Water Science and Engineering, 2010, 3(1): 1-13
doi:10.3882/j.issn.1674-2370.2010.01.001

http://www.waterjournal.cn
e-mail: wse2008@vip.163.com

Application of GIS-based SCS-CN method in West Bank catchments, Palestine

Sameer SHADEED*, Mohammad ALMASRI

Department of Civil Engineering, College of Engineering, An-Najah National University, P. O. Box 7, Nablus, Palestine

Abstract: Among the most basic challenges of hydrology are the prediction and quantification of catchment surface runoff. The runoff curve number (CN) is a key factor in determining runoff in the SCS (Soil Conservation Service) based hydrologic modeling method. The traditional SCS-CN method for calculating the composite curve number is very tedious and consumes a major portion of the hydrologic modeling time. Therefore, geographic information systems (GIS) are now being used in combination with the SCS-CN method. This paper assesses the modeling of flow in West Bank catchments using the GIS-based SCS-CN method. The West Bank, Palestine, is characterized as an arid to semi-arid region with annual rainfall depths ranging between 100 mm in the vicinity of the Jordan River to 700 mm in the mountains extending across the central parts of the region. The estimated composite curve number for the entire West Bank is about 50 assuming dry conditions. This paper clearly demonstrates that the integration of GIS with the SCS-CN method provides a powerful tool for estimating runoff volumes in West Bank catchments, representing arid to semi-arid catchments of Palestine.
Key words: *GIS; SCS-CN method; surface runoff; West Bank catchments; arid and semi-arid regions*

1 Introduction

There are generalized physically based and spatially distributed hydrologic computer models of catchments that are able to compute sequences of runoff generation for a given rainfall event. The main advantage of these models is the accuracy of their predictions. Their major disadvantage is that they require considerable expertise, time, and effort to be used effectively. In between the extremes there are methods like the SCS-CN (Soil Conservation Service curve number) method that are relatively easy to use and yield satisfactory results (Schulze et al. 1992).

The SCS-CN method (SCS 1985) is one of the most popular methods for computing the volume of surface runoff in catchments for a given rainfall event. This approach involves the use of a simple empirical formula and readily available tables and curves. A high curve number

This work was supported by the GLOWA-JR Project of the German Federal Ministry of Education and Research (BMBF).
*Corresponding author (e-mail: *sshadeed@najah.edu*)
Received Nov. 4, 2009; accepted Jan. 22, 2010

means high runoff and low infiltration (urban areas), whereas a low curve number means low runoff and high infiltration (dry soil). The curve number is a function of land use and hydrologic soil group (HSG). It is a method that can incorporate the land use for computation of runoff from rainfall. The SCS-CN method provides a rapid way to estimate runoff change due to land use change (Shrestha 2003; Zhan and Huang 2004).

The SCS-CN method has become the focus of much discussion in recent hydrological literature. For example, Ponce and Hawkins (1996) critically examined this method; clarified its conceptual and empirical basis; delineated its capabilities, limitations, and uses; and identified areas of research. Yu (1998) derived the SCS-CN method analytically assuming exponential distribution for the spatial variation of the infiltration capacity and the temporal variation of the rainfall rate. Hjelmfelt (1991), Hawkins (1993) and Bonta (1997) suggested procedures for determining curve numbers using field data of storm rainfall and runoff. Grove et al. (1998) and Moglen (2000) discussed the effect of spatial variability of CN on the computed runoff. Mishra et al. (2003) modified the SCS-CN method by accounting for the static portion of infiltration and the antecedent moisture. Mishra and Singh (2004) studied the validity and extension of the SCS-CN method for computing infiltration and rainfall-excess rates. Mishra et al. (2006) improved the relation between the initial abstraction (I_a) and the potential maximum storage (S) incorporating antecedent moisture in SCS-CN methodology. Many catchment models, such as AGNPS (Young et al. 1987), EPIC (Williams 1995), and SWAT (Arnold et al. 1996), use the SCS-CN method to determine runoff. In addition, the TR-55, TR-20, HIC-1, WMS, and HIC-HMS runoff calculation models adopt this method (Xu 2006).

The traditional method of calculating the composite curve number from the readily available tables and curves is very tedious, and takes up a major portion of hydrologic modeling time. To overcome this difficulty, the GIS and SCS-CN methods were combined to facilitate the calculation of the composite curve number (Zhan and Huang 2004; Xu 2006). As mentioned earlier, the curve number is a function of soil type and land use. The use of GIS becomes important in providing the accurate spatial information required to apply this method (Bellal et al. 1996). GIS can easily retrieve and process the soil type and land use shapefiles and a new intersection shapefile can be created as a base file for the curve number calculation. This approach can significantly simplify the curve number calculation process.

