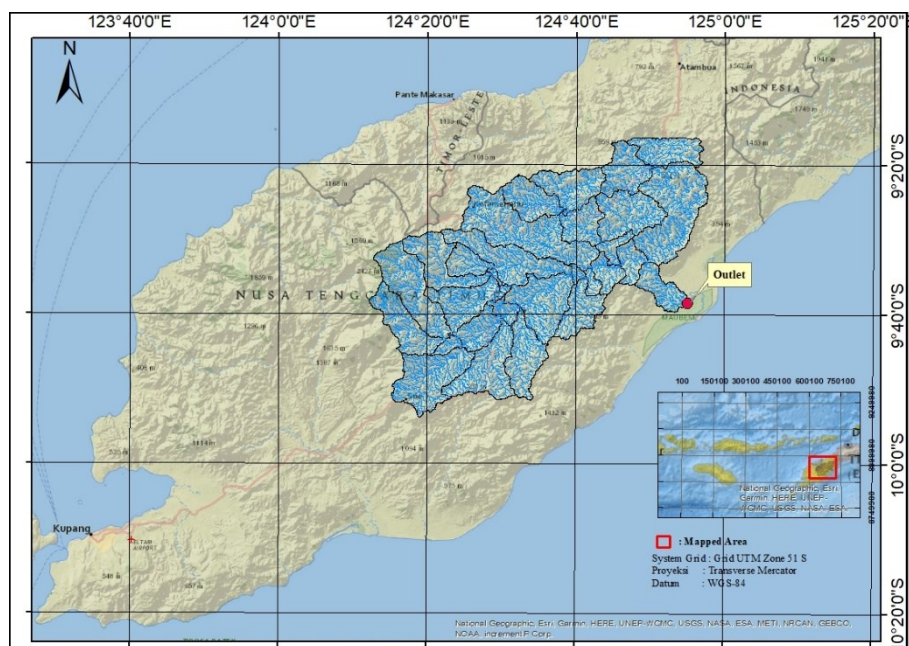
Figure 1. Benanain watershed in Timor Island

Malaka district is approximately 232 km from Kupang City to the east of Timor Island. This research was conducted in the Benanain watershed that flows to the estuary in the southeast of the Timor Sea. Figure 1 shows the changes in the shape of the river flow where there is a meander phenomenon. The river morphology has changed a lot. It has happened as a result of riverbank erosion which causes silting in the river channel. This sedimentation makes things worse if the flood intensity is high enough because the river cross-section was unable to accommodate the water flow.

The Malaka district has a tropical climate with an average temperature of 24 - 34 °C. The maximum daily rainfall has varied between 16-68 mm in the eastern region, while 120-255 mm in most of the northern. The average annual rainfall has estimated at 1,500 mm/year [26]. This research used ten rainfall stations for ten years (1996-2008) and

spread across four districts that crossed by the Benanain watershed. The average areal rainfall for the analyzed part of the catchment was determined using the Thiessen polygon method, as showed in Figure 2. The geographical location of rainfall stations shown in Table 6.
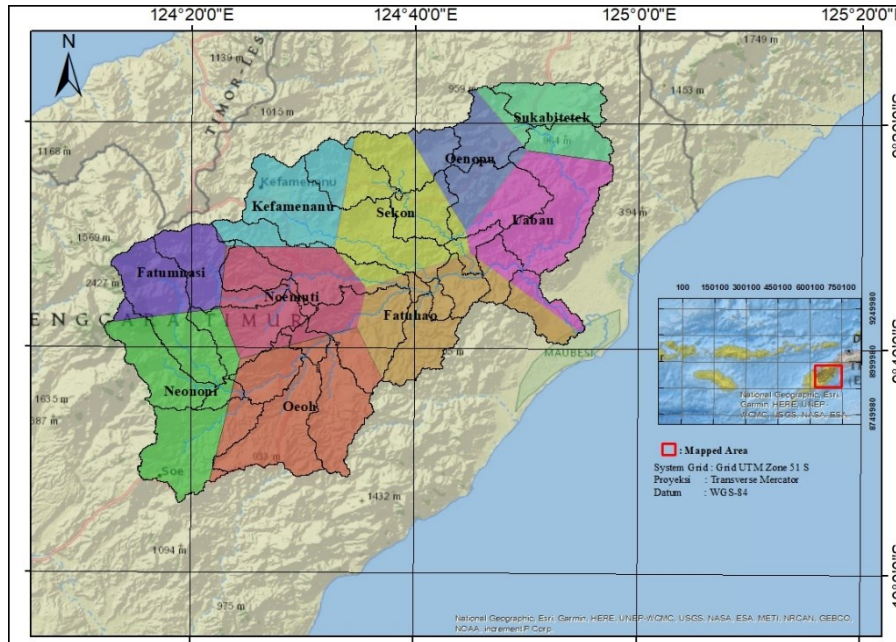

