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Research Article

Determining the Initial Abstraction Ratio of the Upper Sawaga Watershed, Bukidnon, Philippines

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ABSTRACT

The Curve Number (CN) method has been widely used for estimating runoff from rainfall. However, some uncertainties in the method have been recognized by various researchers all over the world. One of which is the NRCS-assumed initial abstraction ratio (Ia/S) of 0.20. In this study, the Ia/S for the upper catchment area of Sawaga River in Bukidnon was determined using event analysis of different rainfall events with a total precipitation depth ranging from 21.50 to 57.90 mm. The resulting representative values of Ia/S and CN are 0.03 and 62.3, respectively. Evaluating the runoff prediction performance of both the original NRCS (Qesti0.20) and locally derived parameter values (Qesti0.03), Qesti0.03 had a lower error rate with a Standard Error of 2.2639 compared to Qesti0.20's 2.6760. For accuracy in predicting runoff, Qesti0.03 also showed better performance with a Nash-Sutcliffe Efficiency of 0.7854 versus 0.6942 for Qesti0.20, and its Percent Bias was lower at 2.6410 compared to 36.4201 for Qesti0.20. Both methods had very good coefficients of determination, with Qesti0.20 at 0.8459 and Qesti0.03 at 0.8343. Overall, Qesti0.03 proved to be more reliable and effective for accurate runoff prediction in this watershed. These findings suggest that the CN method, with certain adjustments on Ia/S and CN, is appropriate for the direct runoff estimation in the upper Sawaga watershed, Bukidnon.

Keywords: curve number; initial abstraction ratio; rainfall; runoff; watershed

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1. INTRODUCTION

The Natural Resources Conservative Service (NRCS) curve number (CM) method is commonly used to estimate direct runoff from rainfall. Although initially developed for conditions governing in the United States, it has been used and adapted in other countries (Ritzema 1994) such as Australia (Boughton, 1989), China (Fu et al, 2013; Liu & Li, 2008; Shi et al., 2009; Zhang et al., 2011), and Brazil (Do Valle Junior et al., 2019; Oliveira, et al., 2016), and utilized in various hydrologic modeling software such as HEC-HMS (Forasteé & Hirschman, 2010; Noori et al., 2012) and SWAT (Arnold et al., 1993; Kim et al., 2010). Due to its convenience and simplicity, computation efficiency, authoritative origins, and satisfactory outputs (Ponce & Hawkins, 1996; Yuan et al., 2012), the CN method was preferred by many practitioners over other methods as the others were more complex, requiring a higher number of parameters yet yielding similar quality of outputs (Lastra et al., 2008). It relies on precipitation and responds to watershed characteristics such as land use/land cover and treatment, soil type, surface conditions, and antecedent runoff conditions aggregated into a watershed CN to estimate total storm runoff from total storm rainfall (Ponce & Hawkins, 1996). According to various researchers worldwide, the initial abstraction ratio (Ia/S) is dependent on geologic and climatic settings (Ling & Yusop, 2014). Considering this, if the actual local Ia/S value deviates from the original NRCS Ia/S, then the existing NRCS-tabulated CNs are not suitable as they are exclusive to Ia/S of 0.20. Consequently, runoff estimation and other hydrograph components will be affected if adjustments to the method are not made, compromising the modeling accuracy, planning, design, and implementation of various works. Additionally, runoff due to extreme rainfall events might be underestimated and may pose higher risk to lives and properties when the inappropriate initial abstraction ratio is used. Furthermore, managing water resources will be affected (Mercado et al, 2024; Tanhueco et al, 2022). To justify the use of the NRCS-CN method for runoff estimation of local watersheds, the suitable Ia/S and CN parameters for the local setting must be identified.