Many studies have shown that surface runoff from the eastern slopes of the West Bank probably occurs when rainfall exceeds 50 mm in one day or 70 mm in two consecutive days (Al-Nubani 2000). Shadeed (2008) studied the runoff generation mechanism in the Faria Catchment, one of the West Bank catchments (area 12 in Fig. 1) that contribute to the Jordan River Basin, using a physically based and spatially distributed rainfall-runoff model, the coupled TRAIN-ZIN model, and confirmed the observed values. One of his main conclusions is that rainfall characteristics and initial soil moisture content are the main factors that control the runoff generation processes taking place in the region. Thus, the previous study (Al-Nubani 2000) is right only in its approximate overall dimension, but it is far from being accurate, or even based on solid data, when it comes to specifications. This is due to the fact that the runoff generation mechanism in arid and semi-arid regions is controlled by rainfall characteristics (mainly the rainfall intensity) and the initial soil moisture content (antecedent soil moisture content), not only by rainfall amount. Accordingly, the earlier studies that estimated the amount of the runoff volume in the West Bank are not correct and lead to misleading results.

In this study, a GIS was employed as a tool to calculate the composite curve number for West Bank catchments, and to estimate the runoff depth and volume based on spatially varying soil and land use information. This provides basic information for managers to assess runoff generation volumes within the region and thus supports the decision-making process for future development of water resources and hydrologic structures in the area.

2 Description of study area

The West Bank, Palestine is located in the Middle East, west of Jordan (Fig. 1). It has a surface area of 5 640 km^2. The West Bank has a varied topography, with ground surface elevations varying between 1 022 m above mean sea level in Tall Asur in Hebron in the south, and 375 m below mean sea level near Jericho (adjacent to the Dead Sea) (UNEP 2003). The summits of West Bank Mountains delineate both catchment lines and the water divide that separates the western and the eastern catchments. The Jordan Valley is part of a long and deep depression of the earth’s crust, widely known as the Jordan Rift, running along the edge of the country and separating it from Jordan (ARIJ 2000).

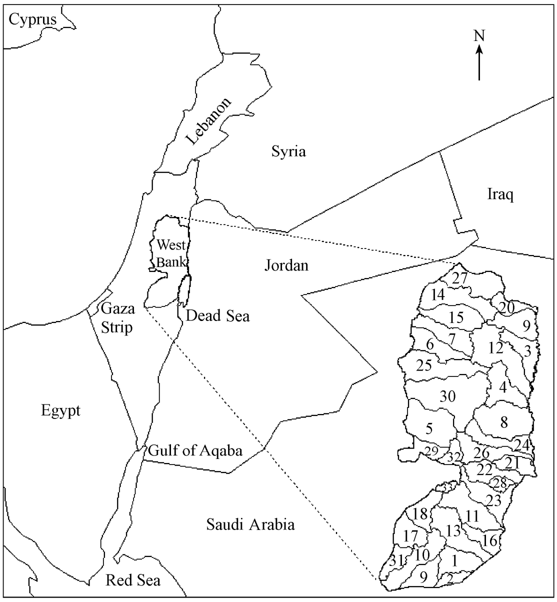

Fig. 1 Location of West Bank along with catchments

The West Bank is mostly composed of limestone hills, brown lithosols and loessial arid brown soils cover on the eastern slopes and grassland, with pockets of cultivation spreading over the steep slopes. Fertile soils are found on the plains. Soil cover is generally thin. Overall, about 12% of the land is desert, eroded or saline (UNEP 2003).

The structural geology of the West Bank is dominated by a series of regional, parallel, southwest-northeast trending folds dissected by faults associated with the Jordan Rift Valley. The faults turn towards the northwest near Jericho. Some faults in the West Bank act as conduits and others represent barriers to groundwater flow.

In the catchments of the West Bank, surface runoff is mostly intermittent and constitutes nearly 2.2% of the total equivalent rainfall (Rofe and Raffety Consulting Engineers 1965). There are 33 main catchments in the West Bank, which drain toward the Mediterranean Sea, the Dead Sea, and the Jordan River (Fig. 1).

The West Bank climate may be broadly described as a Mediterranean type, varying from hot and dry in the summer to wet and cold in the winter, with short transitional seasons. Because of the wind, humidity, latitude, and differences in elevation, there are a considerable number of micro-climatic patterns. The area experiences extreme seasonal variations in climate. Large rainfall variations also occur from year to year. Consecutive years of relatively high or low annual rainfall have an enormous effect on the region and, in the case of dry years, present the greatest challenge to managing the region's precious water resources.