Figure 2. Thiessen Polygon of Benanain watershed

Table 6. The geographical location of rainfall stations in Benanain watershed

Station Name	Station Code	Latitude	Longitude
Sukabitetek	009 TTS	9°18'56.9"	125°51'15.6"
Uabau	018 KUP	9°6.3'3"	124°23'3"
Fatumnasi	006 KUP	9°38'53.7"	124°13' 29.3"
Noenoni	024 TTS	9° 31' 48"	124° 18' 0"
Oeoh	011 TTU	9°7.16'7"	124°4.66'7"
Kefamenanu	009 TTS	9°39'43.81"	123°59'6.36"
Noemuti	008 TTS	9°35'30.39"	124°28'48.56"
Fatuhao		9°42'24.7"	124°34'23.4"
Sekon		9∘ 27'37.2"	124∘ 38' 3.5"
Oenopu		9°42'18.94"	123°57'33.2"

Land use activities in the Benanain watershed cause a change in the type of land cover, changes in vegetation, deforestation, shifting cultivation, converting forests to plantations, and changes in land management. The overflow in the Benanain River occurs almost every year and even repeatedly in a year. The flood tends to increase depending on the intensity of rainfall that occurs upstream. Therefore, it is necessary to the analysis of effects of land use and soil types on the curve number (CN) as one of the determining variables for discharge changes in the Benanain watershed. The characteristic of ten rainfall-runoff direct events for the analysis, with the calculated curve number according to Equations 4 and 6 presented in Table 7.

Table 7. Characteristics data in the Benanain watershed

Category	Unit	Value for the events	
		average	range
1	2	3	4
Rainfall depth/precipitation	mm	82.84	56.71 - 130.27
Maximum retention (S)	-	137.22	89.71 - 195.24
Runoff depth (Q)	mm	17.19	4.41 - 51.67
Curve Number	-	65.32	56.53 - 73.90