This study determined the Ia/S and CN in the USDA-NRCS curve number method for runoff estimation in the upper catchment area of Sawaga River, Bukidnon. Specifically, the Ia/S for the upper catchment area of the Sawaga River watershed was determined by rainfall-runoff event analysis. The watershed CN corresponding to the locally derived Ia/S was also calculated using the NRCS-established relationship between the maximum potential retention and CN. As part of the investigation, the impact of adopting the locally derived Ia/S and CN on the runoff estimation results was examined and compared to that of the original NRCS using various performance assessment methods.

2. METHODOLOGY

2.1. Study Area

The upper catchment area of the Sawaga River (see Figure 1) watershed is in the north-central portion of Bukidnon with 287.9km^2 of land area. The highest peak is 2916 meters above sea level at the Mt. Kitanglad Mountain range, while the lowest elevation is 343 meters above sea level at the outlet point of the study watershed and is located beneath the Cabacungan bridge, Brgy. Linabo, Malaybalay City, Bukidnon at 8.06175 latitude and 125.161389 longitude.

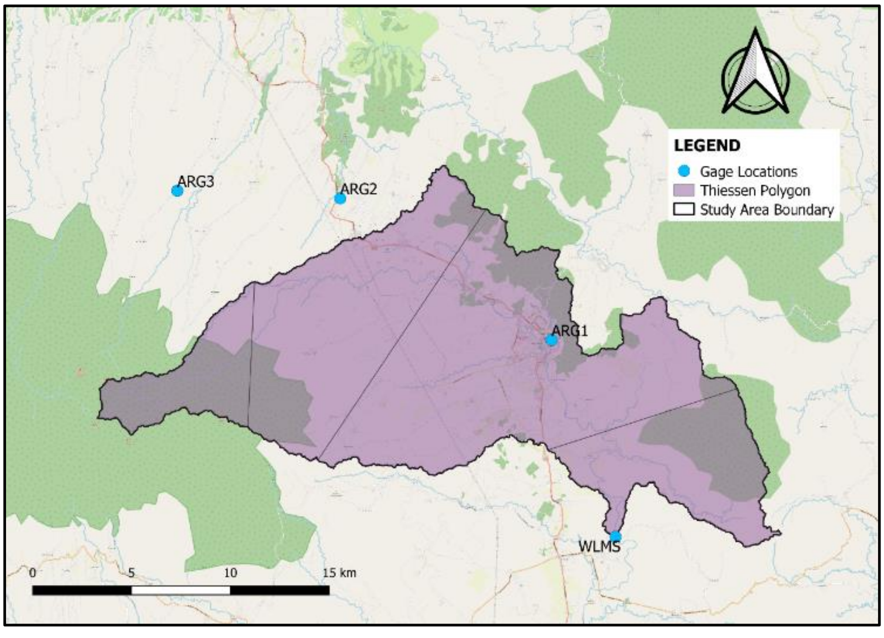

Figure 1. The upper catchment area of Sawaga River, Bukidnon, and relative locations of the rain and water level gages

Based on the Koppen-Geiger system, the climate in the area is tropical rainforest (class Af) with average annual rainfall and temperature of 2664 mm and 23,4°C, respectively. The wet season spans from May to October wherein the area receives around 70% of the total annual precipitation with an average of 305 mm per month, while the dry season stretches from November to April with Monthly average precipitation of 160 mm (Climate-Data, 2020). A significant portion of around 72.5% of the total land area is used for agricultural purposes, followed by forestlands covering approximately 18.0% of the area. Rangeland occupies around 7.2% of the watershed, while the remaining 2.2% is urban and 0.1% is surface water. The majority (83%) of the study area consists of hydrologic soil group D (clay), while the remaining 17% is hydrologic soil group C (clay loam). HSG Class C sustains a slow infiltration rate when thoroughly wetted resulting in a high runoff potential while HSG Class D has an even higher runoff potential due to the clay's high swelling potential, high water table, or being over a nearly impervious material.

