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ORIGINAL PAPER

A simplified GIS-based SCS-CN method for the assessment of land-use change on runoff

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Abstract

The purpose of this study is to evaluate the impact of land-use alteration over years on potential runoff volumes for the Gaza Strip. The runoff curve number (CN) is an important factor to calculate the runoff volume in the standard Soil Conservation Service (SCS) method. The standard SCS-CN method takes too much time when calculating and analyzing composite curve number in hydrologic modeling. Therefore, GIS was coupled with HEC-GeoHMS which includes land topography to produce more accurate CN and runoff volumes for the Gaza Strip catchments. The uniqueness of the developed approach is its simplicity and inclusiveness of influential parameters for accurate CN prediction. Results show that land-use changes over time play an important role in CN number and runoff volumes. Moreover, the use GIS with HEC-GeoHMS and SCS-CN methods provides a quick and accurate method of calculating CN and runoff volumes when compared with the rational method.

Keywords GIS · HEC-GeoHMS · Surface runoff · SCS-CN method · Digital elevation model · Soil type · Land use/land cover

Introduction

There are different physically and conceptually based distributed hydrologic models, which compute runoff volumes at a given watershed with different rainfall events. These models require extensive data and considerable time efforts to be used effectively. To simplify the calculation of runoff volumes, Soil Conservation Service-curve number (SCS-CN) method is considered a relatively more efficient method that can produce acceptable results (Schulze et al. 1992).

The SCS-CN method (SCS 1985) is an accepted method for calculating the runoff volume in watersheds for different rainfall events. This method uses readily accessible tables and empirical formulas to generate representative values of the curve number. In urban areas, runoff is generally high due to low infiltration, which corresponds to high curve number. On the other hand, in suburb areas, runoff is low with high infiltration due to the dry soil which corresponds to low curve number. Hydrologic soil group (HSG) and land use are the main components to calculate the curve number. The SCS-CN method presents a quick method for the estimation of runoff volume and was applied for small watersheds. It can be efficiently used to assess the changes in runoff volumes due to land-use changes (Shrestha 2003; Zhan and Huang 2004).

Many kinds of literature used SCS-CN method to assess runoff generation. For instance, El-Hames (2012) employed the SCS-CN method to obtain the maximum runoff in the catchments. Kottegoda et al. (2000) used CN methods with statistical models to find runoff volumes for many river basins in Italy. Lin et al. (2007) used curve number technique to find out how environmental runoff changed due to land-use change. Isik et al. (2012) used the curve number method and artificial neural networks to investigate how land-use changes affect runoff. Shadeed and Almasri (2010) applied SCS-CN with GIS to predict CN and runoff values for West Bank. Hamdan et al. (2007) and Hamad et al. (2012) studied the impact of land-use change on stormwater runoff and water budget. Hamdan et al. (2007) used the rational method to calculate the runoff volumes due to land-use change in urban and suburban areas in each of Gaza Strip

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governorate. Hamad et al. (2012) used GIS technique to evaluate how the land-use change impacts the water budget for Gaza districts.

In this study, a novel model is developed to produce more accurate CN for the Gaza Strip catchments. In this model, GIS is coupled with HEC-GeoHMS tools and land topography to accurately estimate curve number for varying land use between 2004 and 2010 for these catchments. HEC-GeoHMS tools considered soil type, land use, and digital elevation model (DEM) to calculate the CN using GIS. This approach is simple and inclusive of influential hydrological parameters (e.g., land use/land cover, soil, land topography) for accurate prediction of CN. Moreover, the model is the first of its kind to be developed for the Gaza Strip.

Study area

Gaza Strip is situated on the eastern coast of the Mediterranean Sea and border Egypt on the south and Israel on the North and West, with a total area of 365 km^2. The length of the Gaza Strip is approximately 41 km long. The width of the Gaza Strip varies between 6 and 12 km. Nowadays, the population of the Gaza Strip is approximately 1.9 million with a population density of 5205 people/km^2.

Gaza Strip experiences severe water problems. Groundwater aquifer is considered as the main water supply source, used for all sectors. This groundwater is recharged only by rainfall, with around 55 million cubic meters per year and average rainfall of 317 mm per year (Metcalf and Eddy 2000; Fisher et al. 2005). The study area contains 16 subwatersheds. Around 155 million cubic meters of water abstracted from the aquifer with approximately 105 million cubic meters is recharged into the aquifer with shortage equal to 50 million cubic meters (Fisher et al. 2005).

Data collection

The three parameters (soil type, land use/land cover, and DEM) which are employed to obtain the CN for Gaza Strip watersheds using HEC-GeoHMS will be discussed briefly. The soil-type and land-use maps are obtained from Palestinian Water Authority (PWA 2012). The DEM map was obtained from NASA website. The DEM map shows the ground surface topography. The soil types were converted to HSGs like A, B, C, and D based on the infiltration capacity of a soil.

Soil type

The Gaza Strip has eight different soil types as shown in Fig. 1 (PEPA 1996). The sandy soil is found to be sand dunes along the coastline of the Gaza Strip (A1-Agha 1995). The depth of the sand dunes ranges from 2 to about 50 m. The sand dunes stretch out to 5 km in the north and south and to less extent in the middle of the Gaza Strip. Towards the east, the soil becomes silt, clay, and loess. Towards the northeast, the soil becomes dark brown (clay). The loess soil is found in valleys, with a depth of up to 25 to 30 m (Aish and De Smedt 2004).