The rainy season usually begins in November and ends at the end of March. Rainfall is concentrated over a short period, with more than 60% of the annual rainfall commonly occurring within two months. Rain tends to fall in intense storms. This results in tremendous runoff during a few months while the country remains dry for most of the rest of the year. In general, rainfall is characterized by its high variability, both temporally and spatially. In Nablus, for example, a minimum of less than 315 mm in a season (in the hydrologic years of 1951 and 1952) and a maximum of more than 1 387 mm in a season (in the hydrologic years of 1991 and 1992) have been recorded, while the long-term annual average is 642 mm. Rainfall decreases from north to south and from high to low elevation. The yearly rainfall is as low as 100 mm in the Jordan Valley, located in the rain shadow of the mountain ridge, and as high as 700 mm in the semi-coastal region. The rainfall distribution in the West Bank is shown in Fig. 2.

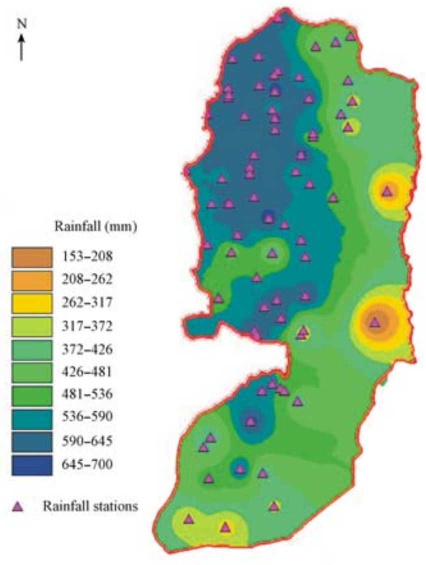

Fig. 2 Rainfall stations and rainfall distribution in West Bank

The land use of the West Bank is classified into seven classes: built-up areas (5%), woodland/forest (0.7%), Israeli settlements (1.4%), arable land (14.31%), rough grazing/subsistence farming (61.7%), irrigated farming (2.63%), and permanent crops (14.3%), as shown in Fig. 3(a). Eight soil types exist in the West Bank, as shown in Fig. 3(b).

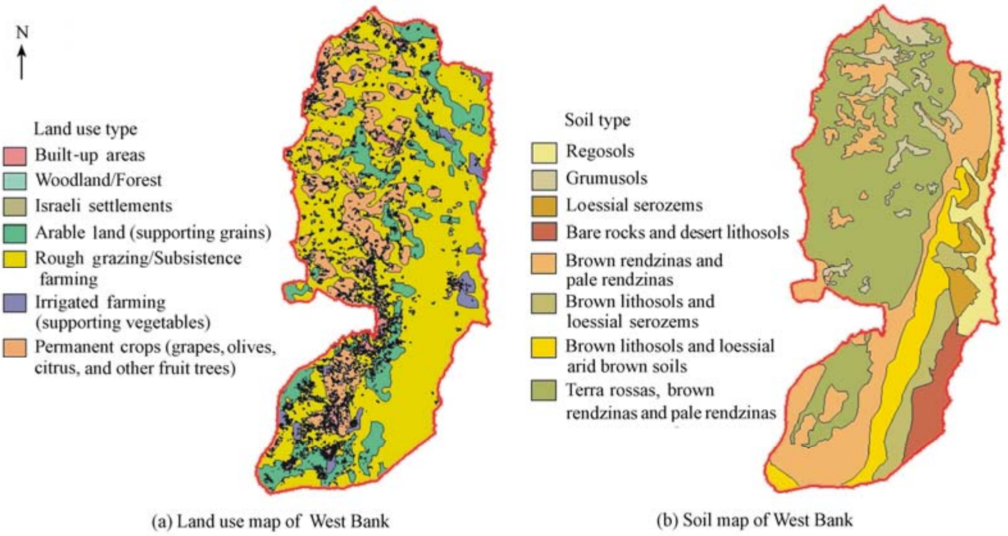

Fig. 3 Land use and soil type map of West Bank

3 Methodology

The chart in Fig. 4 depicts the overall methodology for the GIS-based SCS-CN method utilized in this study. Land use and soil type shapefiles were first obtained and compiled in a GIS-based database. Soil and land use themes were intersected using GIS techniques, to generate new and smaller polygons associated with HSGs and land use cover names. This step keeps all the details of the spatial variation of soil and land use. The curve number database was built based on the intersected land soil layer and its related attribute table. The field calculator, a GIS technique, was used to calculate the curve number and runoff volume from the built database.

