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Use of Nonofficial Intermittent Waterfall Occurrence Data for the Validation of an Infiltration Model for Volcanic Jeju Island, Korea

Minseok Kang [1] and Chulsang Yoo [2,*]

[1] Hanul Co., Daejeon 34134, Republic of Korea; minseok0517@hanmail.net
[2] School of Civil, Environmental and Architectural Engineering, College of Engineering, Korea University, Seoul 02841, Republic of Korea
* Correspondence: envchul@korea.ac.kr; Tel.: +82-2-3290-3912

Abstract: This study attempts to validate an infiltration model, the Soil Conservation Service–Curve Number (SCS–CN) method, using the nonofficial intermittent occurrence data of Eongtto Falls on Jeju Island, Korea. Simply due to the limited official continuous runoff data concerning Jeju Island, the validation of a newly set SCS-CN method for Jeju Island was practically impossible. Instead, this study tries to use nonofficial data for this purpose. This study focuses on the intermittent occurrence of Eongtto Falls, which is one of the most famous tourist attractions on the island. Various records of Eongtto Falls can be collected from newspapers, personal homepages, and various social networking services. The SCS-CN method is, in this study, used to check if effective rainfall occurs or not. In fact, this approach is quite effective on Jeju Island, as most streams are fully dry during non-rain periods. Evaluation of the SCS-CN method is based on the analysis of a contingency table, which measures the consistency of the occurrence of effective rainfall events and waterfall records. Additionally, to quantify the results of the contingency table, some measures such as accuracy, hit ratio, and false alarm ratio are used. This analysis is carried out using all the rainfall events from 2011 to 2019, and the derived results confirm that the newly set SCS-CN method is far better than the conventional one used thus far.

Keywords: nonofficial data; intermittent data; SCS–CN method; Eongtto Falls; Jeju Island

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1. Introduction

The SCS–CN method, developed by the U.S. Soil Conservation Service [1], has been widely used in Korea for estimating the volume of effective rainfall or direct runoff [2–5]. The main parameter of the SCS–CN method is the curve number (CN), which represents the hydrologic infiltration characteristics of a basin. Additionally, the ratio between the initial abstraction and the maximum potential retention and the criteria for dividing the soil moisture condition are, importantly, also considered in the application of the SCS-CN method [6–8].

Finding a representative value of CN has been a main issue in the application of the SCS-CN method [9–12]. Estimation of CN was especially tricky in a heterogeneous basin [9,13]; the variation in CN depending on the total rainfall amount as well as the soil moisture condition was also evaluated [7,8,14]. Applications of the SCS-CN method to basins with somewhat different characteristics from ordinary basins have also been reported globally. Application of the SCS-CN method may be different in a steep mountain area [15–17], in a dry region [18–20], or in a volcanic area [21–24]. This study is related to this exceptional case, i.e., that of application of the SCS-CN method to the volcanic Jeju Island, Korea.

Recently, Kang and Yoo [2] proposed a somewhat different setup for the application of the Soil Conservation Service–Curve Number (SCS–CN) method to Jeju Island. Based on the analysis of rainfall events observed in the Hanchun basin, Jeju Island, they showed that the application of the conventional approach outlined in the guidelines published by the Ministry of Environment [3] could lead to an overestimation of effective rainfall. Kang and Yoo [2] recommended using a new classification rule for the hydrologic soil group, as proposed by Lee et al. [25]. This new classification rule was found to significantly decrease the CN, compared to previous rules such as those proposed by the Rural Development Administration (RDA) [26]. Additionally, they recommended that 0.3 be considered the ratio between the initial abstraction and the maximum potential retention. More interestingly, the criteria for AMC (antecedent moisture condition) were determined using an antecedent five-day rainfall amount (P5) of 100 mm for the dry condition, and 400 mm for the wet condition.

In comparison with the newly set SCS-CN method by Kang and Yoo [2], the guidelines of the Ministry of Environment [3] are somewhat extraordinary. The guidelines for rainfall runoff analysis in Korea, published by the Ministry of Environment [3], include a section for Jeju Island. Regarding the SCS-CN method, the guidelines recommend using the old classification rule for hydrologic soil groups (developed by the RDA) [26], which provide a rather high CN value. On the other hand, a ratio of 0.4 between the initial abstraction and the maximum potential retention is proposed in order to compromise the large initial abstraction of Jeju Island. Finally, the guidelines recommend no use of the antecedent moisture condition (AMC) for adjusting the CN value. As a result, only the AMC-II condition is applied to any rainfall events, regardless of the soil moisture condition. This also serves to consider a rather low portion of the effective rainfall, regardless of most of the rainfall events being categorized into the AMC-III condition based on the generally accepted criteria for AMC in the inland area of Korea.

As the difference between Kang and Yoo [2] and the Ministry of Environment [3] is so large regarding the application of the SCS-CN method, more application cases are required for their comparison. However, somewhat systematic and continuous runoff measurements applicable to this comparison were not available for Jeju Island. This limited measurement is partly due to the fact that most streams on Jeju Island are dry. Jeju Island is covered in porous basalt, which has a high infiltration capacity [27–29]. The infiltrated water fills the groundwater, most of which flows out near the seashore. That is, the base flow is observed only in the downstream region near the seashore. In the upstream and midstream regions, runoff occurs only when the amount of rainfall is quite large [29,30].

As the upstream and midstream regions of Jeju Island are very steep and stepped, large waterfalls are sometimes formed during heavy rain [31,32]. Among them, the most famous is Eongtto Falls, which is located in the Akgeun stream. The Eongtto Falls waterfall occurs only when the rainfall amount is quite large; the tourist information board explanation is that the waterfall occurs only when the total rainfall amount is greater than 70 mm. No justification for this 70 mm threshold can be found, but the figure is assumed to be based on the long-term experience of the people living around the waterfall. No runoff data are available for the Akgeun stream, either.

The authors could find somewhat different information about the runoff in the Akgeun stream, and there are various records on the occurrence of Eongtto Falls in the Akgeun stream. As it is one of the most popular tourist attractions on Jeju Island, many tourists visit and record Eongtto Falls whenever the falls occur. The sources of these records include newspapers, personal homepages, and various social network services such as Facebook, Twitter, and Instagram. While these records of the waterfall do not cover all the occurrences of the Eongtto Falls, they are valuable for evaluating the application of the SCS–CN method.