Land use

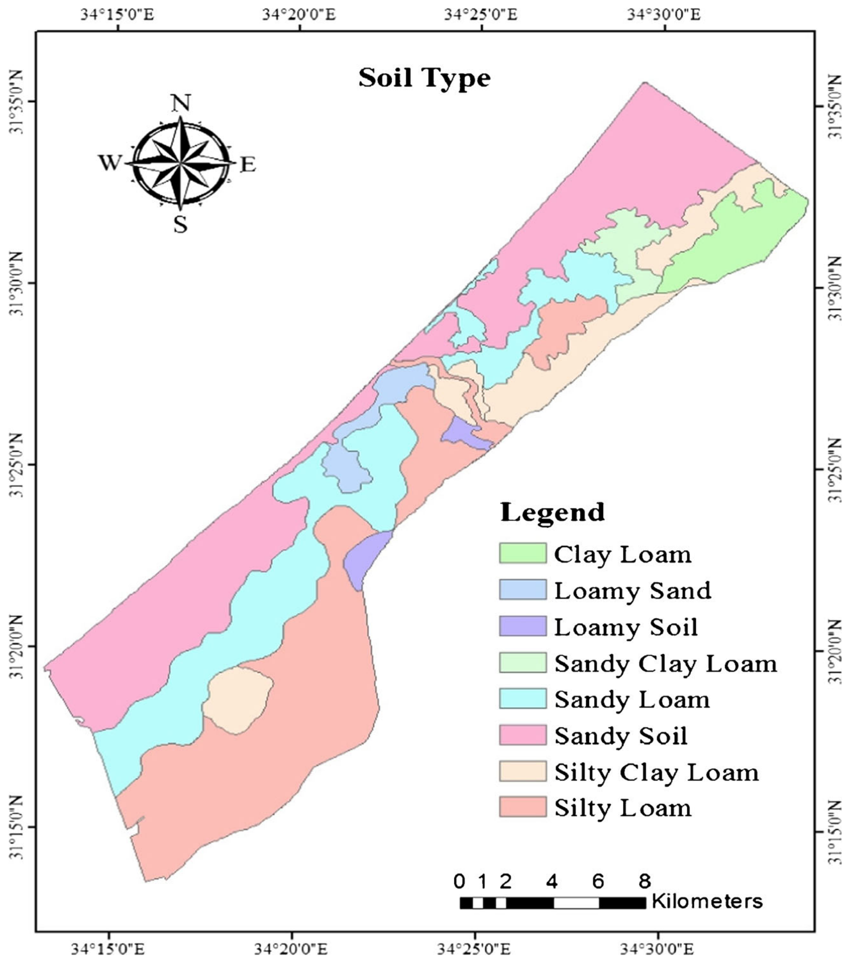
The distributions and classifications of the land use in the Gaza Strip governorates in 2010 are shown in Fig. 2. The agricultural areas comprise approximately 40% of the Gaza Strip. The agricultural areas are situated in the eastern parts of the Gaza Strip. The urban buildup areas represent 25% of the Gaza Strip land use, and the natural resource areas approximately cover 16.99%. The average population density of the Gaza Strip is 5205 people/km^2. Approximately 80% of people reside in the buildup of residential areas.

Land topography—digital elevation model

The DEM map for the Gaza Strip was obtained from NASA website in a resolution of 90 × 90 m based on the Automated Geospatial Watershed Assessment Tool (AGWA) requirements (see Fig. 3). The terrain model in this study was verified through conducting a field survey to cover the whole area of the Gaza Strip. The main equipment that has been used in the land survey is differential global positioning system (DGPS) with an accuracy of millimeters to identify the coordinates of the benchmark (BM) according to the local coordinate system (Palestinian Grid 1923) in each target area of surveying. In addition, the total station device was used to measure the elevation of different points corresponding to the BM. Once the field topography survey has been completed, all measured elevations are used in GIS to produce the digital terrain model (DTM) which represents the natural continuous land topography. Additionally, in order to verify the model results, elevation measurement has been conducted for 25 points that were selected randomly from the Gaza Strip. The results show that there is a match between the model and the field regarding the elevation.

Generally, the land topography of the Gaza Strip tends to incline from east to west with an irregular shape. The maximum elevation reaches around 110 m higher than mean sea level at the eastern border while in the west has the same sea level. A detailed topography map of the Gaza Strip is described in Al-Hallaq and Abu Elaish (2008). Most quantities of stormwater runoff transmit from east to west and are collected in the lowest elevation point.

Fig. 1 Soil type map of the Gaza Strip



Methodology

Figure 6 shows the steps for the GIS-based SCS-CN method which has been adopted for this study. First, soil type and land use/land cover (LULC) were processed in the GIS database. LULC was obtained for the years of 2004 and 2010. Then, soil type has been categorized into four types A, B, C, and D according to HSG characteristics. Using Arc-Map GIS, land use and soil maps were then intersected to generate new polygon linked with HSGs and LULC names. This is to maintain all elements of spatial distribution of LULC and soil type. Afterward, the intersected land use and soil and related attribute table were used with DEM map, to build the curve number database using HEC-GeoHMS (US Army Corps of Engineers 2013). Then, a database of calculated CN from GIS was used to produce curve number (CN) maps for 2004 and 2010. Using the proposed CSC-CN model, a comparison is made to investigate how the change in land use from 2004 and 2010 affected the CN and runoff volume for the Gaza Strip catchments (see Figs. 4 and 5, Table 1). The runoff volumes for the entire Gaza Strip predicted using the proposed SCS-CN model is compared with the results from the rational method. The comparison reveals that the current model reasonably predicts the runoff volumes (6% difference from the rational method, see Table 2). The key feature of the SCS-CN model is the use of GIS maps for Gaza Strip with fewer details of land use that has been categorized according to the relevance of use to the expected changes in runoff values. Hence, the model data input is greatly simplified and the time is significantly decreased. The major advantage of the current model is that it provides a practical tool and robust results with fewer details of land use as input in contrast with the rational method. This leads to a very time-efficient model for predicting runoff volumes.

