Pol. J. Environ. Stud. Vol. 21, No. 5 (2012), 1191-1202

Original Research

Runoff Estimation in Steep Slope Watershed with Standard and Slope-Adjusted Curve Number Methods

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Received: 8 May 2011
Accepted: 11 April 2012

Abstract

The objective of this study was to evaluate the applicability of the standard and slope-adjusted NRCS-CN methods in estimating runoff depth in a steep slope watershed. The study was carried out in the Kardeh watershed, northeastern Iran. The CN method was followed to estimate runoff depth for selected storm events. The effects of slope on CN values and runoff depth were determined using a slope-adjusted CN equation. Positive correlation was found between estimated and observed runoff depths ($r = 0.56$, $P < 0.01$). About 9 and 6% of the estimated and slope-adjusted runoff values were within ±10% of the recorded values, respectively. In addition, about 43 and 37% of the estimated and slope-adjusted values differed with recorded values by more than ±50% error, respectively. While the slope-adjusted CN equation appeared to be inappropriate for runoff estimation in steep slope watershed, the standard CN method can be used with 55% accuracy in such watersheds.

Keywords: geographic information system, Kardeh watershed, slope-adjusted runoff depth, Iran

Introduction

There are several approaches to estimate watershed runoff rate, including the University of British Columbia Watershed Model (UBCWM), artificial neural network (ANN), Soil Conservation Service Curve Number Model (SCS-CN), and geomorphological instantaneous unit hydrograph (GIUH) [1]. Among these methods, the SCS-CN method (now called Natural Resources Conservation Service Curve Number Method (NRCS-CN)) is widely used for runoff estimation because of its flexibility and simplicity [2]. The method combines watershed parameters and climatic factors in one entity called the curve number (CN).

However, NRCS-CN does not take into account the effect of slope on runoff generation because cultivated land in general has slopes of less than 5% in the United States, and this range does not influence the CN value to any great extent. However, under conditions in Iran, for example, slopes vary much more in many cultivated land areas and watersheds. Therefore, the land slope is an important factor determining water movement within the landscape in such areas. Except for the minimum depth of runoff; all other runoff-related variables (e.g. number of runoff events, runoff depth, and mean CN value) increase with slope [2]. Investigations on experimental runoff plots have shown that steep slope plots yield considerably more runoff than lower ones [3]. An increase in surface runoff due to steeper slopes can be explained by reduction of the initial abstrac-

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tion, decrease in infiltration rate, and reduction of the recession time of overland flow [4]. Sprenger's study [5] on SCS-CN application in East Africa showed that in sloping land the standard CN method could not be applied.

Very few attempts have been made to include a slope factor in the CN method, although slope has strong influence on runoff volume. Those studies, which had taken the slope factor into account, were notable [4, 6]. In China, Huang et al. [4] studied the effect of slope on runoff under simulated rainfall for 11 years in order to modify the existing standard NRCS-CN method for land slope. They developed a slope-adjusted CN equation (equation 1) as follows:

$$CN_{2\alpha} = CN_2 \frac{322.79 + 15.63(\alpha)}{\alpha + 3.23.52} \quad (1)$$

...where CN_2 is SCS handbook CN value, $CN_{2\alpha}$ is adjusted CN for a given slope, and α is slope ($m \cdot m^{-1}$) between 0.14 and 1.4 (14-140%). This equation appears to be the most appropriate for runoff prediction in the steep areas [4].

Many researchers [2, 7-9] have utilized the standard CN method along with a geographic information system (GIS) to estimate runoff curve number throughout the world. In India, Pandey and Sahu [7] pointed out that land use/land cover is an important parameter of the SCS-CN model. Nayak and Jaiswal [8] found that there was good correlation between the recorded and estimated runoff depths using CN and GIS. They concluded that GIS is an efficient tool for the preparation of most of the input data required by SCS-CN. Akhondi [10] pointed out that correlation between observed and estimated discharge using the CN method is decreased by increasing watershed area.

While having runoff data is essential in all watershed development and management plans, very little work has been done for surface runoff estimation using the standard CN method in steep slope watersheds. Furthermore, no study reported the use of mentioned slope-adjusted CN equations [4] in other steep slope areas for estimating runoff rate. Therefore, the objective of this study was to evaluate the use of the standard NRCS-CN, the slope-adjusted CN equation, and GIS to develop a database containing all the information of the study watershed for direct runoff depth estimation in a watershed with steep slopes.

Materials and Methods

Study Area

This study was conducted in the Kardeh watershed about 42 km north of Mashhad, in Khorasan Razavi province, northeastern Iran (Fig. 1). The watershed, with a total area of 448.2 km², lies between 59º26'3″ to 59º37′17″ E longitude and 36º37′17″ to 36º58′25″ N latitude. The elevation of the watershed ranges from 1,320 to 2,960 m above mean sea level. The climate of the watershed is semi-arid. The mean annual precipitation and temperature are 296.4 mm and 11.6ºC. The mean relative humidity is approximately 52.6%, but varies from 32.1% in August to 82.3% in February.

In most parts of the Kardeh watershed, topsoil is loamy and the subsoil is sandy clay loamy except in alluvial deposits that have a relatively heavy texture of clay. In barren areas where soil is shallow (less than 10 cm depth), fine platy structure surface soil and compressed blocky structure subsurface soil are found. About 73% of Kardeh is occupied by rangelands. The major land uses in the study watershed are shown in Fig. 2 and Table 1. The watershed is instrumented with three recording rain gauges, two storage rain gauges, two hydrometric stations and two evaporation stations (Fig. 3).