The research flow chart to estimate the curve number model and to predict the amount of surface runoff is presented in Figure 3. The amount of runoff depth obtained in this study includes a rainfall depth (P) and the curve number prediction. Because the catchment area doesn't have observed runoff data, this study only estimates the curve number data from land use maps and soil maps. Furthermore, to determine the correlation between P and Q, Q and CN were done using statistical analysis.
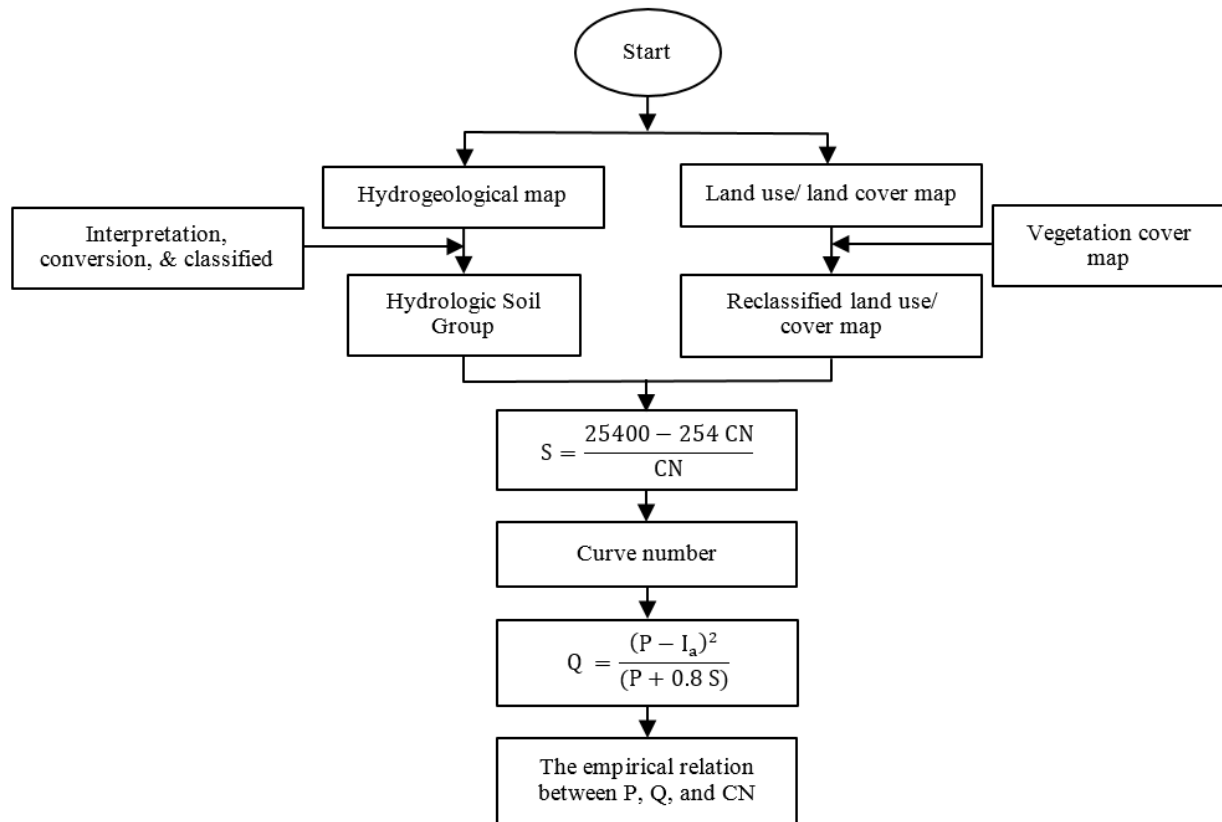
$$S = \frac{25400 - 254 \, CN}{CN}$$

$$Q = \frac{(P - I_a)^2}{(P + 0.8 \, S)}$$

Figure 3. Research methodology flow chart

3. Result and Discussions

3.1. Hydrological Soil Group Map

The Benanain watershed area has divided into 29 sub-watersheds (Figure 4), and based on the land use map for the island of Timor, the land cover types of the Benanain watershed can classify as in Table 8.
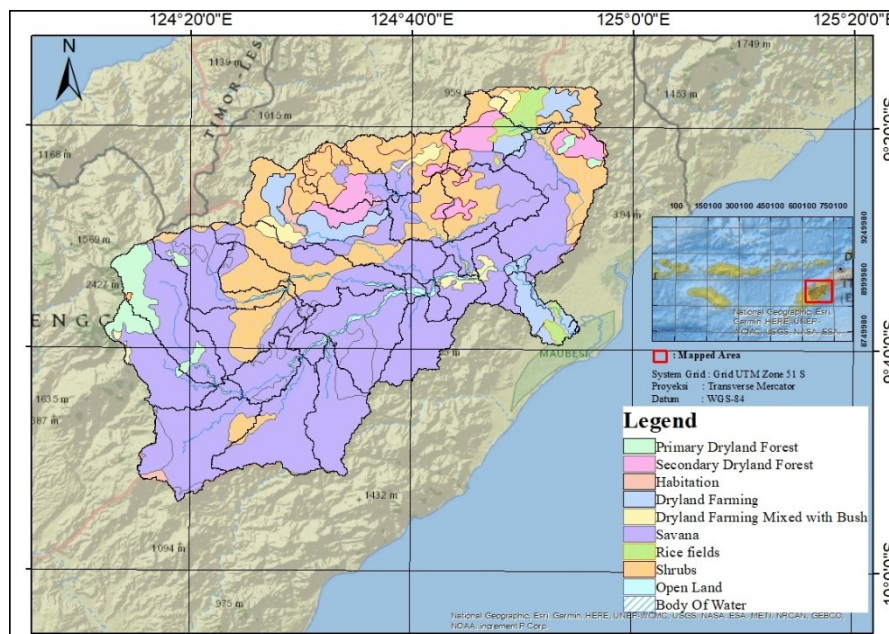
Figure 4. Land use map of Benanain watershed