Soil Conservation Service-curve number

The SCS-CN method has developed to calculate approximately the direct runoff from rainfall. This method was recognized for runoff estimation in small agricultural watersheds (USDA 2004). After a storm event occurs, there is a limit that rainfall should be exceeded prior to the occurrence of runoff. Prior to the start of runoff, the rainfall must satisfy all losses. The losses are composed of infiltration, interception, and depression storage. The rainfall, which is required to satisfy the

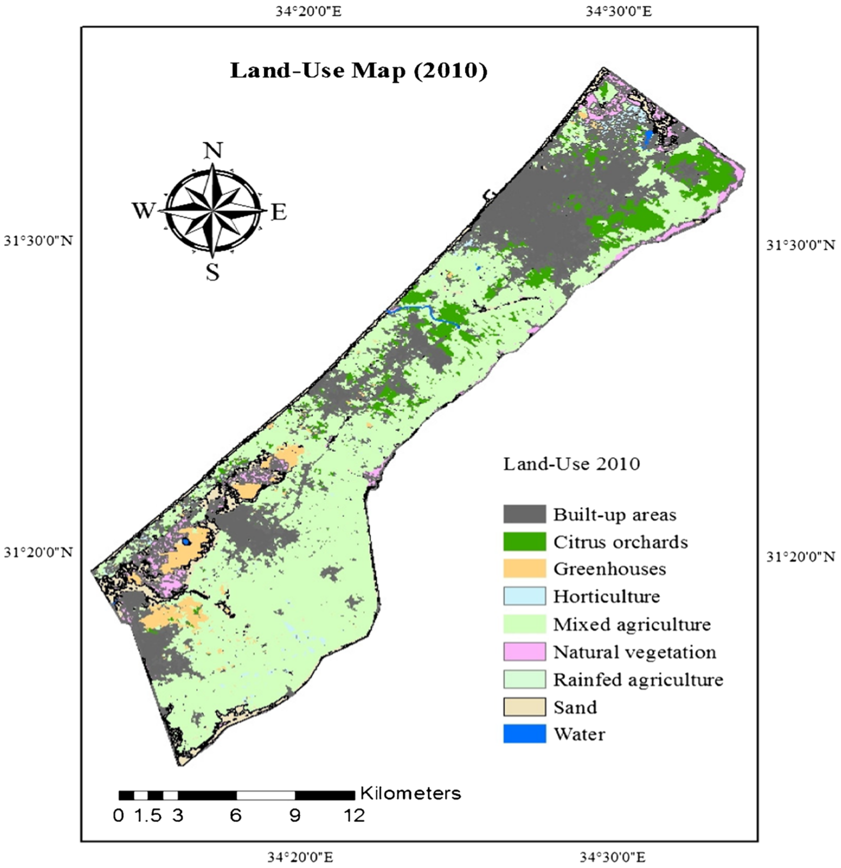


Fig. 2 Detailed map of land use for the Gaza Strip for the year of 2010

losses, is called the initial abstraction (Hawkins et al. 1985; Hawkins 1993; Hjelmfelt 1991; USDA 2004).

The standard SCS-CN method depends on water budget in a recognized time step Δt and can be expressed as:

$$P = I_a + F + Q \tag{1}$$

where P is total precipitation, I_a is an initial abstraction and represents all losses before the beginning of runoff, F is cumulative infiltration except I_a, and Q is direct surface runoff volume occurring in time Δt.

It is assumed that the ratio of actual infiltration to the potential maximum infiltration (e.g., maximum retention) is similar to the ratio of direct runoff Q to the maximum potential runoff $P - I_a$) according to SCS-USDA (1986) and Schulze et al. (1992).

$$\frac{F}{S} = \frac{Q}{P - I_a} \tag{2}$$

When combining Eqs. (1) and (2), the following relation between P (mm) and Q (mm) is obtained (SCS-USDA 1986; Schulze et al. 1992):

$$Q = \frac{(P - I_a)^2}{P - I_a - S}, P > I_a \tag{3}$$

where S (mm) is the highest amount of infiltration after started of runoff. I_a is vastly variable but highly connected to soil and land cover parameters. Another assumption suggested by SCS (1985) is that the amount of initial abstraction I_a is a portion of the ultimate amount of infiltration, as $I_a = \lambda S$, where λ is an initial abstraction ratio. Shrestha (2003) suggests that the λ values are in the range of 0 to 0.3. It is found that the initial abstraction for small agricultural catchments is equal to 0.2S ($I_a = 0.2S$). When substituting I_a in Eq. (3), the final relation between runoff amounts can be and rainfall is estimated as:

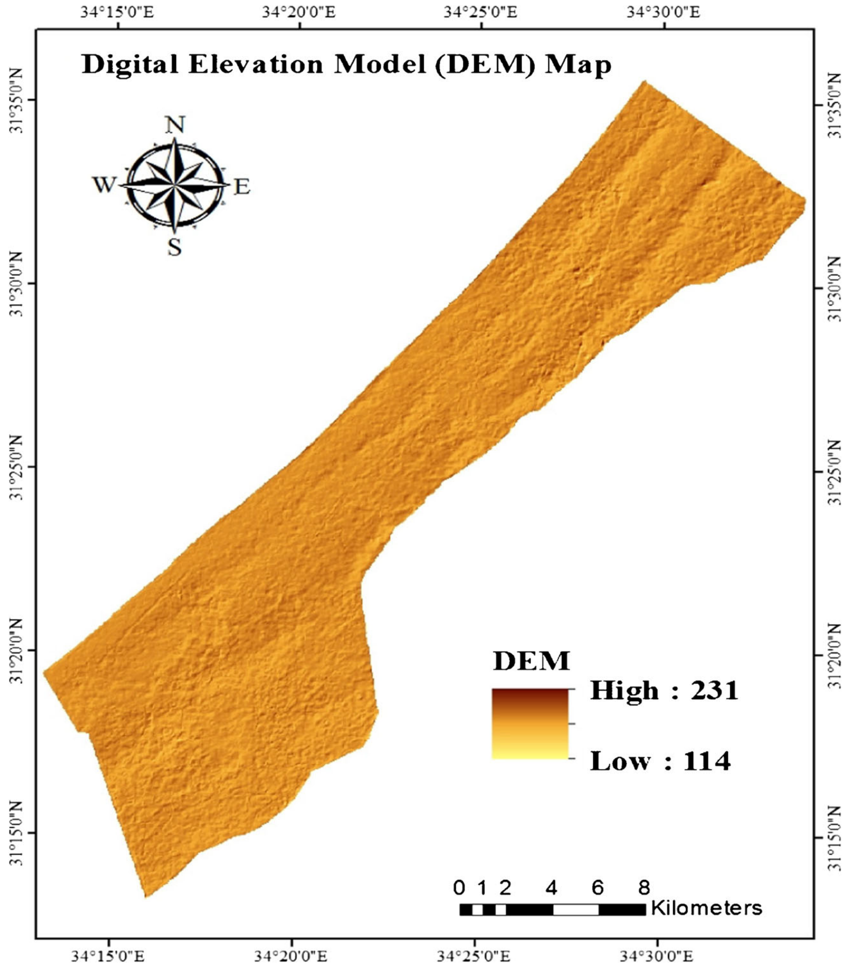
$$Q = \frac{(P - 0.2S)^2}{P + 0.8S}, P > 0.2S \tag{4}$$