Data Sources

Topographic maps of 1:25,000 scale [11], a land use/cover map [12], and a soil map [13] were used for demarcation of study watershed border, identification of type and area of land use classes, and extracting soil information, respectively. Rainfall, evaporation, and temperature obtained from [14] were used to determine the climatic condition of the watershed. Recorded rainfall and runoff data (1990-2000) were used for calculation of model input parameters [14]. Arc View version 3.3 GIS software was used for creating, managing, and generating different layers and maps.

Fig. 1. Location of the studied watershed in Iran.

Table 1. Land use/cover classes present in the Kardeh watershed [12].

Land use/Land cover	Area (km^2)	% of total area
Dry farmland (rainfed farming)	66.90	15
Forest with thin cover	25.50	5.7
Forest with fair cover	5.20	1.2
Rangeland in good condition	32.80	7.3
Rangeland in fair condition	92.70	20.7
Rangeland in poor condition	204.40	45.5
Orchards and irrigation farmland	17.40	3.9
Settlement	0.28	0.1
Rocks	2.90	0.6
Total area	448.20	100

Generating Hydrologic Soil Group and CN Maps with GIS

GIS as a helpful tool employed to generate input parameters in the NRCS-CN method. The hydrologic soil group (HSG) is an attribute of the soil mapping unit (each soil mapping unit is assigned a particular hydrologic soil group: A, B, C, or D). In the preparation of the hydrologic soil group map, a digital text file of soil data was prepared to assign the soil data layers based on soil mapping unit. Spatial Analyst and XTools extensions of Arc View were applied for map preparation. The soil surveys from NRCS, which provide a list of soil types and corresponding hydrologic soil groups, were used. The generated map contains individual polygons of the characterized hydrologic soil group.

To create the CN map, the hydrologic soil group and land use maps were uploaded to the Arc View platform. The Xtools extension of Arc View was used to generate the CN map. The hydrologic soil group field from the soil theme and the land use field from the land use map were selected for intersection. After intersection, a map with new polygons representing the merged soil hydrologic group and land use (soil-land map) was generated. The appropriate CN value for each polygon of the soil-land map was adopted from Technical Release 55 [15].

Antecedent Moisture Condition (AMC)

The calculated CN value for each polygon is for average conditions (i.e. Antecedent Moisture Condition Class II). The CN values for AMC II can be converted into CN values for AMC I and AMC III by using the SCS Standard Tables [16]. To determine which AMC class is the most appropriate relative to study area, the use of rainfall data is necessary. The 5-day rainfall prior to the selected rainfall event date was determined to be used for converting the calculated CN value to AMC class I and AMC class III, based on the NRCS Standard Tables.

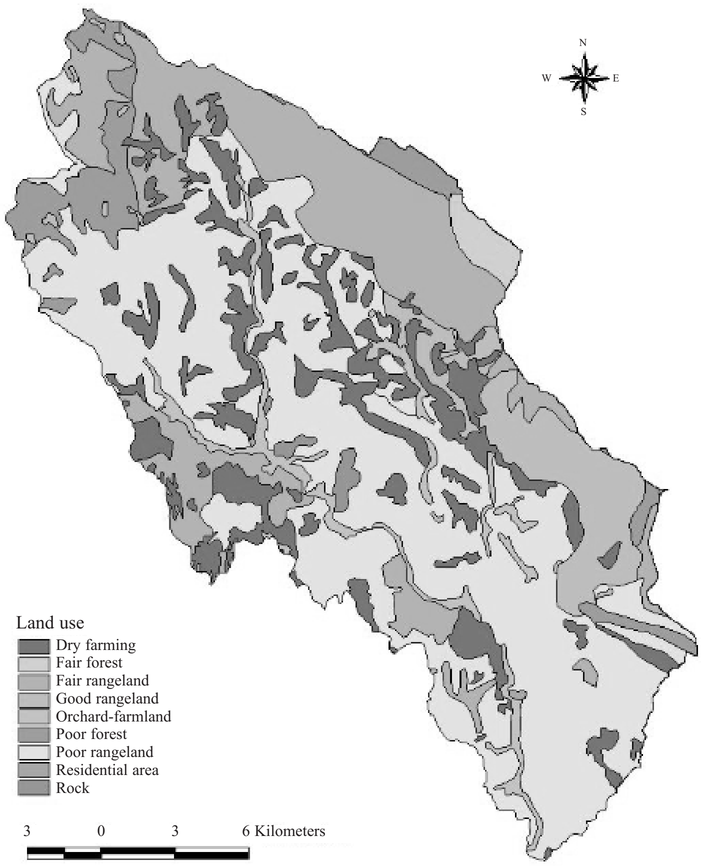

Fig. 2. Land use/cover map of the Kardeh watershed.

Calculating Runoff Depth without Incorporating the Slope Factor

After generating the CN map, the next step was to calculate maximum potential retention (S). The S value was computed for each polygon using equation (2). Runoff depth was ascertained for each rainfall event by using equation (3). Arithmetic mean rainfall of available rain gauge stations in the watershed was used to calculate P in the watershed for selected events. A total of 35 daily rainfall events were employed in the NRCS-CN model to estimate runoff depth for them.

$$S = \frac{25400}{CN} - 254 \quad (2)$$

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

...where S is potential maximum retention (mm); CN is Curve Number; Q is runoff depth (mm); P is rainfall (mm) and S is initial abstraction of rainfall by soil and vegetation (mm).