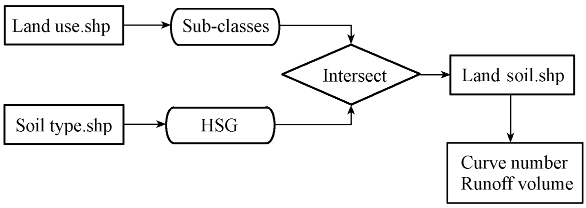

Fig. 4 Methodology chart

4 SCS-CN method

In the early 1950s, the United States Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS) (then named the Soil Conservation Service (SCS)) developed a method for estimating the volume of direct runoff from rainfall. This method, which is often referred to as the CN method, was empirically developed for small agricultural watersheds. Analysis of storm event rainfall and runoff records indicates that there is a threshold that must be exceeded before runoff occurs. The storm must satisfy interception, depression storage, and infiltration volume before the onset of runoff. The rainfall required to satisfy the above volumes is termed initial abstraction. Additional losses will occur as infiltration after runoff begins, whereas accumulated infiltration increases with rainfall up to some maximum retention amount. Runoff also increases with rainfall. The standard SCS-CN method is based on the following relationship between rainfall, P (mm), and runoff, Q (mm) (SCS-USDA 1986; Schulze et al. 1992):

$$Q = \begin{cases} \dfrac{(P - I_a)^2}{P - I_a + S} & P > I_a \\ 0 & P \le I_a \end{cases} \tag{1}$$

where S (mm) is potential maximum retention after runoff begins.

I_a is all loss before runoff begins. It includes water retained in surface depressions, water intercepted by vegetation, evaporation, and infiltration. I_a is highly variable but generally is correlated with soil and land cover parameters. To remove the necessity for an independent estimation of I_a, a linear relationship between I_a and S was suggested by SCS (1985) as: $I_a = \lambda S$, where λ is an initial abstraction ratio. The values of λ vary in the range of 0 to 0.3 and have been documented in a number of studies encompassing various geographic locations in the United States and other countries (Shrestha 2003). Through studies of many small agricultural catchments, I_a was found to be approximated by empirical equations such as $I_a = 0.2S$.

By removing I_a as an independent parameter, a combination of S and P to produce a unique runoff amount can be approximated. Substituting $I_a = 0.2S$ gives

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

The variable S, which varies with antecedent soil moisture and other variables, can be estimated as

$$S = \frac{25\ 400}{CN} - 254 \tag{3}$$

where CN is a dimensionless catchment parameter ranging from 0 to 100. A CN of 100 represents a limiting condition of a perfectly impermeable catchment with zero retention, in which all rainfall becomes runoff. A CN of zero conceptually represents the other extreme, with the catchment abstracting all rainfall and with no runoff regardless of the rainfall amount.

The curve number can be determined from empirical information. The SCS has developed standard tables of curve number values as functions of catchment land use/cover conditions and

HSG. These are listed in the *SCS User Manual* (SCS-USDA 1986).

The HSG refer to the standard SCS soil classifications ranging from A, which refers to sand and aggregated silts with high infiltration rates, to classification D, which corresponds to soils that swell significantly when wet and have low infiltration rates. The HSG reflects a soil's permeability and surface runoff potential. Table 1 summarizes the HSG characteristics (Schulze et al. 1992).

Table 1 Summary of HSG characteristics

HSG	Surface runoff potential	Final infiltration rate (mm/h)	Permeability rate (mm/h)
A	Low	25	> 7.6
B	Moderately low	13	3.8 to 7.6
C	Moderately high	6	1.3 to 3.8
D	High	3	< 1.3

For a catchment with sub-areas that have different soil types and land covers, a composite curve number CN_{c} is determined by weighting the curve number values for the different sub-areas in proportion to the land area associated with each:

$$CN_{\mathrm{c}} = \frac{CN_1 A_1 + CN_2 A_2 + \cdots + CN_i A_i \cdots + CN_n A_n}{\sum_{i=1}^{n} A_i} \tag{4}$$

where CN_i is the curve number of the sub-area *i*, A_i is the area of the sub-area *i*, and *n* is the total number of sub-areas.