It can be seen in Table 8 that the Benanain watershed has dominated by secondary dryland forest covering an area of 1,408.20 km^2 with CN values based on land use A = 25, B = 55, C = 70, and D = 77. Secondary dryland land forest in the Benanain watershed covers 44.26% of the total area, which means that is better than scrub or savanna. The secondary dryland forest has granular aggregates that are better at absorbing water. It has a scaly clay soil texture, moderate soil permeability, very poor soil porosity, moderately content weight, and low soil organic level content. The clay particles are more difficult to detach than sand or gravel, but clay is easier to transport.

Table 8. Percentage of land use types in the Benanain watershed

No.	Land Use	Area (Km^2)	Percentage (%)
1	Secondary dryland forest	1,408.20	44.26
2	Shrubs	716.84	22.53
3	Habitation	20.93	0.66
4	Savanna	663.22	20.85
5	Open land	31.72	1.00
6	Primary dryland forest	100.17	3.15
7	Dryland farming mixed with bush	68.26	2.15
8	Body of water	0.25	0.01
9	Dryland farming	171.94	5.40
		3,181.521	100.00

Hydrologic soil group (HSG) is determined by the water transmitting from the soil layer with the lowest saturated hydraulic conductivity and value of depth to the impermeable layer or a water table. A hydrogeological map gives complete information on the parameters needed for HSG determination as soil permeability, groundwater level position from the surface can use as the basis to determine the HSG value shown in Tables 4 and 5. Digitalization using ArcGIS based on the hydrogeological map of Timor Island obtained soil hydrological types and the groundwater level depth which divided into 19-types with low to very low, low to moderate, and moderate to high passing types with HSG B, C, and D (Table 9). Determination of the Curve Number Value in the Benanain watershed using the SCS-CN method needs to be done by overlying (intersection) the hydrological soil group map and land use map. The results of intersection reclassification of land use maps and soil hydrology group maps are new polygons that represent the value of the curve number from the SCS. The result of the curve number value for 29 sub-watersheds in the Benanain watershed has shown in Table 9.

Table 9. Hydrologic soil group in Benanain watershed

No.	Lithology	Permeability	HSG	Area (Km^2)	Percentage (%)
1	Calcilutite and marl	Low to very low	D	26.564	0.835
2	Conglomerates and crusts, are loose at the top and solid at the bottom	Moderate to high	C	8.869	0.279
3	Calcilutite and marl	Low to moderate	C	3.368	0.106
4	Lava pillow	Low to very low	D	33.895	1.065
5	Conglomerates and limestone	Moderate to high	C	18.559	0.583
6	Alluvium consists of sand, gravel, gravel, clay, and mud	Low to moderate	D	35.514	1.116
7	Alluvium consists of sand, gravel, gravel, clay, and mud	Moderate to high	B	50.846	1.598
8	Conglomerates and crusts, are loose at the top and solid at the bottom	Moderate to high	B	140.021	4.401
9	Conglomerates and limestone	Low to moderate	C	41.916	1.317
10	Coral limestone, localized	Moderate to high	B	69.065	2.171
11	Alluvium consists of sand, gravel, gravel, loam, and sand	Moderate to low	C	62.677	1.970
12	Conglomerates and crusts, are loose at the top and solid at the bottom	Moderate to high	C	482.616	15.169
13	Coral limestone, localized	Moderate to high	B	420.485	13.216
14	Sandstone marl interspersed with sandstone, conglomerates, and dacitic tuffs	Moderate to high	B	537.489	16.894
15	Solid limestone and calcilutite	Moderate to high	B	224.524	7.057
16	The scaly clays contain chunks of other rock	Low to very low	D	816.918	25.677
17	Basalt lherzolite and serpentinite	Low to moderate	C	23.736	0.746
18	Various types of metamorphic rocks from basalt to genes, amphibolite, quartzite, and granulite	Low to moderate	C	147.787	4.645
19	Solid volcanic breccias, agglomerates, lava and tuffs	Moderate to high	B	36.672	1.153
	Total			3181.52	100.00