At the next step, weighted runoff depth was estimated for the watershed by multiplying the area of each polygon with its runoff depth value and divided by total area of watershed (equation 4).

$$\overline{Q} = \frac{\sum QiA_i}{A} \quad (4)$$

...where $\overline{Q}$ is weighted runoff depth of the watershed, Qi is runoff depth for each polygon (mm), A_i is polygon area (ha), and A is watershed area (ha).

Calculating Slope-Adjusted CN Value

Equation 5, developed by Huang et al. [4], was used to adjust the CN values obtained from SCS-CN Standard Tables for the slope. This method assumes that CN obtained from SCS Standard Tables corresponds to a slope of 5%.

$$CN_{2\alpha} = CN_2 \times K$$

$$K = \frac{322.79 + 15.63(\alpha)}{\alpha + 323.52} \quad (5)$$

...where $CN_{2\alpha}$ is value of CN_2 for a given slope, CN_2 is the NRCS-CN for soil moisture condition II (average), K is a CN constant, and α ($m \cdot m^{-1}$) is soil slope.

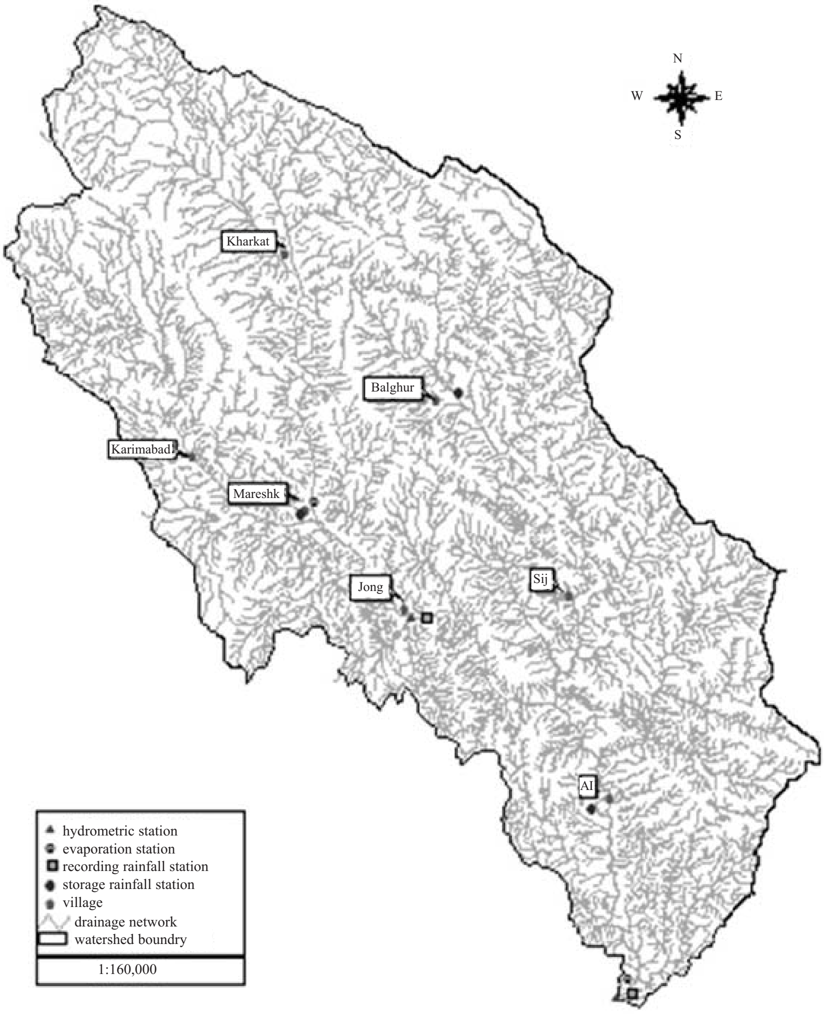

Fig. 3. Hydroclimatological gauging stations in the Kardeh watershed.

Slope and CN maps were intersected to get slopes of each polygon. Since each polygon has different slopes, then calculating weighted slope is needed for each polygon. Weighted slope of a polygon was computed using formula 6. Weighted slope of a polygon was applied in equation 5 to compute slope-adjusted CN values. The Huang et al. [4] approach was used because of the improvement by incorporating the slope factor into the analysis.

$$Weighted\ slope\ = \frac{\sum_{i-1}^{n} a_i \times s_i}{A} \quad (6)$$

...where a_i is area of slope (ha), s_i is slope (%), and A is polygon area (ha).

Calculating Slope-Adjusted Runoff Depth

The same method as discussed above was employed to calculate slope adjusted runoff depth using slope-adjusted CN values for calculating S values. Accordingly, weighted runoff depth was estimated for the watershed for all rainfall events with the corporation of slope factor.

Determining Runoff Depth for Observed Data

Direct runoff volume was calculated by subtracting base flow and total runoff volume in Web-based Hydrograph Analysis Tool (WHAT) software [17]. Runoff depth was calculated by equation 7 as follows:

$$H = \frac{\sum_{i-1}^{24} (Q - bf) \times t}{A} \quad (7)$$

...where H is runoff depth (m), Q is runoff volume (m^3/s), bf is base flow (m^3/s), t is hourly time interval (3600 s), and A is watershed area (m^2).