The objective of this study is straightforward; it is to compare the newly set SCS-CN method of Kang and Yoo [2] with the conventional method of the Ministry of Environment [2,3] in their application to the occurrence problem of Eongtto Falls. For this objective, this study analyzes rainfall events from 2011 to 2019. In this analysis, the SCS-CN method is used only to check if effective rainfall occurs or not. Comparison of the application results is based the analysis of a contingency table, i.e., only a 'pass' or 'fail' in the prediction of the waterfall's occurrence is considered in the evaluation. The accuracy, hit ratio, and false alarm ratio are used as measures to quantify the results of the contingency table.

2. The SCS–CN Method for Jeju Island

The US Soil Conservation Service (SCS) developed a method to estimate the effective rainfall amount by considering the characteristics of soil, vegetation, and land use [1]. As the characteristics of soil, vegetation, and land use are quantified by the CN, this method is called the SCS–CN method. The CN ranges from 0 to 100, and its value represents the relative likelihood of effective rainfall being produced. That is, a CN of 100 indicates a condition in which the total amount of precipitation is converted into the effective rainfall, while a CN of 0 indicates that no effective rainfall is produced.

The SCS–CN method basically relies on the assumption that the ratio of actual retention to the maximum potential retention is identical to that of the effective rainfall to the total precipitation. Additionally, the initial abstraction was introduced to consider losses through processes such as interception and evapotranspiration. As a result, the effective rainfall is then calculated using the following equation:

$$\begin{aligned} Q &= \frac{(P-I_a)^2}{(P-I_a)+S} && (P > I_a) \\ &= 0 && (P \leq I_a) \end{aligned} \tag{1}$$

where P is the total precipitation (mm), Q is the direct runoff (mm), S is the maximum potential retention (mm), and I_a is the initial abstract (mm). In the above equation, the maximum potential retention is represented by the CN, and the initial abstraction is assumed to be proportional to the maximum potential retention. Although the ratio is generally accepted to be 0.2 [1], various other ratios have also been reported worldwide [33]. It should also be mentioned that the AMC has a significant effect on the CN, and for this purpose, three typical conditions (i.e., dry, normal, and wet) are considered.

As explained in the introduction section, the setup of the SCS–CN method of the Ministry of Environment [3] is very different from that of Kang and Yoo [2]. Kang and Yoo [2] adopt the classification rule for hydrologic soil groups proposed by Lee et al. [21]. They also consider 0.3 to be the ratio between the initial abstraction and maximum potential retention. The criterion for AMC is quite specific; the AMC-I condition should be applied when the antecedent five-day rainfall amount is less than 100 mm, and the AMC-III condition when it is more than 400 mm. On the other hand, the guidelines of the Ministry of Environment [3] recommend the classification rule for hydrologic soil groups developed by the RDA [22]. Their ratio between the initial abstraction and the maximum potential retention is 0.4. Additionally, the guidelines do not recommend the use of the AMC condition. That is, only the AMC-II condition is applied, regardless of the soil moisture condition. The differences between these two methods are summarized in Table 1.

Table 1. Comparison of two SCS-CN methods considered in this study.

	MOE [3]	**Kang and Yoo [2]**
Hydrologic soil group	RDA [26]	Lee et al. [25]
Ratio (initial abstraction/maximum potential retention)	0.4	0.3
AMC	AMC-II	AMC-I (P5 < 100 mm) AMC-II (100 $\leq$ P5 < 400) AMC-III (P5 $\geq$ 400 mm)

3. Study Basin and Data

3.1. Study Basin

The study area in this study is the basin of Eongtto Falls on Jeju Island. Eongtto Falls, located in the mid-stream of the Akgeun stream, is about 50 m high. Akgeun stream is located on the western part of Mount Halla [34]. The basin area of Eongtto Falls is

12.73 km^2, and its channel length is 6.90 km. The shape factor is just 0.26, in order to represent the shape of the basin as a long stripe. Most of the Akgeun stream is dry; however, due to some groundwater elution, some flow is observed near the seashore [35]. Thus, most of the time, Eongtto Falls presents no waterfall. The only exception is during periods of rain in which the rainfall depth is very high. However, the waterfall lasts for only a few hours after the rainfall, even in the case that the rainfall depth is high. In general, yearly, less than 10 occurrences of waterfall are observed at Eongtto Falls. Figure 1 shows the location of Eongtto Falls, and also the location of the automatic weather station (AWS) rain gauges around the basin.

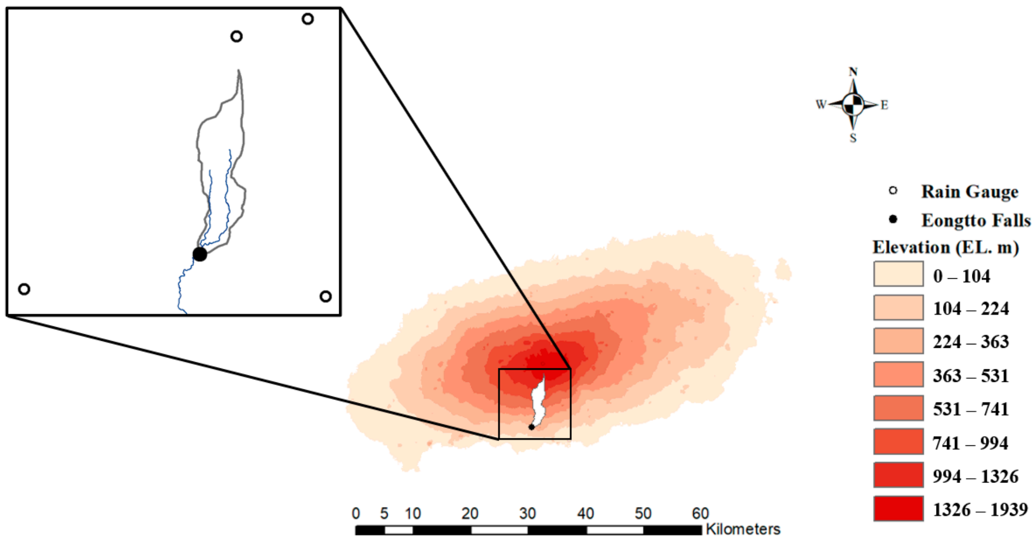


Figure 1. Location of the Eongtto Falls basin on Jeju Island, Korea (the empty circles around the basin represent the rain gauges, and the solid circle the location of the Eongtto Fall).

The basin characteristics of Eongtto Falls are more or less the same as those of other basins on Jeju Island. That is, the soil of the Eongtto Falls basin is mostly basalt, a volcanic rock with high permeability [33]. According to the Jeju Special Self-Governing Province [36], the mean runoff ratio is just 21%, which is far lower than that of the inland mainland area. Most of the basin is mountainous, and covered by trees and shrubs. The coverage of the forest in the Eongtto Falls basin is 95.76%. The coverage of farmland is 2.95%, grassland is 1.05%, urban area is just 0.23%, and bare soil is 0.01%. Information on the soil and land use of the Eongtto Falls basin can be obtained from the Korean Soil Information System (KSIS: http://soil.rda.go.kr/soil/sis/summary.jsp, accessed on 30 September 2020), and the Water Resource Management Information System (WAMIS: http://www.wamis.go.kr/, accessed on 30 September 2020).