The parameter S representing the maximum infiltration depends on antecedent soil moisture and soil-vegetation-land-use complex in the catchment and can be estimated as:

$$S = \frac{25400}{CN} - 254 \tag{5}$$

where CN is a dimensionless parameter for a given catchment varying from 0 to 100. The highest CN of 100 corresponds to a zero retention for an impervious catchment,

Fig. 3 Digital elevation model (DEM) map of the Gaza Strip



in which all rainfall becomes runoff. On the other hand, a CN of zero means no runoff regardless of the amount of rainfall. The HSG represents the standard SCS soil classifications. Type A refers to a soil that has high infiltration rates such as sand or gravel. Type D represents soils that have low infiltration rates, such as clayey loam, clay. The maximum infiltration rates for HSG types A, B, C, and D are 25, 13, 6, and 3 mm/h, respectively. The permeability rates for HSG type A should be greater than 7.6 mm/h, while the permeability rate for type D is less than 1.3 mm/h.

For a catchment that has various land uses and soil types, a composite CN can be computed for the different land uses:

$$CN_c = \frac{CN_1A_1 + CN_2A_2 + .\cdots + CN_iA_i + \cdots + CN_nA_n}{\sum_{i=1}^{n} A_i} \quad (6)$$

where CN_i is the curve number of the subarea i, A_i is the area of each land use/cover i, and n is the number of land uses/covers. In this paper, CN_{II} is original CN which is calculated from the model HEC-GeoHMS. It is considered for moderate antecedent moisture condition ($\mathrm{AMC_{II}}$). Then, the values CN_{II} were transferred to CN_I based on Eq. (7), which is employed for dry antecedent moisture condition ($\mathrm{AMC_I}$), according to Chow et al. (1988).

$$CN_I = \frac{CN_{II}}{2.334 - 0.01334CN_{II}} \quad (7)$$

$$CN_{III} = \frac{CN_{II}}{0.4036 - 0.059CN_{II}} \quad (8)$$

Gaza Strip is considered dry conditions for all four seasons (events) because 5-day antecedent rainfalls are less than 35 mm. Thus, CN_{I} for $\mathrm{AMC_I}$ is considered in calculating the volumes of direct runoff.

Performance of SCS-CN method

In this section, a comparison has been made between the runoff volumes which are estimated by SCS-CN and rational

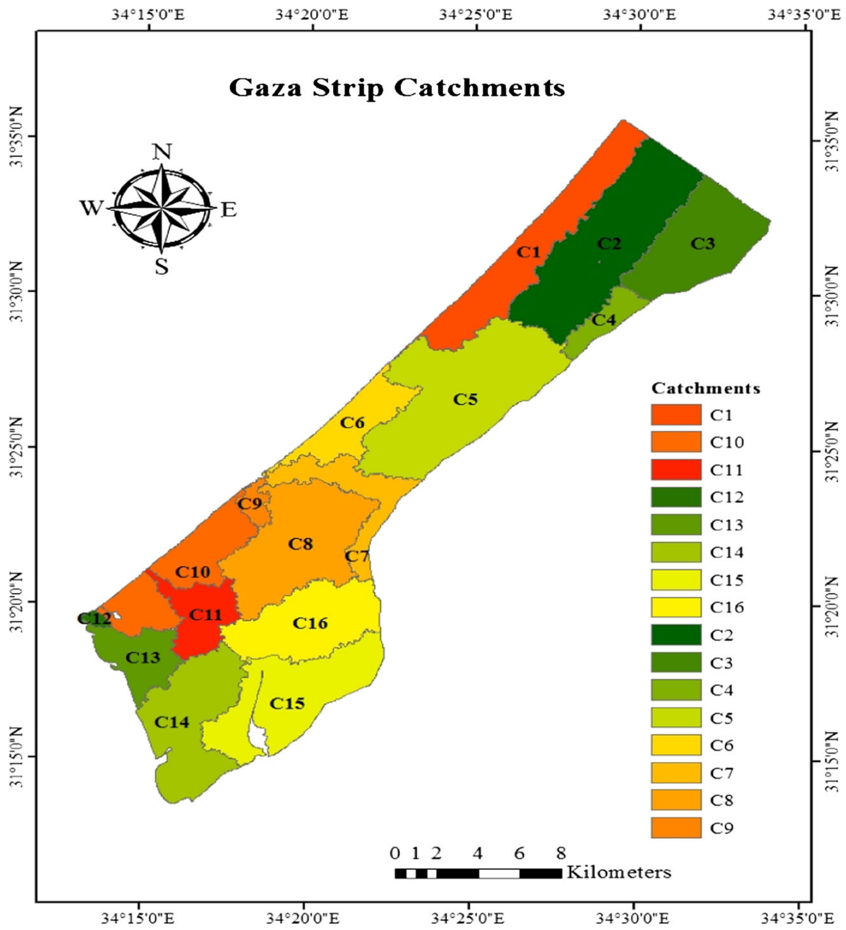


Fig. 4 Gaza Strip catchments

methods. The rational method is applied for Gaza governorates, and runoff values were obtained for each governorate. Then, a comparison of total runoff volumes obtained from the rational method is validated against the runoff volumes