Statistical Analysis

First, estimated and slope-adjusted (dependent variable), and observed (independent variable) runoff data were checked for normality and homogeneity of variances. Pairwise comparison was done with the t-test to compare observed and estimated runoff depth data. The Pearson correlation was used to investigate the relationship between the

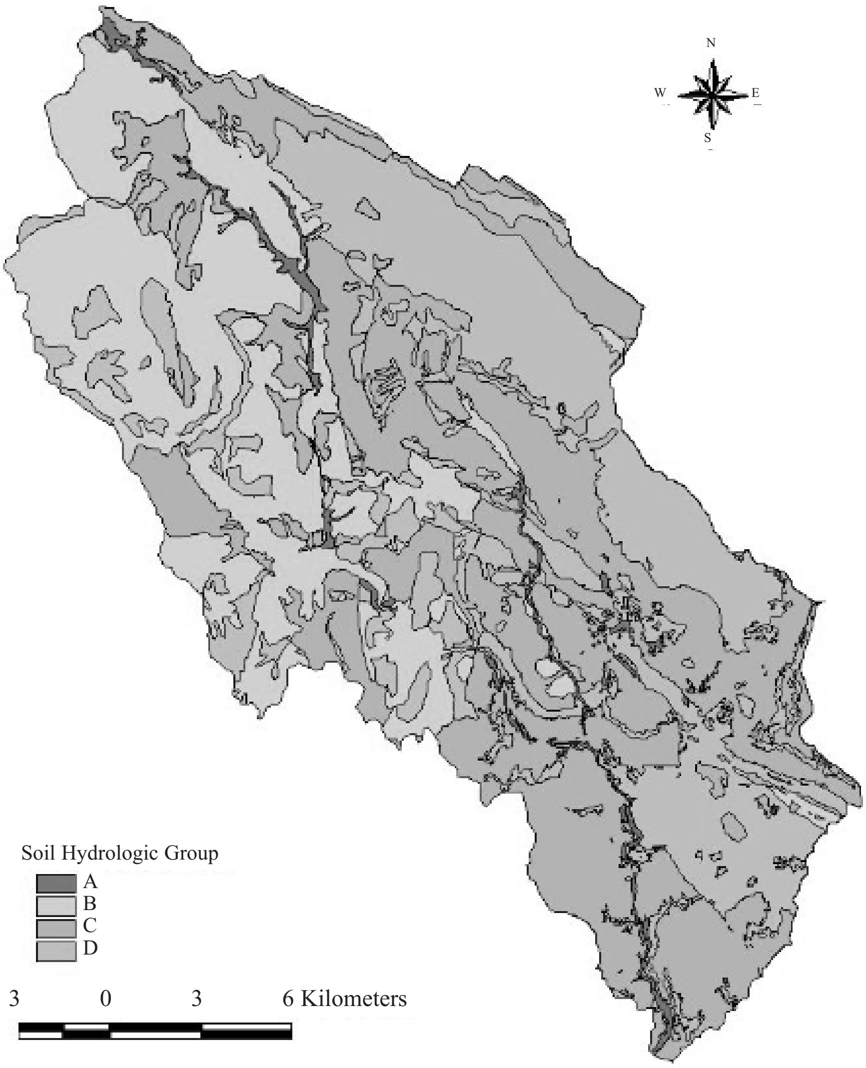

Fig. 4. Hydrologic soil groups of the Kardeh catchment.

estimated and observed runoff depths. Percentage error was calculated to compare the difference between the estimated and slope-adjusted runoff depth with observed runoff depth. All the tests were run using statistical software [18]. The differences were considered significant when P<0.05.

Results and Discussion

Hydrologic Soil Groups

A hydrologic soil group map generated in GIS environment is shown in Fig. 4. All hydrologic groups, including A, B, C, and D were found in the Kardeh watershed: group A with soils having a low runoff potential due to high infiltration rates (7.62-11.43 cm/h), group B with soils having a moderately low runoff potential due to moderate infiltration rates (3.81-7.62 cm/h), group C with soils having a moderately high runoff potential due to low infiltration rates (1.27-3.83 cm/h), and group D with soils having a high runoff potential due to very low infiltration rates (<1.27 cm/h) (USDA-SCS, 1993). Only 2% of soils were placed in group A and about 40.6 and 31.7% of soil were placed in groups C and D, respectively (Table 2).

CN Values

The CN value for each soil hydrologic group and corresponding land use class are presented in Table 2. Hydrologic soil groups A and B led to low CN values, while group D led to a high CN value in the Kardeh watershed. Gandini and Usunoff [9] observed hydrologic soil group B leading to lower CN values in a humid temperate watershed of Argentina. In terms of land use and hydrologic soil group combination, the lowest CN value was found to be 35 and 36 in forest and rangeland with good condition and the highest CN value was found to be 93 in settlement areas. Gandini and Usunoff [9] found a CN value of 92 for urban area and 45 for forest in good condition in Argentina. Table 2 depicts that rangelands with poor condition, settlements and mountainous areas without developed soil layer (rocks), are major contributors to runoff generation in the Kardeh watershed. Nassaji and Mahdavi [19] found that rangeland with poor and very poor conditions had CN values greater than 85 in three rangeland watersheds in semi-arid areas of northern Iran. High CN values in poor rangeland can be explained by low vegetation density, high soil compaction due to treading by grazing animals, and low infiltration rate.