In particular, the soil characteristics are used to derive the hydrologic soil group, which is key information used to determine the CN. In this study, two different classification rules were applied: One was the classification rule of the RDA [26], and the other was that of Lee et al. [25]. Figure 2 compares the classified results by applying both rules, while Table 2 summarizes the results. The results are very different, depending on the classification rules that are applied. For example, if applying the RDA [26] rule, soil group A is just 4.38%, soil group C is 95.17%, soil group D is 0.45%, and soil group B is almost non-existent. However, if applying the Lee et al. [25] rule, soil group A is 9.63%, while the overall soil group is 90.37%. Soil groups C and D are found to be almost non-existent. This totally opposite result is unfortunate, and also explains why studies of the volcanic Jeju Island have been limited. When applying the RDA [26] rule, the resulting CN value for Eongtto Falls basin is 77.8; when applying the Lee et al. [25] rule, it is just 66.3.

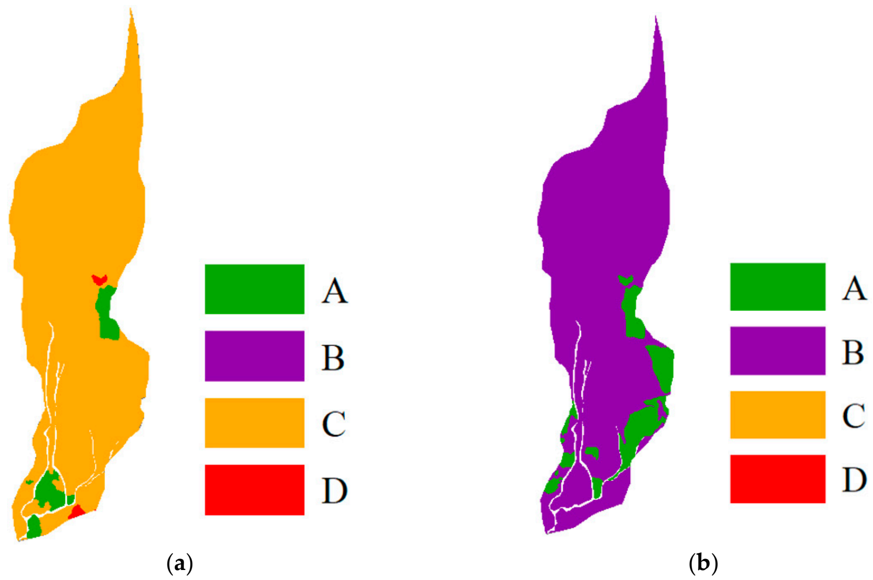


Figure 2. Comparison of spatial distributions of hydrologic soil group over the Eongtto Falls basin depending on the classification rule: (**a**) RDA [26], (**b**) Lee et al. [25].

Table 2. Composition of hydrologic soil groups (%) of the Eongtto Falls basin, classified using RDA [26] and Lee et al. [25].

	A	B	C	D
RDA [26]	4.38	0.00	95.17	0.45
Lee et al. [25]	9.63	90.37	0.00	0.00

3.2. Rainfall Data

This study used the 10 min rainfall data collected by the AWSs near the study basin. As there are no rain gauges available within the study basin, this study considered four AWSs located near the study basin. The areal average rainfall was then estimated by applying the Thiessen polygon method; however, as a result, only two AWSs were found to be relevant to the estimation of the areal average rainfall of the Eongtto Falls basin. These AWSs are located at Seogwipo (gauge #189), near the downstream part of the study basin, and at Witsaeorum (gauge #871), near the upstream part of the basin. The weighting applied to estimate the areal average rainfall for Witsaeorum was 61.9%, and for Seogwipo was 38.1%. Figure 3 shows the derived areal average rainfall, as examples, of the years 2011 and 2019. Obvious seasonality can be seen in this figure. More than 70% of the annual rainfall is concentrated in the wet summer season.

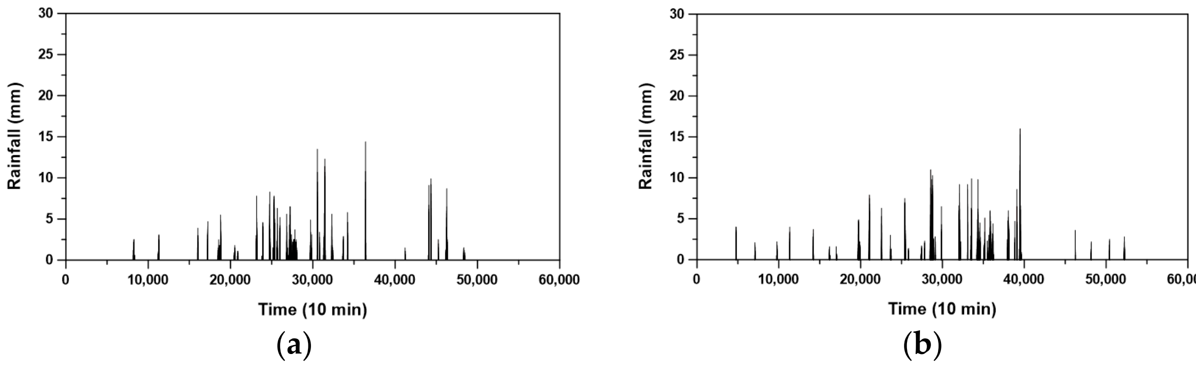


Figure 3. Time series plots of areal average rainfall of the Eongtto Falls basin in the years 2011 (**a**) and 2019 (**b**).

Estimation of the effective rainfall by applying the SCS–CN method was performed on the basis of an independent rainfall event. As an inter-event time definition, 10 h was applied [37]. That is, in the case that the no-rain period between two consecutive rainfall data periods was longer than 10 h, the current rainfall event was assumed to end, and a new rainfall event assumed to begin. As a result, a total of 334 rainfall events were derived, meaning a total of about 37 events per year. The largest number of rainfall events was 45, in 2012, while the smallest was 30, in 2017. The duration of rainfall ranged widely from 80 to 6990 min, i.e., 1.33 to 116.5 h. The mean rainfall duration of rainfall events was 1160 min (19.3 h), the mean rainfall depth was 92.9 mm, the mean rainfall intensity was 4.8 mm/h, and the mean antecedent five-day rainfall was 45.3 mm. Table 3 summarizes the rainfall characteristics of the Eongtto Falls basin.