CN_{II} is considered the base *CN*, and is applied for moderate antecedent moisture condition (AMCII). It can be adjusted for calculating CN_{III}, which is applied for near-saturated antecedent moisture condition (AMCIII), or CN_{I}, which is applied for dry antecedent moisture condition (AMCI), as shown below (Chow et al. 1988):

$$CN_{\mathrm{I}} = \frac{CN_{\mathrm{II}}}{2.334 - 0.013\,34 CN_{\mathrm{II}}} \tag{5}$$

$$CN_{\mathrm{III}} = \frac{CN_{\mathrm{II}}}{0.403\,6 + 0.059 CN_{\mathrm{II}}} \tag{6}$$

5 Results

5.1 Spatial distribution of *CN*, *S*, and I_{a}

To apply this method to West Bank catchments, the available land use and soil type maps were processed using GIS techniques. To determine the HSG, the USDA soil texture must be known. This can be determined according to the percentage of sand, silt, and clay. Table 2 classifies the HSG by its USDA soil texture.

Based on the data published by the Ministry of Planning and International Cooperation (MOPIC 1996), soil texture was defined for the different soil types of West Bank catchments as illustrated in Table 3.

Table 2 HSG for USDA soil texture classes

HSG	Soil texture
A	Sand, loamy sand, or sandy loam
B	Silt or loam
C	Sandy clay loam
D	Clay loam, silt clay loam, sandy clay, silty clay, or clay

Table 3 Soil types according to soil texture

Soil type	Soil texture
Regosols	Sandy loam
Grumusols	Clay
Terra rossas	Clay
Loessial serozems	Sandy loam
Brown rendzinas and pale rendzinas	Clay loam
Brown lithosols and loessial arid brown soils	Loam

The HSG map of West Bank catchments was then processed using GIS according to the data shown in Tables 2 and 3. This step retains all details of the spatial variation of soil and land use. Therefore, it is considered more accurate than using a raster grid to calculate runoff or other dominant methods to determine curve number. The produced theme and its related attribute table were used to determine the CN_{II} value for each catchment in the West Bank. CN_{I} and CN_{III} were then computed using Eqs. (5) and (6) to adjust for antecedent moisture conditions (AMCI or AMCIII). The equation is dependent on the SCS classification conditions shown in Table 4.

Table 4 SCS antecedent moisture condition classifications

Five-day antecedent rainfall (mm)	Antecedent moisture condition
< 35	AMCI
35 to 52.5	AMCII
> 52.5	AMCIII

Since the West Bank has an arid to semi-arid climate, CN_{II} needed to be corrected to match CN_{I}. Using Eq. (5), the final composite CN_{I} of the West Bank catchments was estimated to be about 50. The obtained CN_{I} map of the West Bank catchments for AMCI is shown in Fig. 5.

S was calculated using Eq. (3) and the results are shown in Fig. 6. I_{a} was calculated using the formula $I_{\mathrm{a}} = 0.2S$. Table 5 provides the CN_{I}, S, and I_{a} for West Bank catchments assuming dry conditions prevail.

As shown in Table 5, the values of CN_{I} range from 41 for the Marar Catchment to 69 for the Besor and Shiqma catchments. The values of S for these catchments are 485 mm, 121mm and 128 mm, respectively. In other words, it is expected that the generated runoff depth from the Marar Catchment is low compared to the other catchments in the West Bank for the same rainfall event. This confirms that the generated runoff depth is a function of the catchment characteristics and storm characteristics.