The CN values map is displayed in Fig. 5. The CN map can be viewed as a mosaic of CN values due to differences in land use. About 70% of the Kardeh watershed had CN values between 60 and 80; 4% less than 50 and 0.7% greater than 90. Mellesse and Shih [20] indicated that any changes in land use can alter CN values of the watershed and, accordingly, the runoff response of the watershed by increasing runoff volume. The study also reported that by decreasing the area of croplands and rangelands within two decades, CN values greater than 90 increased by 2.2%, and

Table 2. Curve number of various land uses and HSGs in the Kardeh watershed.

Land use Land cover	Hydrologic soil group	Area (ha)	CN
Dry farmland (rainfed farming)	A	102.30	62
	B	2204.90	71
	C	4378.10	78
Thin forest[1]	A	83.98	36
	B	1262.60	60
	C	809.60	73
	D	398.70	79
Fair forest[2]	B	24.40	55
	C	447.70	70
	D	44.16	77
Rangeland in good condition[3]	A	4.70	35
	B	72.60	35
	C	1208.54	47
	D	1996.19	55
Rangeland in fair condition[4]	A	26.97	51
	B	1809.90	51
	C	2628.26	63
	D	4808.70	70
Rangeland in poor condition[5]	A	215.36	67
	B	5649.30	67
	C	7930.9	80
	D	6649.90	85
Orchards and irrigated farmland	A	428.99	43
	B	510.30	65
	C	803.00	76
Settlement	D	28.40	93
Rocks	D	286.50	91
Total area		44814.95	-

[1]Thin forest: Forest litter, small trees, and brush are destroyed by heavy grazing or regular burning.
[2]Fair forest: Woods are grazed but not burned, and some forest litter covers the soil. Good forest: Woods are protected from grazing, and litter and brush adequately cover the soil.
[3]Rangeland in Good condition: >70% ground cover (litter, grass, and brush overstory).
[4]Fair condition: 30 to 70% ground cover.
[5]Poor condition: <30% ground cover (USDA/NRC, 1986).

Table 3. Slope-adjusted CN values for the Kardeh watershed.

CN	Slope (%)	Area (ha)	CN constant (K)	Slope-adjusted CN
35	17	77.3	1.005	35.2
36	16	83.9	1.005	36.2
43	36	428.9	1.015	43.7
47	30	1208.5	1.010	47.5
51	28	1836.9	1.010	51.5
55	45	2020.6	1.014	55.8
60	26	1262.6	1.010	60.6
62	18	102.3	1.006	62.4
63	31	2628.2	1.012	63.8
65	18.5	510.2	1.006	65.4
67	34	5864.6	1.013	67.9
70	43	5256.4	1.017	71.2
71	28	2204.9	1.010	71.8
73	35	809.6	1.013	74.0
76	28	803.0	1.010	76.8
77	21	44.2	1.007	77.5
78	30	4387.1	1.010	78.8
79	40	398.7	1.016	80.3
80	28	7930.9	1.010	80.8
85	44	6649.9	1.018	86.5
91	20	286.5	1.007	91.6
93	32	28.4	1.012	94.1

the area of the watershed having runoff depth greater than 180 mm increased by 2%.

Slope-adjusted CN values are listed in Table 3. The highest CN value (93) was associated with a steep slope (32%) of the study watershed while the lowest CN value (35) was found in slight slope (17%). In watersheds where land slope is higher than 5%, CN values must be adjusted with slope [4]. The relationship between the calculated CN from SCS Standard Tables and slope-adjusted CN with land slope of the study area is shown in Fig. 6. The figures suggest that there is a direct positive relationship between CN and slope value. Higher CN values are expected in steep slope land. Slope-adjusted CN and Standard CN increase with slope.

Runoff Depth

Comparison of columns 4 (estimated runoff depth) and 5 (estimated slope-adjusted runoff depth) in Table 4 shows that there is not much difference between runoff depth before and after applying slope factor. In other words, after

Table 4. Estimated runoff depth for rainfall events using the NRCS-CN method.

Storm date	Rainfall event (mm)	Sum of prior 5-day rainfall (mm)	Estimated runoff depth (mm)	Estimated slope-adjusted runoff depth (mm)	Observed Runoff depth (mm)
14/5/1991	18.0	18.3	5.44	5.21	3.5
1/6/1992	17.0	0.2	5.71	5.47	8.2
11/7/1992	20.0	14.9	4.94	4.73	3.8
6/1/1993	26.1	29.7	6.56	7.55	5.6
8/3/1993	8.6	11.2	8.56	8.27	6.6
13/4/1993	22.9	4.4	4.30	4.12	11.0
7/5/1993	6.3	4.0	9.54	9.24	5.5
12/3/1994	11.0	22.2	0.92	1.21	4.6
14/6/1994	13.5	0	6.77	6.51	5.2
3/10/1994	5.9	2.8	9.72	9.42	5.6
1/5/1995	9.0	3.0	8.40	8.11	6.8
3/7/1995	19.0	9.6	5.18	4.96	2.4
4/2/1996	14.9	27.7	1.26	1.24	3.9
8/3/1996	17.7	44.9	2.77	3.40	5.0
14/3/1996	9.4	32.8	0.69	0.90	3.4
23/5/1996	6.6	9.8	9.41	9.11	7.2
27/5/1996	6.2	10.3	9.59	9.28	6.1
17/7/1996	23.5	0	4.18	4.01	3.3
6/5/1997	15.6	12.0	6.11	5.87	7.8
19/6/1997	24.1	7.9	4.07	3.90	7.3
1/8/1997	17.5	0.8	5.57	5.34	3.0
6/11/1997	8.0	14.3	2.34	2.19	1.5
9/2/1998	26.1	4.3	3.27	3.23	4.0
14/3/1998	6.1	1.2	7.73	7.47	5.9
26/3/1998	14.0	0.8	5.15	4.96	4.7
6/4/1998	25.1	2.6	3.34	3.29	5.3
27/4/1998	13.1	2.2	5.39	5.18	2.6
30/5/1998	7.8	4.5	7.07	6.82	4.3
22/7/1998	6.9	0	7.41	7.15	4.7
3/8/1998	5.3	0.5	8.07	7.80	7.5
14/8/1998	4.3	0	8.51	8.23	5.1
21/2/1999	27.1	3.8	3.20	3.18	4.4
28/4/2000	19.0	10.5	4.11	3.97	3.2
9/8/2000	8.1	1.1	6.96	6.71	5.2
18/8/2001	15.5	0.3	4.80	4.62	5.3