Table 3. Basic statistics of independent rainfall events observed in the Eongtto Falls basin from 2011 to 2019.

		Duration (min)	**Total Rainfall (mm)**	**Rainfall Intensity (mm/hr)**	**Antecedent 5-Day Rainfall (mm)**
2011	Max.	4220	423.0	15.3	382.5
	Mean	1419	106.4	5.1	66.3
	Min.	250	10.1	0.7	0.0
2019	Max.	4420	861.4	18.8	861.4
	Mean	1153	119.4	5.7	62.0
	Min.	210	11.8	0.7	0.0
All (2011~2019)	Max.	6990	1142.7	32.7	861.4
	Mean	1159	92.9	4.8	45.3
	Min.	80	10.1	0.4	0.0

3.3. Nonofficial Intermittent Occurrence Data of Eongtto Falls

The runoff measurements on Jeju Island have not been intense, and so runoff data for the Eongtto Falls basin are not available. However, as Jeju Island is considered the most famous tourist attraction in Korea, many records on the occurrence of the waterfall at Eongtto Falls can be found. Some of these records include articles in newspapers and on TV news, as well as SMS posts, for example, on personal homepages and Facebook.

A total of 43 waterfall records could be found between 2011 and 2019. Table 4 summarizes the collected waterfall records and their sources. Additionally, Figure 4 shows some photos of Eongtto Falls collected from those sources. Basically, the annual distribution of these records was quite even. That is, five, four, three, six, three, six, three, eight, and five cases could be found per year from 2011 to 2019. As the number of cases was quite steady, without any trend, these case numbers could be assumed to be reliable. However, the authors assume that the number of waterfall occurrences must be much smaller than the number of effective rainfalls. One possible reason is that the amount of effective rainfall could be very small. If the waterfall was small, it might be assumed insignificant to tourists, who then would not try to view the possible waterfall. As a second reason, we might consider the cases in which the waterfall occurred at night. If even though the amount of effective rainfall was large, there was no record of the waterfall, the waterfall may well have occurred at night.

Table 4. Various records of Eongtto Falls occurrences collected in this study.

No	Date	Sources
1	11 May 2011	https://news.naver.com/main/read.nhn?mode=LSD&mid=sec&sid1=102&oid=001&aid=0005057095
2	22 June 2011 (afternoon)	https://blog.naver.com/jjuzzang2007/131565799
3	1 July 2011 (6 pm)	https://blog.naver.com/bush0805/70112506776
4	13 July 2011 (morning)	https://blog.naver.com/yjklso/60136111690
5	18 November 2011	https://blog.naver.com/windwalker81/140146749133
6	23 March 2012 (morning)	https://blog.naver.com/kcg0608/150134767977
7	22 April 2012	http://www.jejudomin.co.kr/news/articleView.html?idxno=31091
8	24 August 2012 (afternoon)	https://blog.naver.com/shinhide/120167615845
9	28 August 2012 (afternoon)	https://cafe.naver.com/fanworldgo/541599
10	18 March 2013 (afternoon)	https://news.naver.com/main/read.nhn?mode=LSD&mid=sec&sid1=102&oid=003&aid=0005035851
11	28 May 2013 (afternoon)	https://blog.naver.com/goodnongbu/90174174580
12	25 August 2013	https://newsis.com/pict_detail/view.html?pict_id=NISI20130825_0008570043
13	28 April 2014	http://www.ihalla.com/read.php3?aid=1398697200461791044
14	12 May 2014 (morning)	https://blog.naver.com/stardom7682/209777561
15	6 July 2014 (morning)	https://blog.naver.com/bl0745/220052153067
16	2 August 2014	https://news.naver.com/main/read.nhn?mode=LSD&mid=sec&sid1=102&oid=001&aid=0007048320
17	20 August 2014	https://cafe.naver.com/curiouspeople/499
18	24 August 2014 (morning)	https://blog.naver.com/cnv799444/220102170580
19	30 June 2015 (morning)	https://blog.naver.com/mugigo04/220423783178
20	1 October 2015 (morning)	https://cafe.naver.com/seogwipoguesthouse2/36634
21	13 November 2015 (afternoon)	https://cafe.naver.com/buba/79906
22	13 February 2016 (afternoon)	https://blog.naver.com/ilovebr1/220633470048
23	6 March 2016 (morning)	http://m.news.zum.com/articles/29170606
24	17 April 2016 (afternoon)	https://blog.naver.com/suntotoroo/220686036610
25	3 May 2016	http://www.ihalla.com/read.php3?aid=1462287600535727059
26	22 June 2016 (afternoon)	https://blog.naver.com/jhchae92/220747448269
27	13 July 2016	https://www.news1.kr/photos/view/?2028656
28	22 February 2017 (afternoon)	https://blog.naver.com/neonadeuli72/220942226936
29	6 April 2017	https://www.news1.kr/photos/view/?2470991
30	2 October 2017 (morning)	https://blog.naver.com/hoo5343/221109603048
31	23 April 2018	http://www.jejudomin.co.kr/news/articleView.html?idxno=99839
32	7 May 2018 (afternoon)	https://blog.naver.com/njchoon/221270105402
33	30 June 2018	https://www.fnnews.com/news/201806301715311101
34	4 July 2018 (morning)	https://blog.naver.com/king89win/221312321985
35	1 September 2018 (afternoon)	https://cafe.naver.com/jejumam/499663
36	3 September 2018	http://www.jejunews.com/news/articleView.html?idxno=2120833
37	13 September 2018 (afternoon)	https://cafe.naver.com/jejutip/1555443
38	6 October 2018	https://blog.naver.com/9443psh/221379255982
39	19 May 2019	http://www.jejuilbo.net/news/articleView.html?idxno=121199
40	27 May 2019 (afternoon)	https://cafe.naver.com/jejutip/1640067
41	18 July 2019,	http://www.ihalla.com/read.php3?aid=1563462000635416059
42	27 August 2019 (afternoon)	http://blog.naver.com/chonmail/221630430545
43	7 September 2019 (afternoon)	https://blog.naver.com/100500jin/221641868980

(**a**) No. 3 (**b**) No. 6
(**c**) No. 9 (**d**) No. 14
(**e**) No. 32 (**f**) No. 37

Figure 4. Several pictures of Eongtto Falls occurrences collected in this study (the numbers are the event numbers in Table 4).