The percentage of each soil type is tabulated in Table 8 to determine the dominance of soil types in the Benanain watershed. The sub-basin area that is classified as low to lowest (Type D) is 28,683%, low to moderate (Type C) is 24,815%, and the remaining moderate to high (Type) B is 46.502%. The lithology of soil types with the highest percentage is scaly clay containing boulders of other rock with low to very low permeability (the potential for water absorption is the least) has a value of 25.677%.

However, it can be seen in Table 9, based on the hydrologic soil group, the B group classification with medium to high absorption potential has a large area. It means water will absorb into the soil surface as infiltration by 46.502% of the watershed area when it rains. The classifications of hydrologic soil group in Benanain watershed with type C and D, which have medium to very low permeability indicate that most of the Benanain watershed has a potential for surface runoff. Soils in this group (Type C/D) have moderately to high runoff potential when thoroughly wet. Water movement through the soil is restricted or very restricted. Group D soils typically have greater than 40 % clay, less than 50 % sand, and have clayey textures.

The CN value of the Benanain watershed ranges from 56.55 to 73.90 and the average value of 65.32, and the highest CN value found in Sub-watershed W-310, which dominated by the type of scaly clay containing boulders of other rock and land cover in the form of shrub bush with an area of 22.61 km^2 or 0.21%. The curve number and hydrologic soil group values of the Benanain watershed depicted on maps (Figure 5).
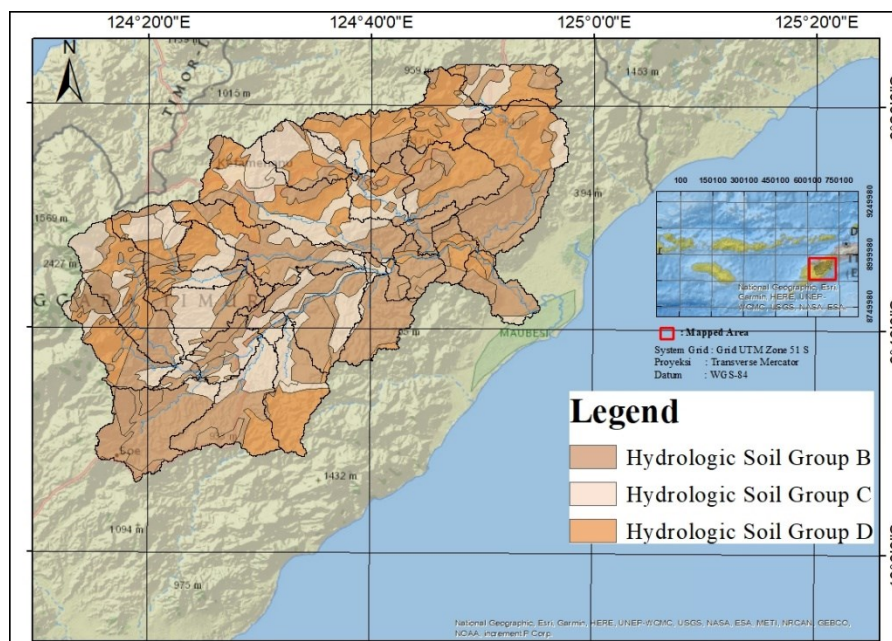

Figure 5. Hydrological Soil Group of Benanain watershed

3.2. Estimating Rainfall-Runoff

The runoff depth (Q) can be estimated using Equation 4 from the annual maximum daily rainfall data of 29 sub-watersheds in the Benanain watershed presented in Table 10.