applying equation (2) and incorporating slope factor in the CN method, the CN values changed (Table 3), but the runoff generation was not affected by the new values considerably. This is largely due to the equation used. The equation used in this study was developed on a plot scale and the application is largely targeted for small sites [4]. To date, there is very little information regarding modification of the NRCS-CN method for a watershed scale. In fact, the equation used here is the only available in the literature to modify runoff response with slope factor. The assessment of the effect of slope on rainfall-runoff relationship in the NRCS-CN method is extended in this study to evaluate the effect on surface runoff generation at a watershed scale. It is obvious that the curve number values must be adjusted with slope degree to overcome to such problems in steep slopes.

Comparison of Estimated and Observed Runoff Depth

As a first step in the analysis, percentage of error was used to compare the difference between estimated and observed runoff depths (Table 5). The maximum and minimum errors between observed and estimated runoff depths were 115 and 7%, respectively. However, the maximum and minimum errors between observed and slope-adjusted runoff depth were 106 and 4%, respectively. The mean percent error between observed and estimated runoff depths was reduced from 46.26% before adjusting for slope to 42.97% after adjusting for slope (Table 5). In India, Pandey et al. [21] reported that the maximum and minimum errors between estimated and observed runoff depths were 68.33 and 3.27%, respectively. Malekian et al. [22] also reported an average percent error of 68.3% between observed and estimated runoff by the CN method for 25 storm events in semi-arid areas of northwestern Iran. In this study, about 9% and 6% of the estimated and slope-adjusted runoff depths were within ±10% of the recorded runoff values, respectively. About 34 and 37% were within ±30% of the observed runoff. About 43 and 37% of the estimated and slope-adjusted values were in error by more than ±50%, respectively (Table 5).

A percentage error of less than 50% was considered acceptable [21, 23]. Statistical analysis indicated that percent error between estimated slope-adjusted and observed runoff depths was significantly ($P<0.01$) lower than the percent error between estimated and observed runoff depths.

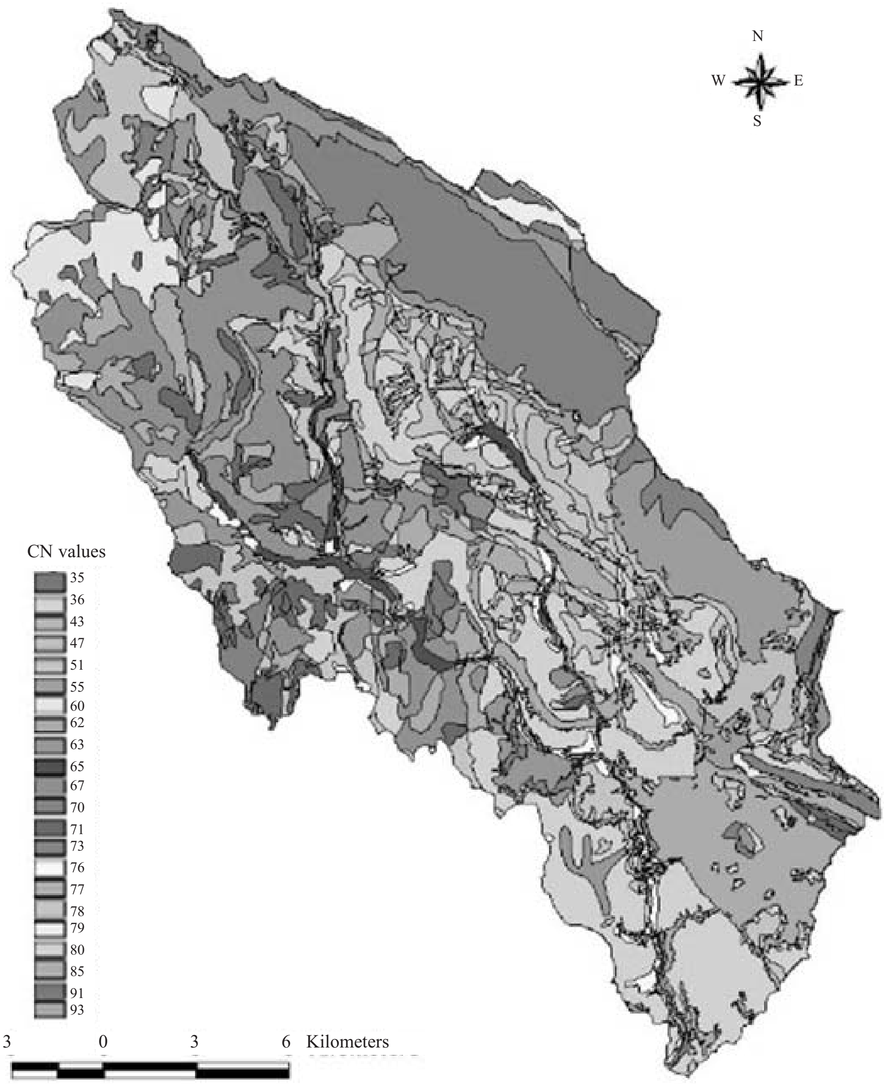

Fig. 5. Map of curve number values for the Kardeh watershed.