4. Results and Discussion

4.1. Comparison of Effective Rainfall

This study derived the effective rainfall by applying the two different setups, one from Kang and Yoo [2] (Case 1), and the other from the guidelines of the Ministry of Environment (Case 2). The differences between these two cases can also be found in Table 1. As a result, the maximum potential retention and the initial abstraction could be derived for the two different setups of the SCS–CN method that were considered in this study (see Table 5). Due to the difference in CN and AMC consideration, the initial abstraction under the AMC-I condition of Kang and Yoo [2] reached up to 92.2 mm; however, when applying the guidelines from the Ministry of Environment [3], it reached just 29.0 mm. All of the rainfall events observed between 2011 and 2019 were considered in this part of the study. For reference, based on the AMC criteria of Kang and Yoo [2], most of the rainfall events were categorized into the AMC-I condition. That is, a total of 284 events among 334 events were categorized as the AMC-I condition, 45 events as the AMC-II condition, and just 5 events as the AMC-III condition.

Table 5. Comparison of initial abstractions, depending on the method and conditions applied.

Method	AMC	CN	Max. Potential Retention (mm)	Ratio	Initial Abstraction (mm)
Case 2: MOE [3]	II	77.8	72.5	0.4	29.0
Case 1: Kang and Yoo [2]	I	45.2	307.4	0.3	92.2
	II	66.3	129.1		38.7
	III	81.9	56.1		16.8

Due to the setups of the SCS–CN method, the resulting numbers of effective rainfall events were also very different. For example, when the setup of Kang and Yoo [2] was applied (Case 1), the number of effective rainfall events was just 104; however, when the guideline of the Ministry of Environment was applied (Case 2), this number increased to 220. The number of effective rainfall events for Case 1 was just one third of the total rainfall events, while for Case 2, it was roughly two thirds. This obvious difference was mainly due to the difference in the consideration of the AMC. In particular, those rainfall events in the AMC-I category in Case 1 produced some effective rainfall, as only the AMC-II condition was applied in Case 2. Additionally, those small rainfall events in the AMC-II category produced some effective rainfall, as a higher CN was applied in Case 2. As mentioned earlier, this is because in Case 2, a different classification rule (that of the RDA [26]) was considered. Due to this difference in the number of effective rainfall events, the basic characteristics of the effective rainfall events were estimated to be quite different. For example, in Case 1, the mean values were generally found to be higher, but in Case 2, the maximum values were found to be higher. Table 6 summarizes these characteristics.

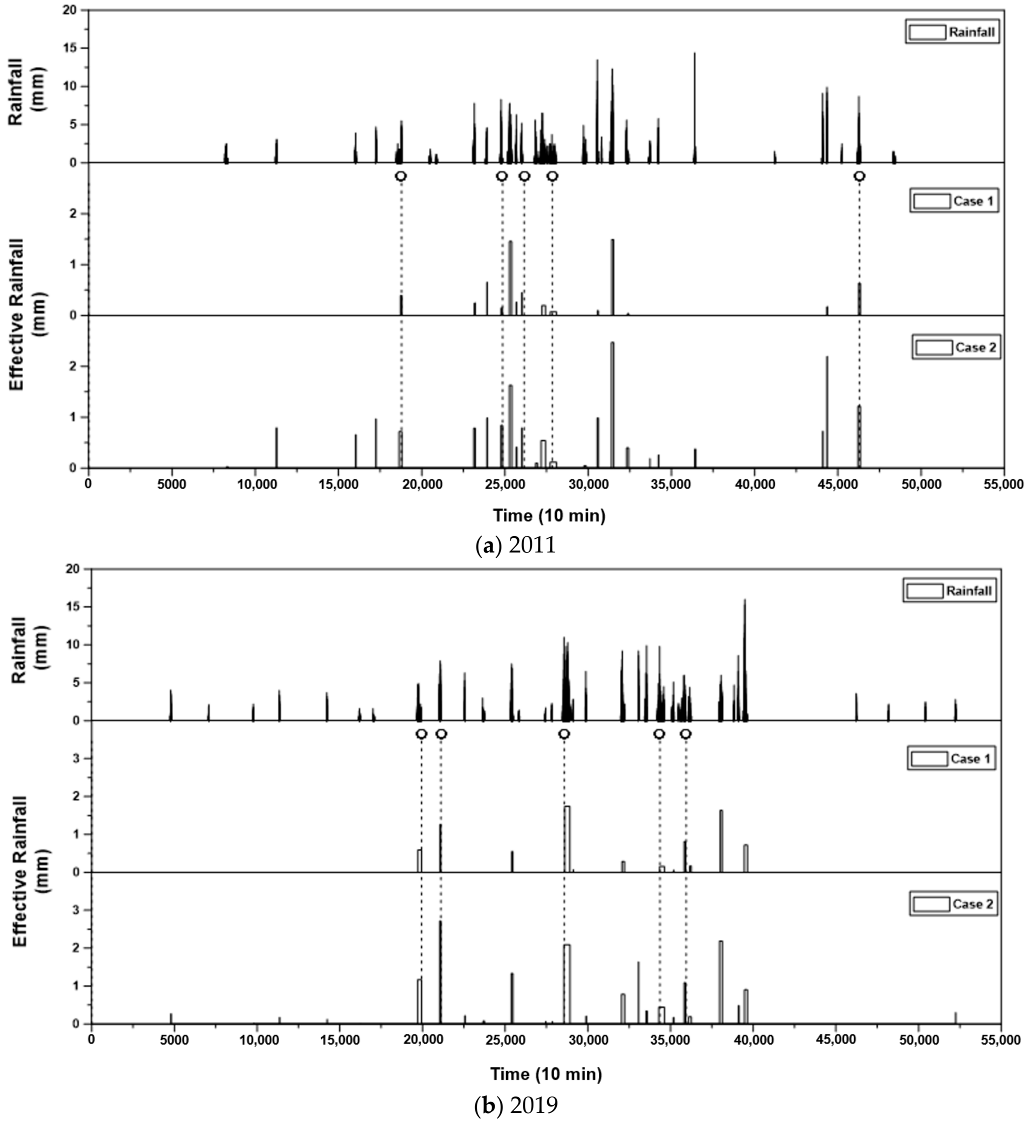
Table 6. Estimation results of effective rainfall for Case 1 and Case 2.