Table 10. The Result of runoff calculation using the Curve Number method

No.	Sub-Watershed	Area (km²)	CN	S	P (mm)	Q (mm)
1	W300	102.02	69.84	109.70	62.00	10.72
2	W310	110.35	73.90	89.71	84.60	28.42
3	W320	278.74	67.48	122.42	56.71	6.72
4	W330	121.4	71.72	100.17	86.72	26.65
5	W340	103.58	70.51	106.24	64.34	12.43
6	W350	83.78	68.78	115.28	130.28	51.67
7	W360	150.13	66.19	129.74	72.90	12.48
8	W370	296.11	71.40	101.76	82.22	23.39
9	W380	31.44	56.54	195.25	70.69	4.41
10	W390	51.06	67.39	122.89	65.26	10.12

No.	Sub-Watershed	Area (km²)	CN	S	P (mm)	Q (mm)
11	W400	47.96	60.08	168.77	82.04	10.74
12	W410	173.66	65.14	135.94	98.95	24.79
13	W420	59.93	71.99	98.84	79.20	22.32
14	W430	10.17	57.26	189.59	79.00	7.32
15	W440	18.68	58.11	183.08	82.00	9.02
16	W450	192.15	66.07	130.44	85.60	18.64
17	W460	76.23	67.59	121.80	70.02	12.45
18	W470	133.41	69.10	113.57	79.87	19.13
19	W480	125.55	65.03	136.60	83.66	16.45
20	W490	11.11	64.49	139.88	82.07	15.09
21	W500	171.12	60.69	164.50	83.92	12.08
22	W510	96.95	56.55	195.15	82.01	7.76
23	W520	127.5	71.01	103.67	92.00	29.03
24	W530	29.75	65.93	131.26	86.28	18.84
25	W540	75.44	62.15	154.67	90.96	16.78
26	W550	163.35	63.26	147.53	92.00	18.60
27	W560	128.85	66.11	130.23	92.09	22.22
28	W570	19.81	62.38	153.20	92.64	17.86
29	W580	191.3	57.50	187.72	92.58	12.48

Model validation should be done to examine the accuracy of the SCS Curve Number Method. However, because there is no observational runoff data in the study area, the design runoff can be assumed from the empirical relationship between the rainfall depth, curve number, and runoff depth. The relationship between rainfall depth (P) and runoff depth for the average of curve number 65.32 and has overlaid with the graphical solution of Equation 6 shown in Figure 6 [27].
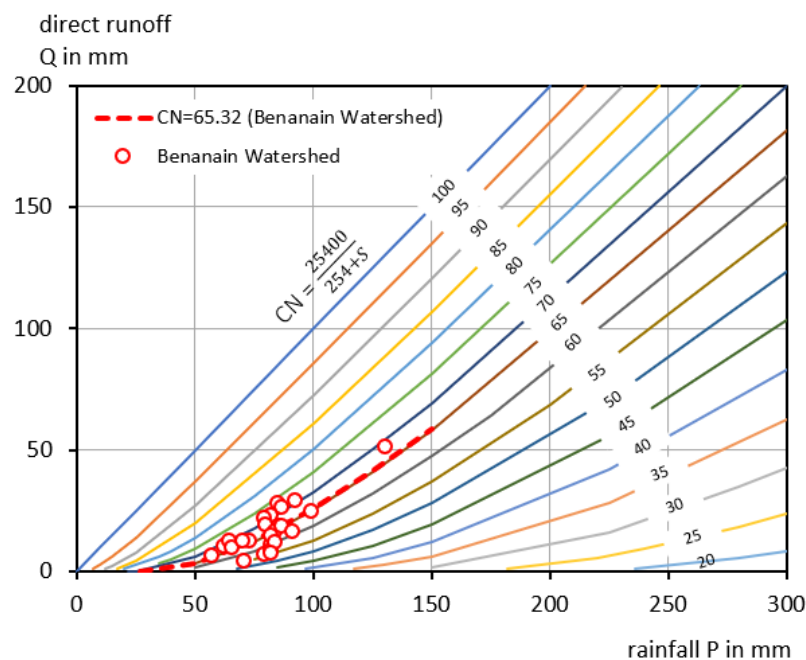