Table 5. Details of percent error between estimated and observed runoff depths.

Study storm date	Percent error between estimated and observed runoff	% of observed runoff	% of total number of storm events	Acceptability	Percent error between slope adjusted and observed runoff	% of observed runoff	% of total number of storm events	Acceptability
14/5/1991	7	0-10	8.58	very high	4	0-10	5.7	very high
1/6/1992	9				5			
11/7/1992	9				12	10-30	37.3	high
6/1/1993	17	10-30	34.30	high	19			
8/3/1993	18				19			
13/4/1993	21				21			
7/5/1993	23				24			
12/3/1994	26				24			
14/6/1994	27				24			
3/10/1994	28				25			
1/5/1995	29				25			
3/7/1995	30				26			
4/2/1996	30				26			
8/3/1996	30				27			
14/3/1996	30				29			
23/5/1996	31	30-50	14.30	fair	32	30-50	20	fair
27/5/1996	33				33			
17/7/1996	36				34			
6/5/1997	44				37			
19/6/1997	45				46			
1/8/1997	55	> 50	43	unacceptable	46			
6/11/1997	56				48			
9/2/1998	57				52	> 50	37	unacceptable
14/3/1998	57				52			
26/3/1998	60				58			
6/4/1998	64				61			
27/4/1998	66				62			
30/5/1998	68				68			
22/7/1998	73				68			
3/8/1998	73				68			
14/8/1998	80				73			
21/2/1999	80				73			
28/4/2000	85				78			
9/8/2000	107				99			
18/8/2001	115				106			
Minimum = 7 Maximum = 115 Mean = 46.23			100	Minimum = 4 Maximum = 106 Mean = 42.97				100

Table 6. Means comparison of estimated and observed runoff for the Kardeh watershed.

Variable	Estimated runoff depth (mm)	Slope-adjusted runoff depth (mm)	Observed runoff depth (mm)	P	
				Estimated vs. observed	Slope-adjusted vs. observed
Mean	5.63	5.50	5.11	0.16	0.27
SD	2.53	2.41	1.90		

This decline in percent error can be explained by the role of slope in runoff generation in steep watersheds. One of the potential sources of error in runoff depth estimation is believed to be due to the rainfall and recorded runoff data input. The quality of the input data is the main determinant of the quality of the results in runoff estimation [23, 24]. The presence of various land use/cover classes or condition in the watershed, and mountainous topography and large area of the watershed, may have played a part in the lack of acceptable runoff estimate results for selected storm events in this study. Field worker errors in recording rainfall and associated runoff data probably are another source of error.

Pair-wise comparison between the variable (estimated vs. observed runoff) means showed that there is no significant difference between the means of estimated and observed data ($P>0.05$) (Table 6). Therefore, estimated runoff depth by standard CN method was near to corresponding observed runoff depths. Interestingly, Pandey et al. [21] found that estimated direct runoff depth by the standard NRCS-CN method was significantly ($P<0.05$) near to corresponding observed runoff depth in the Karso watershed, India. Similar results were reported by Pandey and Sahu [7], and Pandey et al. [21] in India and Akhondi [10] in Iran. The results showed that there is no provision to apply the standard NRCS-CN model in the Kardeh watershed for runoff estimation. It is noteworthy that the P values in Table 6 indicate that mean of slope-adjusted estimated runoff depth (5.50) is nearer to mean of observed data