2.2. Selection of Rainfall Events and Pre-Processing of Data

Rainfall and water level data for January 2016 – June 2017 in a 15-minute interval and November 2018 - December 2019 in a 10-minute interval were acquired from the online data bank of the Department of Science and Technology - Advanced Science and Technology Institute (DOST-ASTI). There are four (4) automated rain gages (ARG) within and near the watershed and one (1) water level measuring system (WLMS) at the outlet point. These devices were simultaneously operational for those durations.

The point rainfall data collected from the ARGs were converted to a real rainfall via the Thiessen Polygon method. The water level data to discharge flow rate was converted using a generated rating curve for the outlet. The rating curve for the river at the outlet point was developed by analyzing the relationship between stage or water level (S) and discharge (Q). The flow velocity data was acquired by performing the float method. The water level data from the existing WLMS simultaneous to the conduct of the float method was utilized for this process.

Rainfall events were selected from the acquired hydrologic data, which conformed to the following criteria (Do Valle Junior et al., 2019):

- Rainfall depth P of at least 20 mm to avoid bias from having a large number of small rainfall events
- Detected in all identified ARGs located within and near the study watershed to ensure minimal spatial variability

The baseflow separation was performed using the straight-line-constant slope method for all hydrographs due to lack of available baseflow data and for the method's simplicity. Although the endpoint of the straight line that divides the direct runoff and baseflow is arbitrary, the time of concentration computed using the Kirpich-Kerby method for overland flow and channel flow was used to identify the endpoint of the straight line in all individual streamflow hydrographs. Conforming to the hydrologic data, the time step of the analysis was fifteen (15) minutes for the events occurring between January 2016 and June 2017, while then (10) minutes for the events occurring between November 2018 and December 2019.

2.3. Determining of the Initial Abstraction Ratio

Figure 2 represents the rainfall-runoff event analysis (Woodward et al., 2003). Sequentially, the values in depth units determined by this procedure are the initial abstraction (Ia), excess rainfall (Pe) or runoff depth (Q), maximum potential retention (S), and subsequently, the Ia/S.

Ia and Q can be directly identified, while S can be computed using the general runoff equation developed by NRCS (2004):

$$Q = \frac{(P-I_a)^2}{(P-I_a)+S} \quad \text{(Eq. 1)}$$

Ia is the combined losses before the runoff, mainly due to interception, initial infiltration, and surface storage, while S is the infiltration that occurs after the runoff has commenced. Pe is the excess rainfall. For every selected rainfall event, the Ia/S value was computed.

2.4. Determination of the Curve Number

The CN corresponding to the watershed Ia/S was computed using the S-CN relationship:

$$CN = \frac{25400}{254+S} \quad \text{(Eq. 2)}$$

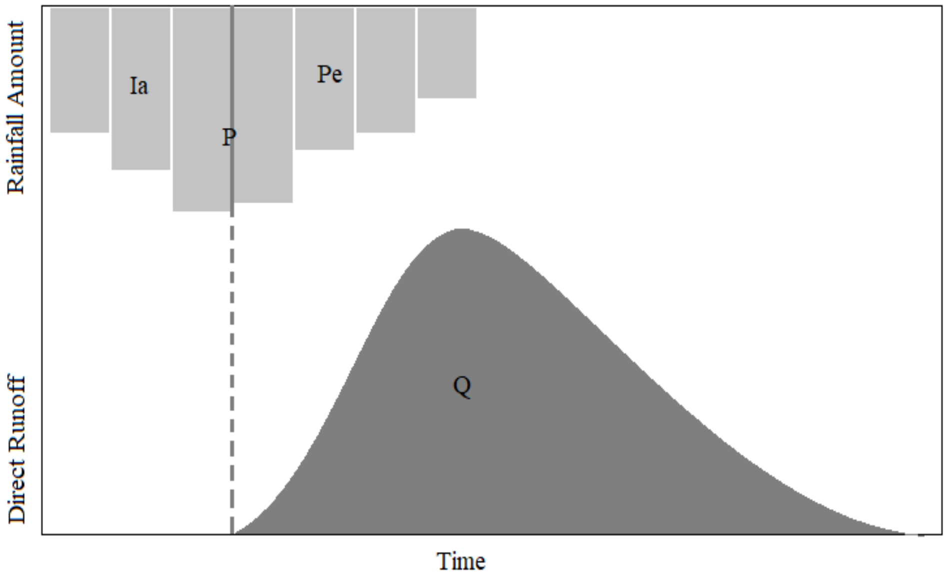

Figure 2. Rainfall-runoff event analysis method

where S is in millimeters. The resulting unitless CN values range from zero to 100; zero CN indicates an impermeable watershed while 100 indicates an infinitely abstracting watershed.

2.5. Data Analysis

Measures of central tendency and dispersion of the event Ia/S values were evaluated to describe the basic features of the dataset. The cumulative frequency distribution of Ia/S was also assessed. Initially, event Ia/S values were ranked in ascending order, and their plotting positions were identified. The ordered Ia/S values were then plotted against their cumulative frequency to produce a cumulative frequency distribution graph. The standard error (SE) (Eq. 3), coefficient of determination (R^2) (Eq. 4), Nash-Sutcliffe Efficiency (NSE) (Eq. 5), and percentage of mean bias (PBIAS) (Eq. 6) were calculated to evaluate and compare the goodness of fit and bias of the original NRCS and the locally derived values. The SE shows how spread out the values in the dataset are, while the R^2 shows how related the two variables are, which are the observed and estimated Q values. A high R^2 value and a low SE value indicate a good prediction performance. The PBIAS measures the average tendency of the estimated values to be larger or smaller than their observed values. For this study, the average tendency of the estimated Q values to be greater or lesser than the observed Q values was evaluated. The closer the PBIAS values are to zero, the more accurate the model is. A positive PBIAS indicates overestimation, while a negative indicates underestimation. Finally, the NSE (Nash & Sutcliffe, 1970) determines how the observed values plotted against the estimated values fit the 1:1 where the perfect match of observed and estimated values is $NSE = 1.0$. A zero NSE indicates that the model predicts just as accurately as the mean observed flow, while NSE values less than zero indicates that the prediction is worse than the observed value. The following formulas were used for the performance evaluation methods:

$$SE = \sqrt{\frac{\sum(Q_{obsi} - Q_{esti})^2}{n}} \quad \text{(Eq. 3)}$$

$$R^2 = \left\{ \frac{\sum_{i=1}^{n}(Q_{obsi} - Q_{obsavg})(Q_{esti} - Q_{estavg})}{\left[\sum_{i=1}^{n}(Q_{obsi} - Q_{obsavg})^2 \sum_{i=1}^{n}(Q_{esti} - Q_{estavg})^2\right]^{0.5}} \right\}^2 \quad \text{(Eq. 4)}$$

$$PBIAS = \left[\frac{\sum_{i=1}^{n}(Q_{obsi} - Q_{esti}) \times 100}{\sum_{i=1}^{n}(Q_{obsi})} \right] \quad \text{(Eq. 5)}$$

$$NSE = 1 - \left[\frac{\sum_{i}^{n}(Q_{esti} - Q_{obsi})^2}{\sum_{i}^{n}(Q_{obsi} - Q_{obsavg})^2} \right] \quad \text{(Eq. 6)}$$

Where Q_{obsi} is the observed Q at event i, Q_{esti} is the estimated Q at event i, Q_{obsavg} is the average of the observed Q values, and Q_{estavg} is the average of the estimated Q values.

These performance metrics were selected as together they provide a comprehensive assessment of and a holistic view of the model's performance which addresses accuracy using SE, bias using PBIAS, efficiency using NSE, and goodness of fit using R^2.