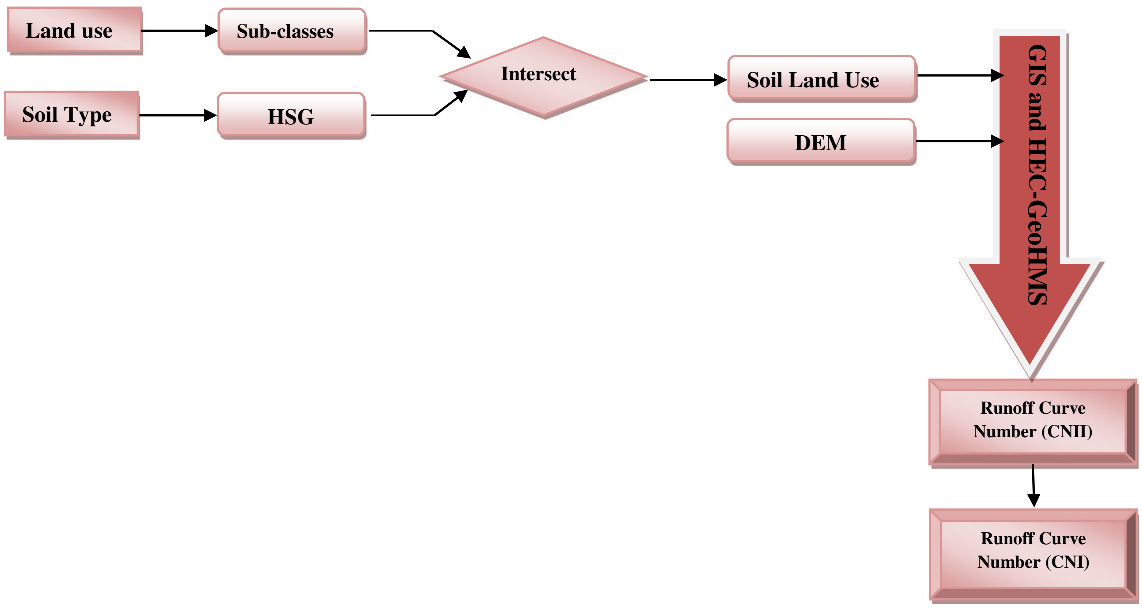


Fig. 5 Flowchart of the methodology

Table 1 Obtained CN values from SCS-CN and computed runoff volume (m^3)

Catchment	Precipitation (mm)		2004					2010				
		Area (km^2)	*CN*	*S*	I_a (mm)	*Q* (mm)	*Q* (m^3)	*CN*	*S*	I_a (mm)	*Q* (mm)	*Q* (m^3)
C1	300	31.5	82	56	28	215	6,762,841	85	45	18	237	7,455,595
C2	335	44.9	86	41	21	268	12,059,116	90	28	11	293	13,165,636
C3	380	27.0	80	64	32	282	7,600,170	80	64	25	292	7,879,860
C4	300	6.8	80	64	32	205	1,395,479	80	64	25	215	1,462,328
C5	330	51.5	70	109	54	182	9,380,117	73	94	38	211	10,873,331
C6	290	14.7	59	177	88	94	1,389,510	62	156	62	125	1,841,649
C7	280	14.6	59	177	88	87	1,274,951	60	169	68	108	1,584,035
C8	275	35.8	49	264	132	42	1,502,559	52	234	94	71	2,544,290
C9	270	3.4	68	120	60	121	412,267	71	104	41	148	504,438
C10	260	23.2	84	48	24	186	4,327,699	86	41	17	202	4,701,632
C11	250	12.8	81	60	30	163	2,091,106	83	52	21	180	2,312,094
C12	245	1.3	80	64	32	154	198,288	80	64	25	163	210,273
C13	210	12.5	85	45	22	143	1,782,058	87	38	15	158	1,966,022
C14	210	27.8	69	114	57	78	2,156,020	69	114	46	90	2,489,761
C15	235	31.2	69	114	57	97	3,024,917	69	114	46	110	3,425,339
C16	250	26.0	69	114	57	109	2,832,551	69	114	46	122	3,177,523
Total		365.0					58,189,649					*65,593,805

*The summation of the runoff volume for 2010 is 65.59 Million m^3 (MCM)

obtained from the SCS-CN method for all Gaza Strip. The runoff volume deviation (D_v) in percentage was calculated to check the SCS-CN performance and was computed as follows:

$$D_v = \frac{Q_{SCS-CN} - Q_{RM}}{Q_{SCS-CN}} \times 100\% \tag{9}$$

where Q_{SCS-CN} is the simulated runoff volume from SCS-CN and Q_{RM} is the calculated runoff volume from the rational method.

The rational method

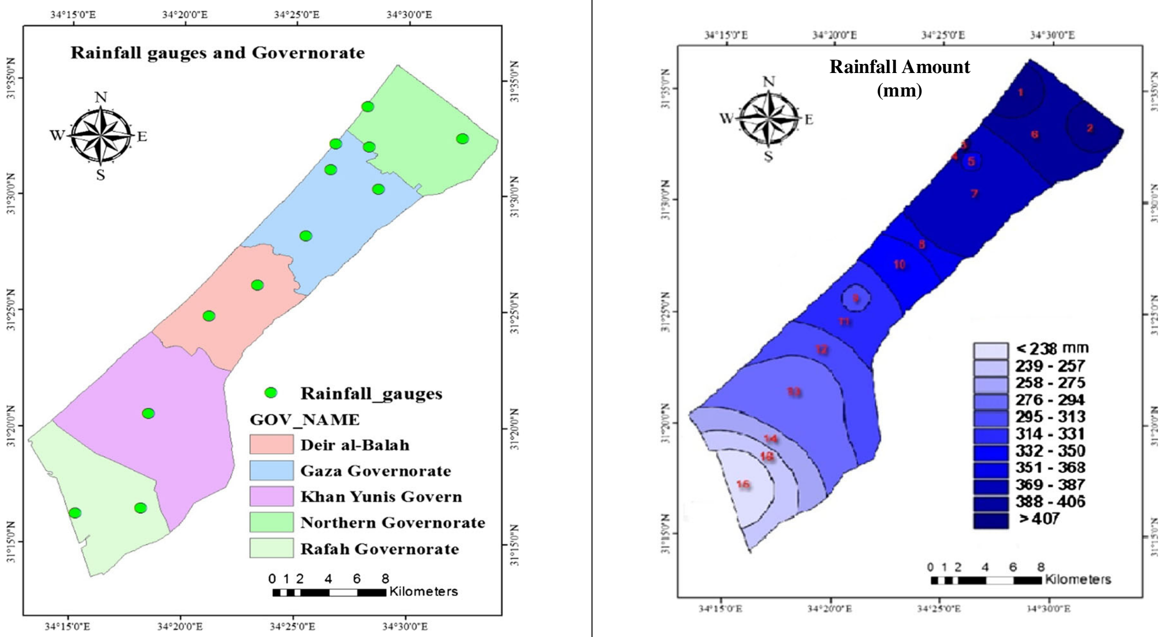
The rational method has been used for estimation of annual runoff volume from stormwater in each governorate according to Kiely (1996):