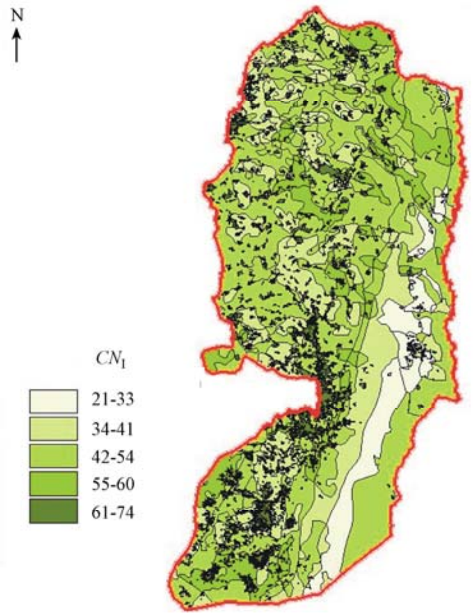

Fig. 5 Spatial distribution of CN_I in West Bank

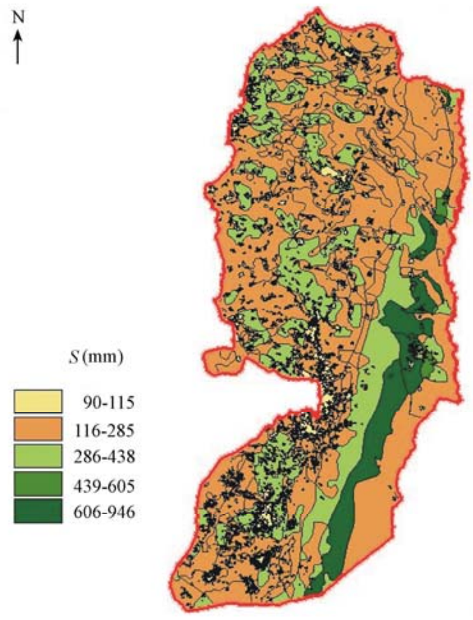

Fig. 6 Spatial distribution of S in West Bank

Table 5 West Bank catchments information

No.	Catchment	Area (km^2)	AMCI		
			CN_I	S (mm)	I_a (mm)
1	Abu El-hayyat	150	68	136	27
2	Abu Muradin	54	60	214	43
3	Daraja	234	67	142	28
4	Ghar	227	66	153	31
5	Hasasa	108	51	323	64
6	Mukallak	138	59	196	39
7	Nar	189	57	204	40
8	Qumran	47	47	342	68
9	Abu Sidra	146	52	289	58
10	Al'Ahmar	181	60	211	42
11	Auja	291	51	309	62
12	Faria	320	50	254	51
13	Malih	161	64	159	32
14	Malih-Shubash	89	62	190	38
15	Marar	98	41	485	97
16	Nueima	151	47	385	77
17	Qilt	172	58	230	46
18	Al-Dilb	275	64	163	33
19	Alexander-Abraq	155	68	131	26
20	Alexander-Zeimar	173	66	150	30
21	Besor	120	69	121	24
22	Besor-Nar	204	65	156	31
23	Hadera-Abu Nar	248	66	152	30
24	Hadera-Massin	187	68	140	28
25	Lakhish	136	68	132	26
26	Lakhish-Saint	127	67	140	28
27	Qana	281	67	139	28
28	Qishon	206	67	138	28
29	Salman	119	64	164	33
30	Sarida	466	68	131	26
31	Shiqma	88	69	128	25
32	Soreq	67	63	162	32
33	Soreq Al-sarar	27	64	159	32

5.2 Performance of SCS-CN method

The primary goal of using the SCS-CN method for West Bank catchments is to determine the runoff amounts that result from selected rainfall events in order to manage these amounts to save water for future demand. This section provides a comparison between the storm runoff amounts estimated by the SCS-CN approach and observed runoff. Selected storm events in the Al-Badan sub-catchment (Fig. 7), one of the sub-catchments shaping the Faria Catchment, were chosen to assess the applicability of the SCS-CN method to producing the runoff amounts of a given rainfall event and to verify the model output by comparison with observed data. The observed runoff data were obtained from the Parshall Flume, which was constructed by An-Najah National University in coordination with the GLOWA-JR project at the outlet of Al-Badan sub-catchment.

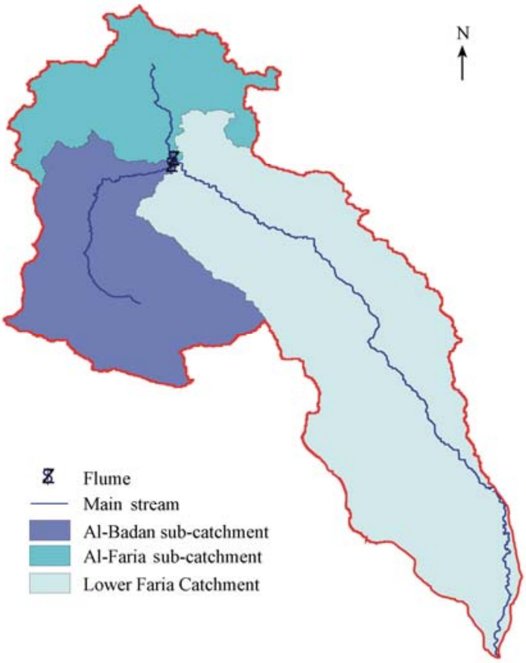

Fig. 7 Upper and lower Faria sub-catchments

For this purpose, four rainfall events were chosen: February 4 to 6, 2005 (Event 1), February 8 to 9, 2006 (Event 2), December 26 to 27, 2006 (Event 3), and February 3 to 6, 2007 (Event 4). Characteristics of these events are summarized in Table 6.

It is apparent that dry conditions prevailed for the four events, since the measured five-day antecedent rainfall was less than 35 mm. Therefore, CN_{I} for AMCI was used in assessing the predicted runoff volumes for the four events. By substituting the average CN_{I} into Eq. (2), direct runoff depths of these events were estimated. The estimated runoff depths are shown against the observed runoff depths in Table 7. The runoff depth deviation (D_{v}) in %, one of the most widely used goodness-of-fit measures used to evaluate rainfall-runoff model performance, was computed as follows:

$$D_{\mathrm{v}} = \frac{Q_{\mathrm{s}} - Q_{\mathrm{o}}}{Q_{\mathrm{s}}} \times 100\% \tag{7}$$

where Q_{o} is the observed runoff depth, and Q_{s} is the simulated runoff depth.