3. RESULTS AND DISCUSSION

3.1. Selection of Rainfall Events

Twenty (20) rainfall events with precipitation depths ranging from 21.50 mm to 57.90 mm were selected. All these events were detected by all ARGs in Figure 1. Table 1 below shows the rainfall depth of the selected rainfall events arranged in a chronological sequence.

Table 1. Selected rainfall events and their corresponding depths

Event No.	Rainfall Event	Rainfall Depth, P (mm)
1	July 2, 2016	29.43
2	July 5, 2016	55.70
3	July 28, 2016	40.20
4	August 5, 2016	30.90
5	September 9, 2016	27.30
6	December 14, 2016	45.50
7	January 16, 2017	38.80
8	January 18, 2017	57.90
9	April 14, 2017	32.40
10	May 16, 2017	24.20
11	May 20, 2017	36.60
12	June 18, 2017	22.70
13	June 21, 2017	21.50
14	June 26, 2017	24.90
15	November 22, 2018	28.40
16	January 11, 2019	23.70
17	July 2, 2019	39.30
18	October 29, 2019	24.50
19	October 30, 2019	23.90
20	November 20, 2019	27.20

3.2. Watershed Ia/S and CN

As shown in Table 3, Ia/S values vary from rainfall event to rainfall event wherein the majority is less than 0.20, similar to other studies conducted in different regions (Ling 7 Yusop, 2014; Mishra & Singh, 2004). These findings have prompted other researchers to suggest a lower Ia/S value of 0.05 instead of the original Ia/S of 0.20 (Ajmal et al., 2015; Jiang, 2001). According to Ling and Yusop (2014), the Ia/S values for watersheds in tropical hot and humid climates range from 0.000 to 0.864. The spread of 0.864 is a sufficient reason that Ia/S should be computed for every watershed. For the upper catchment area of the Sawaga River, the median Ia/S value of 0.03 serves as the representative watershed Ia/S.

Table 2. Selected rainfall events and their corresponding characteristics

No.	Date	P (mm)	Q (mm)	D (hr)	Intensity, I (mm/hr)		
					Max	*Ave*	*Min*
1	07/02/2016	29.43	3.854	5.00	16.03	5.61	0.23
2	07/05/2016	55.70	11.767	7.00	46.40	7.70	0.80
3	07/28/2016	40.20	5.716	7.50	15.60	5.20	0.40
4	08/05/2016	30.90	4.683	9.50	8.80	3.20	0.04
5	09/09/2016	27.30	2.946	8.50	13.60	1.70	0.04
6	12/14/2016	45.50	10.034	5.50	30.00	8.80	0.40
7	01/16/2017	38.80	7.776	7.75	31.20	4.90	0.40
8	01/18/2017	57.90	21.327	26.25	14.80	2.20	0.04
9	04/14/2017	32.40	0.561	3.50	32.40	8.60	0.40

10	05/16/2017	24.20	2.108	6.00	21.20	3.90	0.04
11	05/20/2017	36.60	5.603	5.25	24.00	6.70	0.80
12	06/18/2017	22.70	0.604	2.25	33.20	9.10	0.40
13	06/21/2017	21.50	3.796	3.75	26.00	5.40	0.40
14	06/26/2017	24.90	1.886	2.75	24.00	8.30	0.40
15	11/22/2018	28.40	0.949	5.17	35.40	5.50	0.06
16	01/11/2019	23.70	0.470	9.17	7.20	2.60	0.60
17	07/02/2019	39.30	5.704	5.83	28.80	6.60	0.06
18	10/29/2019	24.50	1.960	7.33	17.40	3.30	0.06
19	10/30/2019	23.90	0.453	5.00	39.00	4.60	0.06
20	11/20/2019	27.20	5.363	3.50	25.80	7.40	0.60

For the watershed CN, (Eq. 2) was used and the S value is the median S. The calculated CN for the watershed is 62.3.