Figure 6. Relationship between rainfall depth (P) and runoff depth (Q) for the average of CN = 65.32 (overlaying to figure depicted from SCS 1972)

The 29 pair runoff depth to rainfall depth is plotted and obtained relationship:

$$Q = f(P) = 0.006 P^2 - 0.5314 P + 19.066 \tag{9}$$

With $r^2 = 0.683$ of CN = 65.32. Based on Equation 9, the increase in rainfall depth value by 7.03% will also affect the

increase in runoff depth by 8.68 % for CN =65.32 in the Benanain watershed. Dots distribution shown in Figure 6 indicates a strong secondary relationship between rainfall depth vs. runoff depth for the mean of CN = 65.32. Hawkins [29] proposed to use an asymptotic function for the approximation of the relationship CN vs. rainfall depth values with the following equation:

$$CN = CN_\infty + (100 - CN_\infty) \exp^{(-kP)} \tag{10}$$

Where CN_∞ is the constant values as P $\rightarrow \infty$; and k = fitting constant. Equation 10 was fitted using a least-square procedure for CN_∞ and k. The fitting "k" can be following the equation:

$$CN = CN_\infty + (100 - CN_\infty) = 100 \ (2 + kP) / (2+P) \tag{11}$$

Where $CN_\infty = 100/ (1 + P/2)$ for P $\rightarrow \infty$ then CN (P) $\rightarrow$ 100 k = CN_∞

A standard asymptote occurs if there is a tendency for CN to decrease and then approach a constant value with increasing rainfall depth (mm) [25, 28]. A similar trend was found for rainfall depth events and respective CN values as shown in Figure 7, considering P > 0.2 S and $CN_\infty = 100/ (1 + 50.8 \ P)$.
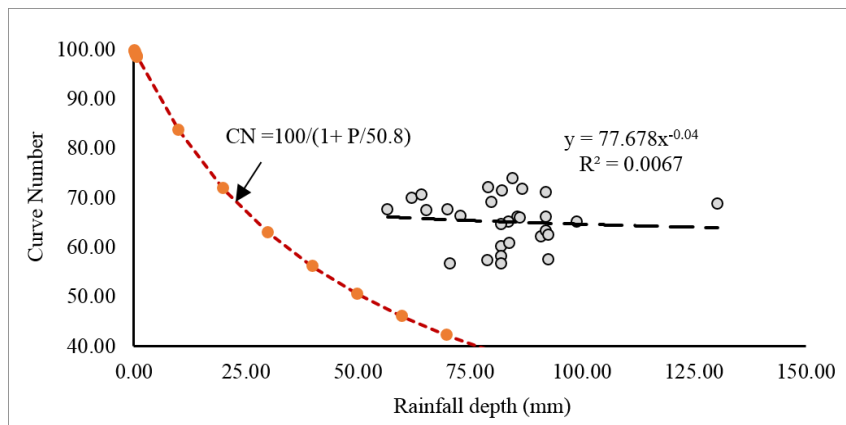

Figure 7. Relationship between rainfall depth (P) and curve number (CN) in Benanain watershed

Figure 7 shows a tendency for CN to decrease and then approach a constant value with increasing rainfall depth (mm) according to the formula:

$$CN = f (P) = f (77.67 \ P^{-0.04}) \tag{12}$$

Where the values of the curve number are estimated from 56.54 -73.90 with the mean value equals 65.32. As there is a tendency for curve numbers to decrease with the increase of rainfall depth. Therefore, in the application of mean CN (65.32) for design floods estimation is not allowed. The trend line obtained on the Benanain watershed is similar to previous researchers [21, 26], but the area study (watershed area) is smaller than this case. Hawkins (1993) suggests that the asymptotic line is a common and standard hydrological response to watershed behavior [29]. Therefore, in the Benanain watershed, the relationship between rainfall depth and CN is classified as a standard response. The asymptotic approach has the advantages that the more efficient use of the available data sources may be applied to ungauged watersheds and the results are similar to those derived from original data [30].