		Case 1			Case 2		
		Duration (min)	Total Effective Rainfall (mm)	Mean Intensity (mm/10 min)	Duration (min)	Total Effective Rainfall (mm)	Mean Intensity (mm/10 min)
2011	Max.	3760	206.3	1.49	3860	332.8	2.47
	Mean	974	43.6	0.45	974	67.4	0.76
	Min.	110	1.9	0.03	60	1.1	0.03
2019	Max.	3160	549.6	1.74	3670	765.8	2.72
	Mean	1391	109.4	0.67	944	98.3	0.68
	Min.	120	0.8	0.06	50	0.3	0.07
All (2011~2019)	Max.	3890	812.7	5.12	5860	1046.0	7.26
	Mean	964	83.6	0.63	819	71.9	0.65
	Min.	60	0.1	0.00	40	0.1	0.01

4.2. Comparison of Waterfall Occurrences

It is obvious that when applying different setups of the SCS–CN method, different effective rainfall values are derived. In this study, two different setups were considered to derive the effective rainfall in the Eongtto Falls basin on Jeju Island. If runoff measurements had been made during the data period of this study, the evaluation of the derived effective rainfall might have be straightforward. Unfortunately, runoff measurements from the Eongtto Falls basin were not available; however, a total of 43 waterfall records could be found between 2011 and 2019.

In fact, these records are far smaller than the number of effective rainfall events derived in Case 1, as well as in Case 2. However, as the number of waterfall records was very small, the occurrence of effective rainfall events did not always correspond with the waterfall records. Particularly, for Case 1, there were five mismatching cases (one in each year for 2012, 2014, 2015, 2016, and 2017). However, for Case 2, there were no exceptions. That is, when the effective rainfall was positively estimated, all the waterfall records were produced. Figure 5 compares the occurrence of the effective rainfall events and waterfall records, as examples, in the years 2011 and 2019. The waterfall records are represented by empty circles in the time series plot of the effective rainfall events.



(**a**) 2011

(**b**) 2019

Figure 5. Comparison of estimated effective rainfall and the occurrence of Eongtto Falls in the years of 2011 and 2019 (the empty circle represents the time at which the occurrence of waterfall was recorded).

The consistency of the occurrence of effective rainfall events and the corresponding waterfall records was evaluated using a contingency table. Additionally, to quantify the results of the contingency table, the measures of accuracy, hit ratio, and false alarm ratio were used. Table 7 summarizes the definitions of those measures used in this study.

Table 7. Measures used for evaluating the contingency table (where TP represents the number of correct predictions of occurrence, TN the number of correct predictions of non-occurrence, FP the number of false predictions of occurrence, and FN the number of false predictions of non-occurrence).

	Equation	Remarks
Accuracy	$\frac{TP+TN}{TP+FP+FN+TN}$	Overall ratio of correct predictions
Hit Ratio	$\frac{TP}{TP+FN}$	Ratio of correct predictions among all occurrences
False Alarm Ratio	$\frac{FP}{FP+TN}$	Ratio of false predictions among all non-occurrences

Table 8 summarizes the evaluation results produced by the mentioned accuracy measures, based on the contingency tables derived every year. Due to the differences between the parameter sets applied, some measures may be controversial when compared with the others. For example, the hit ratio for Case 1 was estimated to be just 0.88, but for Case 2, it was 1.0. On the other hand, the false alarm ratio for Case 1 was 0.23, while that for Case 2 was higher, at 0.61. As a more comprehensive measure, the accuracy for Case 1 was 0.79, but that for Case 2 was just 0.47. Overall, it was evident that Case 1 showed more accurate results than Case 2. However, to verify the reason for this result, the five mismatching cases should be explained in more detail.

Table 8. Comparison of accuracy measures for the application results of Case 1 [2] and Case 2 [3] in Table 5.

Year	Accuracy		Hit Ratio		False Alarm Ratio	
	Case 1	Case 2	Case 1	Case 2	Case 1	Case 2
2011	0.71	0.39	1.00	1.00	0.35	0.73
2012	0.89	0.49	0.75	1.00	0.10	0.56
2013	0.78	0.53	1.00	1.00	0.24	0.52
2014	0.82	0.56	0.83	1.00	0.18	0.52
2015	0.74	0.33	0.67	1.00	0.26	0.72
2016	0.67	0.44	0.83	1.00	0.35	0.65
2017	0.93	0.63	0.67	1.00	0.04	0.41
2018	0.76	0.46	1.00	1.00	0.31	0.69
2019	0.80	0.43	1.00	1.00	0.23	0.67
All	0.79	0.47	0.88	1.00	0.23	0.61

The first mismatching event occurred on 22 March 2012. The total rainfall was 93.0 mm, and the antecedent five-day rainfall amount was just 1.8 mm. As the soil was dry (to meet the AMC-1 condition_, when Case 1 was applied, the effective rainfall was estimated to be zero. On the other hand, as Case 2 did not consider the AMC condition, CN(II) was simply applied, resulting in a positive effective rainfall amount of about 30 mm. Unfortunately, the real waterfall was reported to contradict the hydrological condition, which indicates that effective rainfall occurred, even though its amount was small. A possible reason for the occurrence of this effective rainfall might be the spatial distribution of the storm. That is, the rainfall intensity around the storm center must be notably high. Even though the total rainfall amount is not significant, a localized storm event could produce this effective rainfall. In fact, this explanation could be confirmed by comparing the rainfall data. Simply put, the rainfall intensity measured at one rain gauge station (in this case, at Witsaeorum (gauge #871)) was much higher than that measured at other rain gauge stations.

Other events that occurred in 2014, 2015, 2016, and 2017 were also similar to the event in 2012. The total rainfall amounts were all less than 100 mm (i.e., 93.9, 91.6, 94.6, and 84.9 mm, respectively), while the antecedent five-day rainfall amounts were also all smaller than 100 mm, for inclusion in the AMC-I condition for Case 1 (i.e., 0.0, 39.7, 54.2, and 2.7 mm, respectively). Interestingly, these rainfall events were all located near the boundary of the effective rainfall occurring or not. As a result, these rainfall events might have resulted in the effective rainfall occurring locally; they could also have generated a small waterfall when the storm was small but intense. There were also several other events with a similar total rainfall amount, under the AMC-II or AMC-III condition; however, they were all found to result in effective rainfall, even though Case 1 was applied.

4.3. On the Waterfall Occurrence Guidelines (the Total Rainfall Amount of 70 mm) of Eongtto Falls

This study also evaluated the criterion accepted as a general guideline of the waterfall of Eongtto Falls, i.e., the total rainfall amount of 70 mm, or simply the initial abstraction of 70 mm. Table 9 shows the contingency table derived by applying this simple condition; this was also compared with those of two cases with different setups of the SCS–CN method. Table 9 shows that the application of the initial abstraction of 70 mm was found to produce very good results.

Table 9. Contingency table derived by applying the general guideline (a total rainfall amount of 70 mm) for the occurrence of Eongtto Falls across an entire year, from 2011 to 2019.