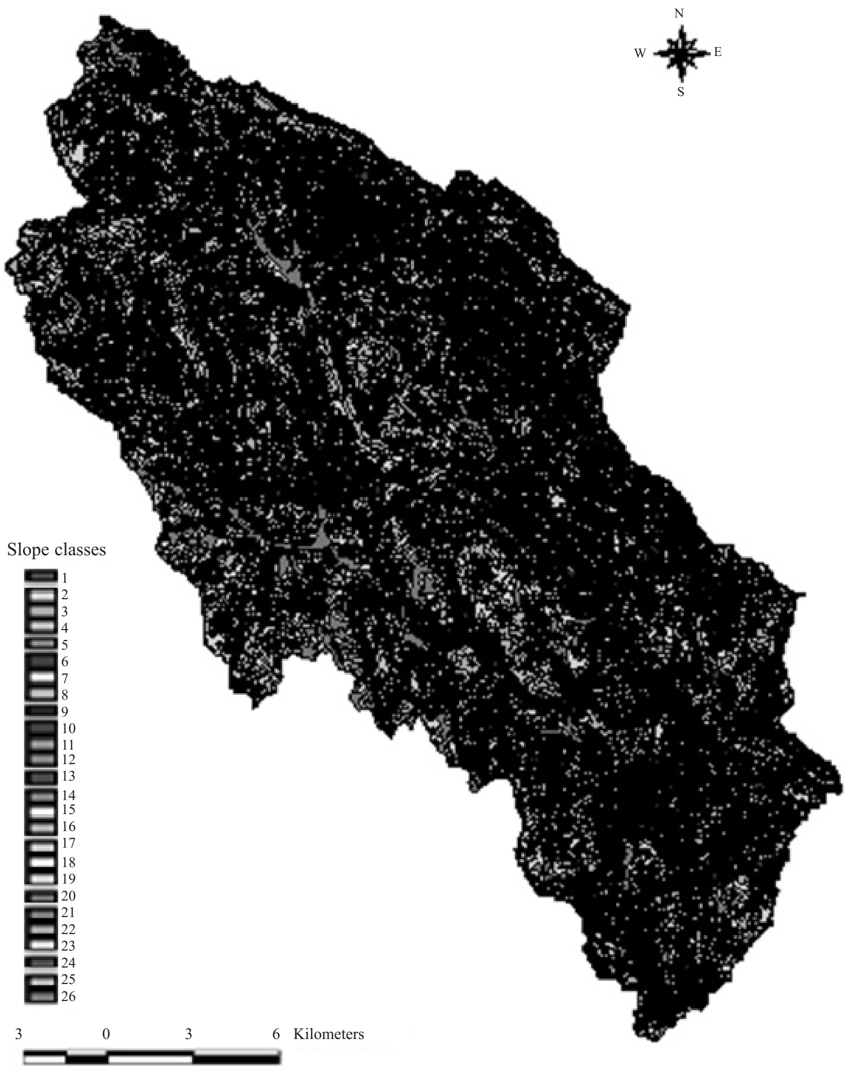

Fig. 6. Slope map of the Kardeh watershed.

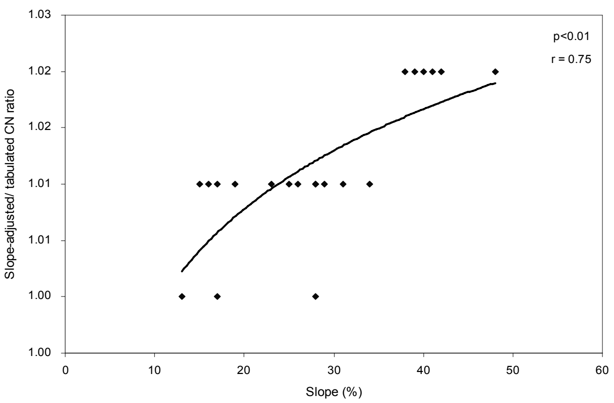

Fig. 7. Relationship between the calculated CN from SCS Standard Tables and slope-adjusted CN ratio and land slope.

(5.11) than estimated data (5.63). High P-value means estimated and observed data are roughly far from each other and vice versa.

The comparison of estimated slope-adjusted runoff with observed runoff showed there is no significant difference between the means of slope-adjusted estimated and observed runoff (P>0.05). It should be noted that for slope-adjusted runoff vs. observed runoff, the P value (0.27) was greater than the P value for estimated runoff vs. observed runoff (0.16) (Table 6). This means that when runoff depths were adjusted for slope, their means (5.50) were nearer to observed runoff depths (5.11). This indicates that slope is an important factor in runoff estimation. In steep slope watersheds, estimated runoff must be adjusted for slope since the estimations are affected more.

Fairly positive correlations were found between estimated and observed data (r = 0.55; P<0.01) and slope adjusted vs. observed runoff data (r = 0.56; P<0.01). In India, [8] found a good correlation (about 90%) between estimated and observed data in all eight sub-basins with various areas (less than 100 km^2) of the Bebas watershed, although correlation decreased with increasing area of the sub-basins. Akhondi [10] pointed out that correlation coefficient (r) between observed and estimated runoff using the CN method decreased from 98% to 17% with increasing watershed area and decreasing rainfall (from semi-humid to semi-arid) in four watersheds with various areas and climate in semi-arid and semi-humid areas of southwestern Iran. Furthermore, Malekian et al. [22] reported a correlation coefficient of 73% between observed and estimated runoff by the CN method in a semi-arid watershed of northwestern Iran. In the present study, a fair correlation (about 55%) between estimated and observed runoff depth could be attributable to the big area of the watershed. As discussed above, correlation is higher in small watersheds compared to bigger ones. Another reason behind this fair correlation may be due to the use of a non-localized CN method in this study. The CN method parameters still have not been localized and modified based on Iranian conditions. This should serve as a caution to managers and researchers utilizing the standard CN method for hydrologic modelling in Iran [25, 22].

Conclusions

The incorporation of the NRCS-CN model and GIS facilitates runoff estimation and can augment the accuracy of computed data. In this study, use of combined GIS and NRCS-CN methods to estimate runoff data in the Kardeh watershed was neither approved nor rejected completely. The results indicate that the combined GIS and CN method can be used in an ungauged watershed with the same conditions to the Kardeh with about 55% accuracy only for management and conservation purposes, but not for computation of design floods. Nevertheless, there was not high correlation (r = 0.55) between estimated and observed runoff depths in this study, but one of the alternative methods which can be considered for ungauged watersheds to produce runoff data for the purpose of management and conservation is the CN method.

Although the results of this study failed to show the real effect of slope on runoff generation in the watershed due to equation 6 at the watershed scale, the assessment of the effect of slope on rainfall-runoff relationship in the NRCS-CN method should be extended further at the watershed scale to get the effect on surface runoff generation.

Acknowledgements

Authors acknowledge Universiti Putra Malaysia for providing research fellowship to make this research possible. We are particularly grateful to Khorasan Razavi Regional Water Authority, the Department of Watershed Management, and Abkhiz Gostar Shargh Co. Ltd. for providing the data and maps of the studied watershed.

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