$$Q = C \times i \times A \tag{10}$$

where Q is the calculated volume of runoff (m^3), i is rain intensity (mm/h), and $A$is the land-use area (m^2). The total

Table 2 Land-use areas for the year of 2004 and 2010 with the corresponding coefficient of runoffs (C)

ID	Land-use type	C of existing land use	Area (km^2) 2004	Percent	Area (km^2) 2010	Percent
0	Airport	0.80	7.5	2.05%	7.5	2.05%
1	Buildup	0.865	46	12.60%	54	14.79%
2	Cultivated	0.15	168	46.03%	157.5	43.15%
3	Existing industrial area	0.865	0.9	0.25%	0.9	0.25%
4	Wastewater treatment site	0.00	0.45	0.12%	0.45	0.12%
5	Fishery site	0.865	0.3	0.08%	0.3	0.08%
6	Harbor	0.865	0.35	0.10%	0.35	0.10%
7	Important natural resources 1	0.075	24	6.58%	24	6.58%
8	Mawasi (sand)	0.075	14.5	3.97%	14.5	3.97%
9	Natural resource 2	0.075	62	16.99%	62	16.99%
10	Natural reserve	0.075	27	7.40%	26.5	7.26%
11	Proposed treatment site	0.00	1.1	0.30%	1.1	0.30%
12	Recreation	0.075	6.7	1.84%	6.1	1.67%
13	Roads	0.891	6.2	1.70%	9.8	2.68%



a) Rainfall gauges stations of the Gaza Strip.

b) Rainfall amount distribution (mm) for the Gaza Strip (adapted from Al-Hallaq and Abu Elaish 2008).

Fig. 6 Rain gauges distribution and rainfall amounts in the Gaza Strip. **a** Rainfall gauges stations of the Gaza Strip. **b** Rainfall amount distribution (mm) for the Gaza Strip (adapted from Al-Hallaq and Abu Elaish 2008)

amount of surface runoff is obtained based on the total amount of runoff volumes in all governorates:

$$Q = \sum Q_{NorthernGaza} + Q_{Gaza} + Q_{DeirAl-Balah} + Q_{KhanYunis} + Q_{Rafah} \tag{11}$$

The rational formula is used to calculate the runoff volume for each governorate:

$$Q_{gn} = i_g \times \sum \left(C_{Lg} \times A_{Lg} \right) \tag{12}$$

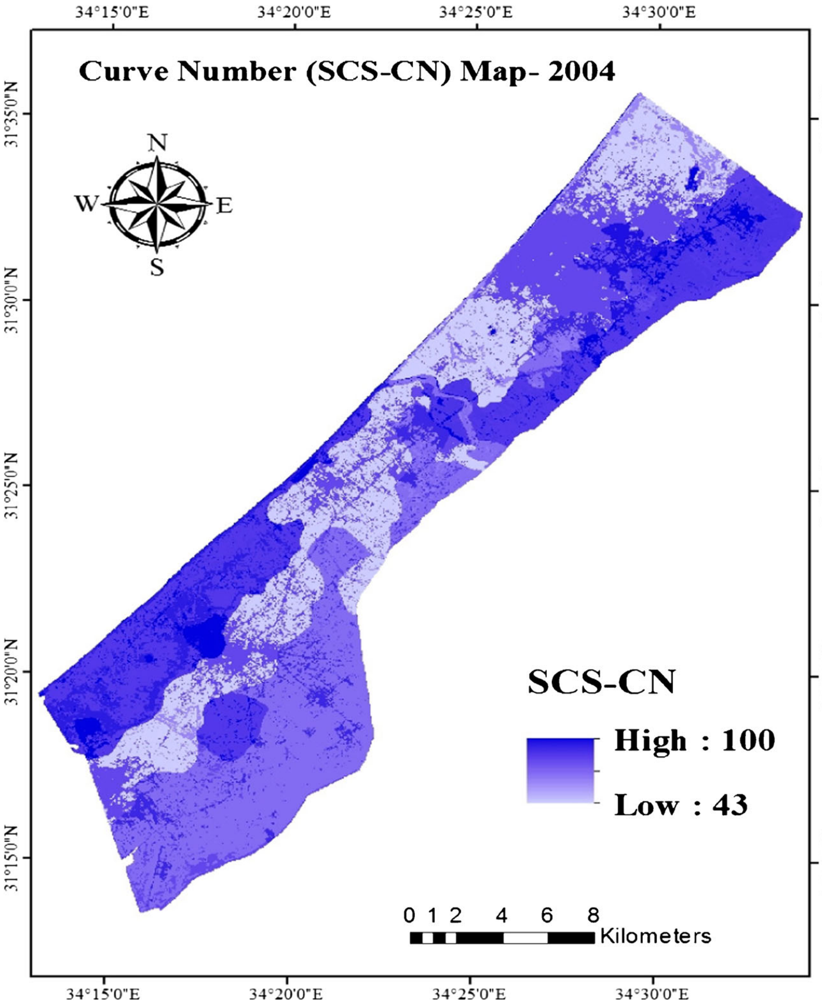
where Q_{gn} is the quantity of runoff volume in the governorate n (m^3/s), i_g is the average annual rainfall, C_{Ln} is the coefficient of runoff of land use L in the governorate g (dimensionless), and A_{Lg} is the area of land use (L) in the governorate g (m^2). More details about the runoff coefficients and precise land-use area are described in details in Hamdan et al. (2007).