		Effective Rainfall	
		Y	N
Waterfall	Y	41	2
	N	80	211

The total number of events with positive effective rainfall (that is, a total rainfall amount higher than 70 mm) was 121, which was a bit higher than Case 1 (i.e., 104), but far smaller than Case 2 (i.e., 220). When considering only those events with waterfall reported, the criterion of 70 mm was met in 41 events (higher than the 38 events of Case 1) among a total of 43 events. That is, the hit ratio based on analysis of the contingency table was estimated to be 0.95, which was a bit higher than Case 1 (i.e., 0.88), but a bit smaller than Case 2 (i.e., 1.0). The false alarm ratio was also estimated to be just 0.27, a bit higher than Case 1 (i.e., 0.23), but much smaller than Case 2 (i.e., 0.61). Finally, the accuracy was estimated to be good, at 0.75, a bit less than the 0.79 of Case 1, but much higher than the 0.47 of Case 2. This result indicates that the criterion of 70 mm, determined empirically by the residents living around the falls, was proven to be quite accurate and reasonable. In fact, this amount was also found to be more consistent with the initial abstraction of the newly set SCS CN method.

4.4. Parameter Sensitivity of the SCS–CN Method in the Estimation of Effective Rainfall

It is obvious that by applying different setups of the SCS–CN method, different effective rainfall values can be derived. This study performed a simple analysis of the sensitivity of the parameters of the SCS–CN method in the estimation of effective rainfall. The purpose of this sensitivity analysis was to find the most sensitive parameter for the estimation of effective rainfall. Among the parameters of the SCS–CN method, the following parameters were selected for evaluation: the classification rule of the hydrologic soil group, the ratio applied to estimate the initial abstraction, and the AMC. Among them, the classification rule of the hydrologic soil group is in line with the estimation of the CN.

As only two setups (i.e., parameter sets) of the SCS–CN method were compared in this study, new setups were also derived by combining the two. Table 10 summarizes the setups to be considered in the sensitivity analysis. Among them, Case 1 is the setup by Kang and Yoo [2], and Case 2 the setup from the guidelines of the Ministry of Environment [3]. Case 1 was used as the base condition. Cases 3 and 4 may be assumed to be opposite combinations of the parameters of Kang and Yoo [2] and the Ministry of Environment [3]. That is, Case 3 used Lee et al. [25]'s classification rule for hydrologic soil groups, and the ratio applied to the initial abstraction, but the Ministry of Environment [3]'s AMC. On the other hand, Case 4 considered the RDA [26]'s classification rule, but Kang and Yoo [2]'s ratio applied to the initial abstraction, and their AMC. Although it was possible to separate the ratios applied to the initial abstraction and the AMC, this was not considered, as they are closely dependent on each other to derive the effective rainfall. On the other hand, the curve number should be pre-determined using soil, vegetation, and land use information before deriving the effective rainfall.

Table 10. Four cases used for the analysis of the sensitivity of SCS-CN parameters in the estimation of effective rainfall.

	Classification Rules of Hydrologic Soil Groups	Ratio for Initial Abstraction	AMC
Case 1 (Kang and Yoo [2])	Lee et al. [25]	0.3	AMC-I (P5 < 100 mm) AMC-II (100 ≤ P5 < 400) AMC-III (P5 ≥ 400 mm)
Case 2 (MOE, [3])	RDA [26]	0.4	AMC-II Only
Case 3	Same as Case 1	Same as Case 2	Same as Case 2
Case 4	Same as Case 2	Same as Case 1	Same as Case 1

The sensitivity of the setup (i.e., the parameter set) of the SCS–CN method in effective rainfall estimation was evaluated using the same rainfall data used in previous sections. The number of occurrences of effective rainfall was then used for comparison. Figure 6 shows these comparison results from 2011 to 2019. Basically, the number of occurrences for Case 3 is higher than that for Case 1, while that for Case 4 is higher than that for Case 3. In particular, the gap between Cases 1 and 3 was found to be greater than that between Cases 3 and 4. That is, the number of occurrences of effective rainfall during the entire period of Case 1 was just 104, but for Case 3, then number increased to 149, and for Case 4 to 158. In simple terms, the effect of the classification rule for the hydrologic soil groups was found to be much more significant than that of the other two parameters. However, it is also important to remember that when applying the parameter set of the Ministry of Environment [2], the number of occurrences of effective rainfall was 220. Use of both misleading parameters may result in totally different estimates of effective rainfall.

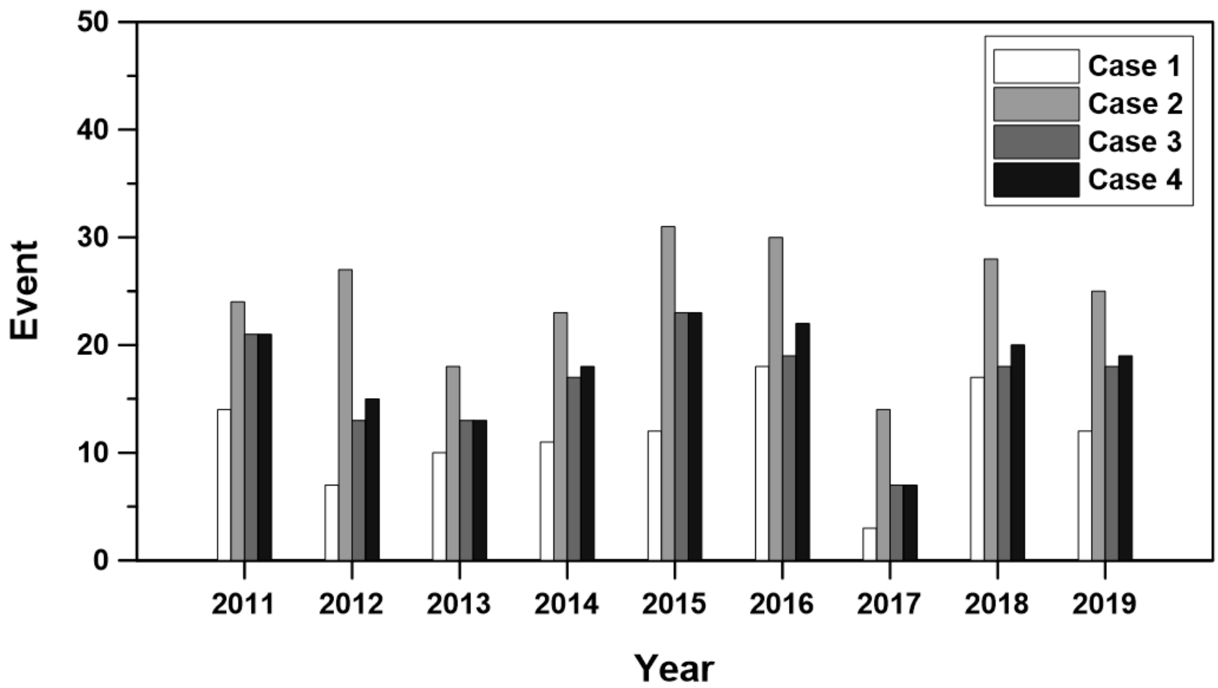


Figure 6. Comparison of the numbers of positive effective rainfall events derived by applying the four different cases shown in Table 10.