3.3. Data Analysis

The mean of the Ia/S dataset is 0.0936, while the median is 0.0302. the significant difference between the mean and median indicates skewness in the dataset and that the values are far from being normally distributed. Since the median value signifies the data distribution better than the mean, it is preferred to represent the watershed Ia/S. Regarding the dispersion, the Ia/S values ranged from 0.0019 to 0.4603 with a standard deviation of 0.1345. These indicators show a relatively high variation in the dataset. There is also a high skewness with a value of +1.8915, which indicates that most of the Ia/S values are low, with only occasional high values. Eighty-five percent (85%) of the total rainfall events have an Ia/S of less than the original NRCS value of 0.20 (see Figure 3). It implies that the resulting Q depths would be underestimated if Ia/S of 0.20 were used to estimate runoff corresponding to those rainfall events.

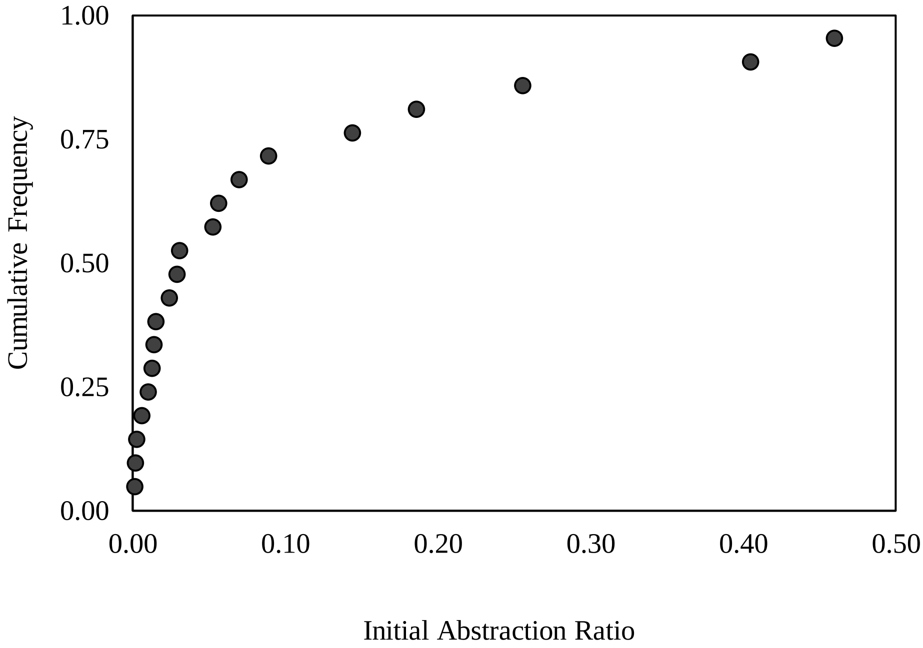

Figure 3. Cumulative frequency distribution of the Ia/S values

SE, R^2, NSE, and PBIAS were evaluated (Table 4) using the observed and estimated runoff values plotted i Figure 4. Qobs is the observed runoff values, Qesti0.03 is the estimated runoff when Ia/S is 0.03 and CN is 62.3, and Qesti0.20 is the estimated runoff when the Ia/S is 0.20 and CN is 75.0 based on the CN tables of the National Engineering Handbook Part 4 Hydrology (NRCS, 2004).