The calculation of runoff volume depends on applying the rational method on various land-use categories in each of the Gaza Strip governorates. The rainfall intensities are obtained from Al-Hallaq and Abu Elaish (2008) based on Isohyets method. Rainfall intensities are obtained from spatially distributed rain-gauge stations (see Fig. 6). GIS is also is used to obtain the area of each land-use category in each governorate. Therefore, the runoff coefficient (C) varies among land-use categories. More details of the runoff coefficient for different land-use categories are shown in Table 2 and described in Khalaf et al. (2006) and Hamdan et al. (2007). The potential runoff volume was estimated for both the urban and suburban land-use categories and compared with the runoff volumes obtained from the SCS-CN model (see Table 3). The results show that simulated runoff volumes from SCS-CN are slightly higher than the calculated runoff volumes from the rational method. This could be interpreted as a low estimation of maximum infiltration (S) in the SCS-CN method. The maximum infiltration (S) may be underestimated in the

Table 3 Computed runoff volume in Million m^3 (MCM) for 2004 and 2010 using the rational method and compared with SCS-CN

	Rational method	
Governorate	Land use 2004	Land use 2010
Northern	7,355,976	8,760,579
Gaza	17,768,709	19,375,420
Deir al-Balah	8,979,242	9,682,981
Khan Yunis	12,926,095	13,846,787
Rafah	7,471,398	8,672,188
Total (MCM) rational method	54,501,420	60,337,955
Total (MCM) SCS-CN	58,189,649	65,593,805
Deviation (%)	6.19	8.01

Fig. 7 Computed CN map (2004) of the Gaza Strip



SCS-CN, as they should be increased to represent dry regions such as the Gaza Strip. Since the SCS-CN was developed for calculating runoff volume for the wet region, an empirical formula for calculating S should be developed to represent dry regions. However, the values of D_v between the simulated runoffs from SCS-CN and rational method for 2004 and 2010 are 6.19 and 8.01%, respectively (see Table 3). This deviation is not very significant and may occur because of initial abstraction. In other words, when comparing the calculated runoff from SCS-CN and rational method, the accuracy of estimating runoff from SCS-CN method is about 93%. This accuracy is practically sufficient to present good credibility of utilizing SCS-CN method for estimating runoff volume for the semi-arid regions.

Results and concluding remarks

Curve numbers and runoff values for the Gaza Strip are an important factor as the area is expanding due to the increase in population. It considers as a major data for flood and hydrologic cycle calculations. This paper integrated GIS with the SCS-CN methods to predict the runoff volume for the Gaza Strip catchments. The CN values were obtained and examined by analysis of meteorological data, land use, and land topography (DEM) within the GIS, which is coupled with HEC-GeoHMS. Using HEC-GeoHMS along with GIS allows including the land topography (DEM) as an important factor to accurately predict the CN and runoff volumes. In this study, CN and runoff were estimated for the years of 2004 and 2010, based on different land uses for those years.

Figures 7 and 8 show the values of CN for whole Gaza Strip in both years 2004 and 2010, respectively. The result shows that the land alteration has affected the CN and runoff volumes. For instance, CN values for 2004 for catchment 1 and catchment 2 were 52 and 64, respectively (see Fig. 7). While the values of CN for 2010 for catchments 1 and 2 are 61 and 66, respectively. This increase in CN value refers to the urban sprawl (expending) of the residential areas. Correspondingly, the values of runoff increased from 2004 to 2010 in catchments C1 and C2, as

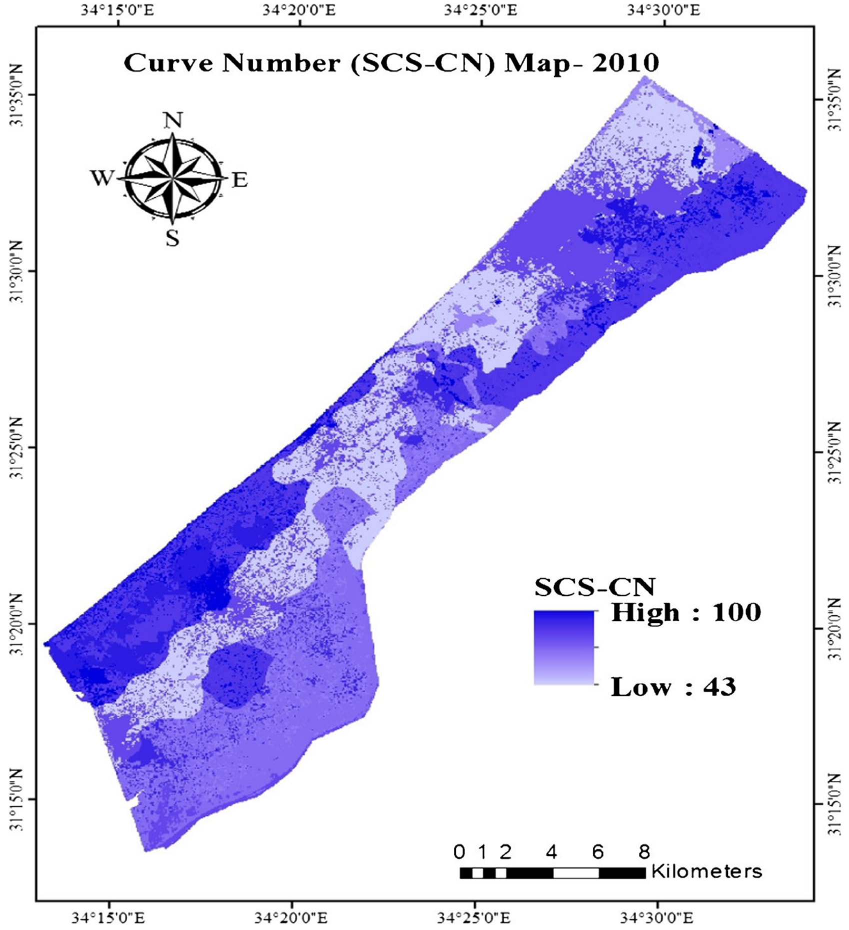


Fig. 8 Computed CN map (2010) of the Gaza Strip

shown in Table 1. Therefore, it can be clearly concluded that the results provide accurately informative information about land-use change on runoff.