Analysis of the contingency table also confirms the above result. Table 11 summarizes the results, using several accuracy measures, of evaluating the contingency tables, comparing the occurrence of effective rainfall and the waterfall record. The overall results are similar to those of the comparison of Cases 1 and 2 in the previous section. That is, the hit ratio for Case 1 was just 0.88, but for the other three cases, it was 1.0. When considering the other measure, the false alarm ratio, the exact opposite trend was found. That is, the false alarm ratio for Case 1 was estimated to be just 0.23, but for Cases 2, 3, and 4, it was 0.61, 0.36, and 0.40, respectively. Finally, as a more comprehensive measure, the accuracy for Case 1 was estimated to be 0.79, but for Cases 2, 3, and 4, it was just 0.47, 0.68, and 0.66, respectively. As can be seen in this result, Case 3 was found to be much more effective than Case 4. This means that the use of proper classification rules for hydrologic soil groups is more important than the other parameters, such as the ratio for determining the initial abstraction, and the criteria for AMC conditions.

Table 11. Comparison of evaluation measures derived from the contingency tables of the four cases considered in this study.

Measures	Case 1	Case 2	Case 3	Case 4
Accuracy	0.79	0.47	0.68	0.66
Hit Ratio	0.88	1.00	1.00	1.00
False Alarm Ratio	0.23	0.61	0.36	0.40

5. Summary and Conclusions

Due to the limited official runoff data from Jeju Island, Korea, the validation of a newly set SCS-CN method for Jeju Island was practically impossible. Instead, this study used nonofficial data on the intermittent occurrence of Eongtto Falls, which is one of the famous tourist attractions on the island. Various records of the occurrence of Eongtto Falls could be found in newspapers, personal homepages, and on various social network services. In this study, the SCS-CN method was used to check if effective rainfall had occurred or not. This approach was especially effective in the case of Jeju Island, as most streams are fully dry during non-raining periods. This study analyzed all the rainfall events from 2011 to 2019. Evaluation of the application results was based on the analysis of a contingency table, which only considered the consistency of the occurrence of effective rainfall events and waterfall records.

This analysis was carried out using two different setups of the SCS-CN method. One was based on Kang and Yoo [2], while the other was based on the conventional method in the guidelines of the Ministry of Environment [3]. Simply comparing the two methods, first, Kang and Yoo [2] used a new classification rule for hydrologic soil groups, as proposed by Lee et al. [25], to consider the large infiltration capacity of the basalt soil of the volcanic Jeju Island. Compared to the previous rule from the RDA [26], this new classification rule was found to decrease the CN significantly. Additionally, Kang and Yoo [2] determined the ratio between the initial abstraction and the maximum potential retention to be 0.3. Finally, the criteria for AMC were an antecedent five-day rainfall amount of 100 mm for the dry condition, and 400 mm for the wet condition. On the other hand, the parameters from the guidelines published by the Ministry of Environment [3] are quite different. That is, the classification rule for the hydrologic soil groups developed by the RDA [26] is recommended. A 0.4 ratio of initial abstraction is recommended, and finally, the guidelines of the Ministry of Environment do not recommend the use of the AMC condition.

The results derived are as follows. First, due to the different setup of the SCS–CN method, the resulting numbers of effective rainfall events were also very different. For example, when the setup of Kang and Yoo [2] was applied (Case 1), the number of effective rainfall events was just 104; however, when the guidelines of the Ministry of Environment were applied (Case 2), that number was increased to 220. For Case 1, the number of effective rainfall events was just one third of the total rainfall events, but for Case 2, it was roughly two thirds. This obvious difference was mainly due to the difference in the consideration of the AMC.

Second, the contingency table was used to evaluate the consistency of the occurrence of effective rainfall events and the waterfall records. Additionally, to quantify the results of the contingency table, the measures of accuracy, hit ratio, and false alarm ratio were used. For example, for Case 1, the hit ratio was estimated to be just 0.88, but for Case 2, it was 1.0. On the other hand, for Case 1, the false alarm ratio was 0.23, but for Case 2, it was high, at 0.61. For Case 1, a more comprehensive measure, the accuracy, was 0.79, but for Case 2, was just 0.47. Overall, it was obvious that Case 1 showed more accurate results than Case 2.

Third, this study evaluated the criterion generally accepted as the guideline for the waterfall of Eongtto Falls to appear, i.e., a total rainfall amount of 70 mm. The contingency table was derived by applying this simple condition, and was also compared with those of two cases with different setups of the SCS–CN method. The table showed that the application of this simple guideline (a total rainfall amount of 70 mm or simply an initial abstraction of 70 mm) was found to produce very good results. The total number of events with positive effective rainfall (that is, a total rainfall amount higher than 70 mm) was 121, which was a bit higher than Case 1 (i.e., 104), and far smaller than Case 2 (i.e., 220). When considering only those events with a waterfall reported, among the total of 43 events, this simple threshold was met in 41 events (higher than the 38 events of Case 1). The false alarm ratio was also just 0.27, a bit higher than that of Case 1 (i.e., 0.23), but much smaller than Case 2 (i.e., 0.61). This result indicates that the criterion of 70 mm as the total rainfall amount or the initial abstraction, which was determined empirically by the residents living around the waterfall, was proven to be quite accurate and reasonable.

Finally, this study performed a simple sensitivity analysis of the parameters of the SCS–CN method in estimating effective rainfall. The purpose of this sensitivity analysis was to find the most sensitive parameter for the estimation of effective rainfall. As a result, among the parameters of the SCS–CN method (the classification rule of the hydrologic soil groups, the ratio applied to estimate the initial abstraction, and the AMC), the classification rule of the hydrologic soil groups was found to be the dominant factor in reasonably determining the amount of effective rainfall.

The above results show that the setup proposed by Kang and Yoo [2] is much better than that recommended in the guidelines published by the Ministry of Environment [3]. Additionally, very interestingly, this study confirmed that the criterion of 70 mm as the initial abstraction, which was empirically determined by the residents living around Eongtto Falls, is quite accurate and reasonable.

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