Table 6 Characteristics of four rainfall events

Event	Parameter				
	Amount of rainfall (mm)	Number of hours	Average rainfall intensity (mm/h)	Number of days since previous event	Five-day antecedent rainfall (mm)
1	118	55	2.5	2	30
2	88	22	4.2	5	5
3	72	28	2.8	40	0
4	75	48	1.5	3	17

Table 7 Performance of SCS-CN method

Event	Rainfall (mm)	Q_{s} (mm)	Q_{o} (mm)	D_{v} (%)
1	118	14.06	11.76	16.35
2	88	4.75	3.81	19.85
3	72	1.63	1.44	11.95
4	75	2.11	1.95	7.44

It can be seen in Table 7 that the simulated runoff values for the four events are slightly greater than the observed ones. This may affect the estimated values of *S*. The estimated values of *S* should be increased to tackle dry region hydrology. This can be achieved by developing an empirical formula that can represent the runoff generation mechanisms in dry regions, since the available formula was developed for humid regions. This will enhance the performance of the SCS-CN method in dry catchments. However, the table shows that D_{v} values obtained with the present approach range between 7% and 20%. These deviations are not significantly different and may have resulted from the effects of initial abstractions, which may also differ from one event to another as a result of dissimilar antecedent moisture content.

By considering all the rainfall events, the accuracy of the proposed approach in estimating direct surface runoff is found to be about 85%. This value is good enough to assume the applicability of the SCS-CN method in predicting runoff generation amounts for the Faria Catchment.

6 Conclusions

The SCS-CN method is a widely used method for estimating the surface runoff volume for a given rainfall event. The major advantage of employing GIS in rainfall-runoff modeling is that more accurate sizing and catchment characterization can be achieved. Furthermore, the analysis can be performed much faster, especially when there is a complex mix of land use classes and different soil types.

A GIS-based SCS-CN approach was developed in this study to calculate the composite curve number of West Bank catchments. The insufficiency of rainfall-runoff records has limited the verification of the validity of the proposed approach to generally arid to semi-arid catchments. However, four rainfall events were simulated in the Al-Badan sub-catchment of the Al-Faria Catchment using the generated curve number map. Estimated and observed runoff depths of the four events were close enough to assume the applicability of the GIS-based SCS-CN approach for the region.

In this context, it is important to note that, originally, the SCS-CN method was developed for humid catchments, whose characteristics can be quite different from those of the arid to semi-arid Palestinian catchments. To overcome this problem, it is recommended that the I_a formula used by the SCS-CN method be investigated and its applicability in dry conditions verified. This can be best done by measuring runoff volumes at catchment outlets and comparing them with those obtained by using the GIS-based SCS-CN approach.

Acknowledgements

This work was performed within the GLOWA-JR Project, funded by the German Federal Ministry of Education and Research (BMBF). The financial support is gratefully acknowledged.

References

Al-Nubani, N. I. 2000. *Rainfall-Runoff Process and Rainfall Analysis for Nablus Basin*. M. S. Dissertation. Nablus: An-Najah National University.

Applied Research Institute, Jerusalem (ARIJ). 2000. *Overview of the Palestinian Environment, Agenda-21, Part 2*. Bethlehem, West Bank: ARIJ Main Office.

Arnold, J. G., Williams, J. R., Srinivasan, R., and King, K. W. 1996. *SWAT: Soil and Water Assessment Tool*. Temple: Grassland, Soil & Water Research Laboratory, U. S. Department of Agriculture.

Bellal, M., Sillen, X., and Zeck, Y. 1996. Coupling GIS with a distributed hydrological model for studying the effect of various urban planning options on rainfall-runoff relationship in urbanized watersheds. Kovar, K., and Nachtnebel, H. P., eds., *Hydro GIS 96: Application of GIS in Hydrology and Water Resources Management (Proceedings of the Vienna Conference)*, 99-106. Vienna: International Association of Hydrological Sciences.

Bonta, J. V. 1997. Determination of watershed curve number using derived distributions. *Journal of Irrigation and Drainage Engineering*, 123(1), 28-36. [doi:10.1061/(ASCE)0733-9437(1997)123:1(28)]

Chow, V. T, Maidment, D. R., and Mays, L. W. 1988. *Applied Hydrology*. New York: McGraw-Hill.