The average rainfall depth (mm) for the 29 sub-watersheds in the Benanain watershed has decreased by about 74.65% when being surface runoff depth. The runoff depth of the Benanain watershed may also be affected by land-use of the watershed (secondary dryland forest), river slope (0.45%) into the watershed, shallow soils (0.56 m), drainage density, and the confluence of tributaries so that the estuary is like a bottleneck. The equilibrium of trend line (flat slope) when rainfall depth value of 56.71 mm and CN approaches 66.30. The rainfall-runoff value that takes into account the curve number value in the Benanain watershed is also one of the factors that influence the flooding that occurs. The CN value in the Benanain watershed is in AMC I during the dry season, but a significant change will occur during the rainy season, where the CN value in the watershed becomes AMC III. Determination of CN value with a large watershed area and the high variability of rainfall intensity has a significant effect on the CN value, which results in the amount of surface runoff.

Analysis of the value of the curve numbers in the ungauged watershed is very helpful to estimate the percentage of water infiltration and water flow as surface runoff. Analysis of large catchment areas such as the Benanain watershed required mapping in smaller sub-watershed areas so that prediction data could be obtained closer to real conditions in the field. Therefore, it is necessary to conduct a similar investigation of the small watershed, with long rainfall records and observed runoff data, so calibration values can be obtained to flood frequency analysis.

4. Conclusion

The hydrological soil types in the Benanain watershed has classified into 19-types with three levels of permeability, namely, moderate to high permeability, moderate to low permeability, and low to very low permeability consisting of HSG B (moderate water absorption potential), HSG C (less water absorption potential) and HSG D (very less water absorption potential). The land-use type in the Benanain watershed is secondary dryland land forest covers 44.26% of the total area, which means that is better at absorbing water than shrub or savanna. Based on the hydrologic soil group, the B group classification with medium to high absorption potential reaches 46.502% of the total area of the Benanain watershed. It means water will absorb into the soil surface as infiltration when it rains. The Benanain watershed is dominated by soil types with scaly clay lithology containing other rock blocks with low to very low permeability and grouped into HSG-D groups with an area percentage of 25.667%.

The curve number value of the Benanain watershed ranges from 56.55 to 73.90, where the highest curve number value is found in the W-310 sub-basin which is dominated by the type of scaly clay containing boulders of other rock. The land cover in the form of shrub agriculture with an area of 22.61 km^2 or 0.21%. The runoff depth value increased by 8.68% with increasing rainfall depth, and the increased runoff depth is directly proportional to the increased curve number value of 3.14%. Determination of CN value with a large watershed area and the high variability of rainfall intensity has a significant effect on the CN value in Benanain watershed. For further analysis with flood hydrograph using the HSS SCS method, it is necessary to have long rainfall data and observations runoff depth are required as calibration data for controlling the use of curve numbers.

5. Declarations

5.1. Author Contributions

D.S.K., W.B., and J.H.F. contributed to the conception, methodology, and research design of the study; Y.A.S. performed numerical studies and analyzed the data in the field; J.L. contributes guided, reviewed, and commented on the previous version of the manuscript; D.S.K and Y.A.S. wrote the first draft of the manuscript; D.S.K., W.B., J.H.F, and J.L. added review and editing in the discussion. All authors have read and agreed to the published version of the manuscript.

5.2. Data Availability Statement

The data presented in this study are available on request from the corresponding author.

5.3. Funding

5.4. Acknowledgements

5.5. Conflicts of Interest

The authors declare no conflict of interest.

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