As shown in Table 2, it is also noticed that CN and runoff values remain constant in most of the area where no significant change in agricultural production and land use occurs, especially in the south eastern governorates of Deir al-Balah, Khan-Younis, and Rafah (corresponds to catchments 14, 15, and 16 in Fig. 4).

In conclusion, this study developed a model to produce a more accurate CN for the Gaza Strip catchments. When GIS is coupled with HEC-GeoHMS tools and land topography, it provides more accurate estimate of curve number and runoff volumes for changing land use between 2004 and 2010. This approach provides useful information for decision-makers with regard to land development and future runoff potential to mitigate the risk of flood. Moreover, this approach is accurate, quick, and inclusive to all influential parameters for accurate prediction of CN and runoff values when compared to the rational method.

Since SCS-CN was developed originally for agricultural catchments in a humid region, it is therefore recommended that the initial abstraction is used to calculate the runoff volume to be verified for semi-arid catchments.

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References

Al-Agha M (1995) Environmental contamination of groundwater in the Gaza Strip. Environ Geol 25:109–113

Aish A, De Smedt F (2004) Modeling of a groundwater mound resulting from artificial recharge in the Gaza Strip, Palestine, Proceedings of the Second Israeli-Palestinian International Conference on Water for Life in the Middle East, October 10–14, 2004, Turkey, pp 114–122

Al-Hallaq A, Abu Elaish BS (2008) Determination of mean areal rainfall in the Gaza Strip using geographic information system (GIS) technique. University of Sharjah Journal of Pure and Applied Sciences 5(2):105–126

Chow VT, Maidment DR, Mays LW (1988) Applied hydrology. McGraw-Hill, New York

El-Hames AS (2012) An empirical method for peak discharge prediction in ungauged arid and semi-arid region catchments based on morphological parameters and SCS curve number. J Hydrol 456-457:94–100

Fisher FM et al (2005) Liquid assets: an economic approach for water management and conflict resolution in the Middle East and beyond, resources for the future. Routledge, Washington, D.C 272

Hamad J, Eshtawi T, Abushaban A, Habboub M (2012) Modeling the impact of land-use change on water budget of Gaza Strip. J Water Resour Prot 4:325–333

Hamdan S, Troger U, Nassar A (2007) Stormwater availability in the Gaza Strip, Palestine. Int J Environ Health 1(4):580–594

Hawkins RH (1993) Asymptotic determination of runoff curve numbers from data. J Irrig Drain Eng 119(2):334–345

Hawkins RH, Hjelmfelt AT, Zevenbergen AW (1985) Runoff probability, storm depth, and curve numbers. J Irrig Drain ASCE 111(4):330–340

Hjelmfelt AT (1991) Investigation of curve number procedure. J Hydraul Eng 117(6):725–737

Isik S, Kalin L, Schoonover J, Sirvastava P, Lockaby G (2012) Modeling effects of changing land use/cover on daily streamflow: an artificial neural network and curve number based hybrid approach. J Hydrol 485:103–112

Khalaf A, Al-Najjar H, Hamad J (2006) Assessment of rainfall runoff due to proposed regional plan for Gaza governorates. J Appl Sci 6(13): 2693–2704

Kiely G (1996) Environmental Engineering, Mulvancy 1851, Kuichling 1889 and Lioyd-Davis 1906. In: Kiely G (ed) McGraw Hill, Boston. pp 187–199. ISBN 0-07-116424-3

Kottegoda NT, Natale L, Raiteri E (2000) Statistical modeling of daily streamflows using rainfall input and curve number technique. J Hydrol 234(3–4):170–186

Lin YP, Hong NM, Wu PJ, Wu CF, Verburg PH (2007) Impacts of land use change scenarios on hydrology and land use patterns in the WuTu watershed in Northern Taiwan. Landsc Urban Plan 80:111–126

Metcalf, Eddy (2000) Integrated aquifer management plan: final report. Gaza Coastal aquifer Management Program (CAMP), Chicago

Palestinian Water Authority (PWA) (2012) Status report of water resources in the occupied state of Palestine, year of flooding water harvesting, Annual water resources status report. 17 p

PEPA (1996) Gaza environmental profile, Part one-inventory of resources. Palestinian Environmental Protection Authority (PEPA), Gaza, pp 1–21

Schulze RE, Schmidt EJ, Smithers JC (1992) SCS-SA user manual PC based SCS design flood estimates for small catchments in Southern Africa. Department of Agricultural Engineering, University of Natal, Pietermaritzburg

Shadeed S, Almasri M (2010) Application of GIS-based SCS-CN method in West Bank catchments, Palestine, Water Science and Engineering, 2010. 3(1):1–13

Shrestha MN (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. Soil Conservation Service, USDA, Washington, D. C

Soil Conservation Service, United States Department of Agriculture (SCS-USDA) (1986) Urban hydrology for small watersheds. U. S. Government Printing Office, Washington, D. C

United States Department of Agriculture (USDA) (2004) Estimation of direct runoff from storm rainfall. Part 630 Hydrology, National Engineering Handbook, Chapter 10, 78 p

US Army Corps of Engineers (2013) HEC-GeoHMS geospatial hydrologic modeling extension. User's manual. Version 10.1. Accessed August 8, 2014. http://www.hec.usace.army.mil/software/hec-geohms/documentation/HECGeoHMS_Users_Manual_10.1.pdf

Zhan XY, Huang ML (2004) Arc CN-runoff: an ArcGIS tool for generating curve number and runoff maps. Environ Model Softw 19:875–879