Table 3. Rainfall-runoff data of the upper catchment area of Sawaga River

No.	Date	P (mm)	Q (mm)	Ia (mm)	S (mm)	Ia/S
1	07/02/2016	29.43	3.854	15.83	34.4	0.4603
2	07/05/2016	55.70	11.767	23.20	57.3	0.4051

3	07/28/2016	40.20	5.716	1.40	224.6	0.0062
4	08/05/2016	30.90	4.683	5.80	109.4	0.0530
5	09/09/2016	27.30	2.946	2.00	192.0	0.0104
6	12/14/2016	45.50	10.034	15.40	60.2	0.2558
7	01/16/2017	38.80	7.776	12.10	65.0	0.1862
8	01/18/2017	57.90	21.327	2.20	89.8	0.0245
9	04/14/2017	32.40	0.561	19.60	279.3	0.0702
10	05/16/2017	24.20	2.108	3.00	192.0	0.0156
11	05/20/2017	36.60	5.603	2.50	173.4	0.0144
12	06/18/2017	22.70	0.604	2.00	688.7	0.0029
13	06/21/2017	21.50	3.796	0.20	98.2	0.0020
14	06/26/2017	24.90	1.886	7.80	137.9	0.0565
15	11/22/2018	28.40	0.949	15.20	170.4	0.0892
16	01/11/2019	23.70	0.470	16.20	112.2	0.1444
17	07/02/2019	39.30	5.704	2.60	199.4	0.0130
18	10/29/2019	24.50	1.960	5.10	172.6	0.0295
19	10/30/2019	23.90	0.453	2.00	1036.8	0.0019
20	11/20/2019	27.20	5.363	2.70	87.4	0.0309

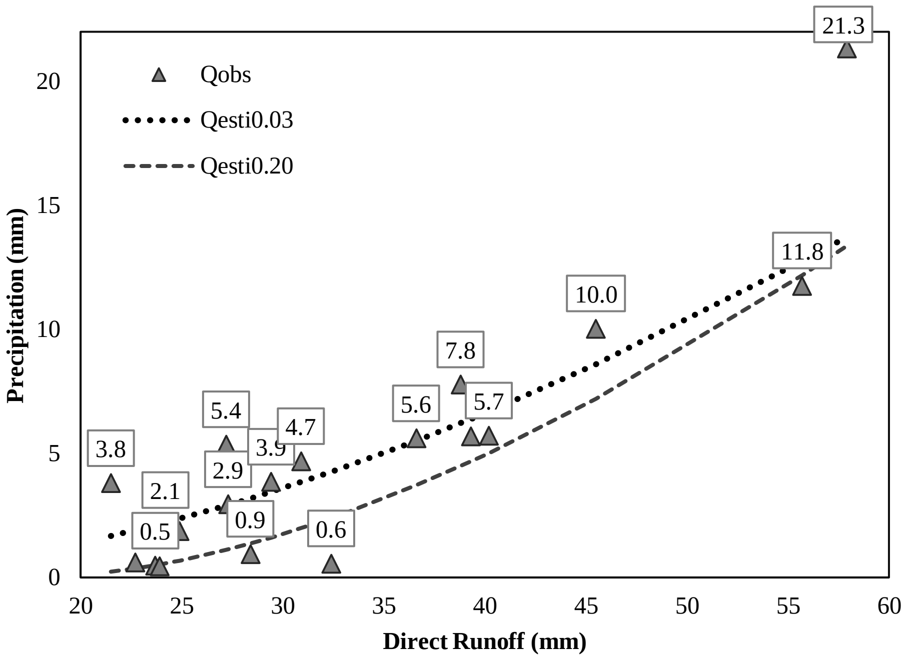

Figure 4. Observed and estimated direct runoffs versus precipitation.