Grove, M., Harbor, J., and Engel, B. 1998. Composite vs. distributed curve numbers: Effects on estimates of storm runoff depths. *Journal of the American Water Resources Association*, 34(5), 1015-1023. [doi:10.1111/j.1752-1688.1998.tb04150.x]

Hawkins, R. H. 1993. Asymptotic determination of runoff curve numbers from data. *Journal of Irrigation and Drainage Engineering*, 119(2), 334-345. [doi:10.1061/(ASCE)0733-9437(1993)119:2(334)]

Hjelmfelt, A. T. 1991. Investigation of curve number procedure. *Journal of Hydraulic Engineering*, 117(6), 725-737. [doi:10.1061/(ASCE)0733-9429(1991)117:6(725)]

Ministry of Planning and International Cooperation (MOPIC). 1996. *Valuable Agricultural Land in the West Bank Governorate Emergency Natural Resources Protection Plan*: *Directorate for Urban and Rural Planning*. Palestine: General Directorate of the Ministry.

Mishra, S. K., Singh, V. P, Sansalone, J. J., and Aravamuthan, V. 2003. A modified SCS-CN method: Characterization and testing. *Water Resources Management*, 17(1), 37-68. [doi:10.1023/A:1023099005944]

Mishra, S. K., and Singh, V. P. 2004. Validity and extension of the SCS-CN method for computing infiltration and rainfall-excess rates. *Hydrological Processes*, 18(17), 3323-3345. [doi:10.1002/hyp.1223]

Mishra, S. K., Sahu, R. K, Eldho, T. I., and Jain, M. K. 2006. An improved I_a-S relation incorporating antecedent moisture in SCS-CN methodology. *Water Resources Management*, 20(5), 643-660. [doi:10.1007/s11269-005-9000-4]

Moglen, G. E. 2000. Effect of orientation of spatially distributed curve numbers in runoff calculations. *Journal of the American Water Resources Association*, 36(6), 1391-1400. [doi:10.1111/j.1752-1688.2000.tb05734.x]

Ponce, V. M., and Hawkins, R. H. 1996. Runoff curve number: Has it reached maturity? *Journal of Hydrologic Engineering*, 1(1), 11-19. [doi:10.1061/(ASCE)1084-0699(1996)1:1(11)]

Rofe and Raffety Consulting Engineers. 1965. *Nablus District Water Resources Survey: Geographical and Hydrological Report*. Hashemite Kingdom of Jordan Central Water Authority.

Schulze, R. E., Schmidt, E. J., and Smithers, J. C. 1992. *SCS-SA User Manual PC Based SCS Design Flood Estimates for Small Catchments in Southern Africa*. Pietermaritzburg: Department of Agricultural Engineering, University of Natal.

Shadeed, S. 2008. *Up To Date Hydrological Modeling in Arid and Semi-arid Catchment, the Case of Faria Catchment, West Bank, Palestine*. Ph. D. Dissertation. Freiburg: Freiburg University.

Shrestha, M. N. 2003. Spatially distributed hydrological modeling considering land-use changes using remote sensing and GIS. *Map Asia Conference*.

Soil Conservation Service (SCS). 1985. *Hydrology, National Engineering Handbook*. Washington, D. C: Soil Conservation Service, USDA.

Soil Conservation Service, United States Department of Agriculture (SCS-USDA). 1986. *Urban Hydrology for Small Watersheds*. Washington, D. C.: U. S. Government Printing Office.

United Nation Environment Programme (UNEP). 2003. *Desk Study on the Environment in the Occupied Palestinian Territories*. Nairobi.

Williams, J. R. 1995. The EPIC model. Singh, V. P., ed., *Computer Models of Watershed Hydrology*. CO: Water Resources Publications.

Xu, A. L. 2006. A new curve number calculation approach using GIS technology. *ESRI 26th International User Conference on Water Resources*.

Young, R. A., Onstad, C. A., Bosch, D. D., and Anderson, W. P. 1987. *AGNPS, Agricultural Non-Point Source Pollution Model: A Watershed Analysis Tool*. Washington, D. C.: USDA-ARS.

Yu, B. F. 1998. Theoretical justification of SCS method for runoff estimation. *Journal of Irrigation and Drainage Engineering*, 124(6), 306-310. [doi:10.1061/(ASCE)0733-9437(1998)124:6(306)]

Zhan, X. Y., and Huang, M. L. 2004. ArcCN-Runoff: An ArcGIS tool for generating curve number and runoff maps. *Environmental Modeling & Software*, 19, 875-879. [doi:10.1016/j.envsoft.2004.03.001]