The SE for Qesti0.20 and Qesti0.03 is 2.6760 and 2.2639, respectively. Specifically for SE, a smaller number is ideal. In this case, Qesti0.03 achieved a smaller number than the Qesti 0.20 which implies that Qesti 0.03 is more accurate in predicting the observed values compared to Qesti 0.20. the R2 for the Qesti 0.20 and Qesti 0.03 are 0.8459 and 0.8343, respectively. Both are considered "very good" since they are beyond the 0.50 typical acceptability value (Golmohammadi et al., 4014); however, the original NRCS fits the observed data better than the local. The difference, though, is relatively small. The NSE for Qesti 0.20 and 0.7854, respectively. They are considered good and very good, with the local values having an advantage of 0.0912 over the original NRCS making it more efficient. The PBIAS for Qesti 0.20 and Qesti 0.03 are 36.4201 and 2.6410, respectively. Qesti 0.20 was considered unsatisfactory, while Qesti 0.03 is very good. These imply that the original NRCS parameter values can estimate runoff unsatisfactorily and may return an underestimated runoff Q value. On the other hand, the locally derived parameter values would produce a very good estimate and have a relatively small tendency to overestimate the runoff. Overall, the Ia/S of 0.03 showed a more dominant performance in estimating direct runoff from rainfall than the NRCS-established Ia/S of 0.20 for this local watershed. A summary of the performance metrics is shown in Table 4

Table 4. The goodness of fit and bias of the original NRCS and local values

Method	Range	Performance classification	Values	
			NRCS	Local
SE			2.6760	2.2639
R^2	0.7 – 1.0 0.6 – 0.7 0.5 – 0.6 0.0 – 0.5	Very good Good Satisfactory Unsatisfactory	0.8459 (very good)	0.8343 (very good)
PBIAS	< ±10 ±10 – ±15 ±15 – ±25 > ±25	Very good Good Satisfactory Unsatisfactory	36.4201 (unsatisfactory)	2.6410 (very good)
NSE	> 0.75 0.65 – 0.75 0.50 – 0.65 0.40 – 0.50 < 0.40	Very good Good Satisfactory Acceptable Unsatisfactory	0.6942 (good)	0.7854 (very good)

3.4. Practical Relevance

The result of this work is directly relevant to the study area where the derived values may be used for the runoff estimations and/or calculations for various purposes such as water supply and irrigation. Furthermore, the methods and the algorithm of the study may be used to investigate any watershed where composite CN and Ia/S values are to be determined for estimating the runoff quantity from rainfall of that specific watershed.

4. CONCLUSION

The rainfall-runoff event analysis method was used to compute the Ia/S and CN values for the upper catchment area of the Sawaga River watershed in Bukidnon. The median Ia/S is 0.03, while the corresponding CN is 62.3. After evaluating the performance of the USDA-NRCS curve number method using the locally derived Ia/S and CN parameter values, the SE is 2.2639, the R^2 is 0.8343, the NSE is 0.7854, and the PBIAS is 2.6410. The performance evaluation results for the original NRCS Ia/S and CN parameter values are 2.6760, 0.8459, 0.6942, and 36.4201, respectively. These numbers collectively indicate that the locally derived Ia/S and CN parameter values better predict the direct runoff than that of the original NRCS.

Similarly, the Ia/S and CN values of any watershed in any part of the globe may also be different from that of the original NRCS values, thus, the steps taken in this study may be applied for the determination of the said values of any watershed of interest. By identifying better local parameters (Ia/S of 0.03 and CN of 62.3), the findings lead to better runoff predictions which are crucial for effective flood management and infrastructure planning. This improved accuracy helps in preparing for extreme weather events, thus, reducing potential risks to the community and infrastructure. Additionally, these results can guide policymakers in developing sustainable water management strategies to ensure that resources are allocated efficiently and that environmental impacts are minimized.

5. RECOMMENDATION

Although similarly noted in other studies that there are no solid observable relationships established between different parameters in this method specifically the Ia and S, the assumption of the USDA-NRCS that they are linearly related is still reasonable as it still serves its purpose of minimizing the number of unknown parameters to maintain the method's simplicity. Thus, retaining this assumption while looking for other aspects of the method that can be altered to increase its prediction accuracy would be a good route for further study.

Author Contributions: J.R.P. conceived and designed the analysis, collected the data, performed the analysis, and wrote the manuscript. R. L. F. provided guidance and expertise in the conception, performance, and finalization of the manuscript.

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Data Availability Statement: The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

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Conflicts of Interest: The authors have no conflict of interest to disclose.

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