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SCS-Curve Number in Tropics: A Review

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Abstract – Rainfall-runoff information is critical for water resource and river basin management. Runoff can be estimated by using two methods; gauged method (direct measurement) and ungauged method (indirect formula and equation). The in-situ measurement provides real-time and accurate yet required time-consuming operation and inaccessibility topography. Therefore, the runoff estimation modelling and equation was developed to overcome the limitation of in-situ measurement. SCS-CN is a simple model of ungauged method, where runoff volume (Q) resulting from rainfall (P) is formulated using equation of ($Q= (P-Ia)^2 / (P-Ia + S)$). It was known as the best technique to be adopted for large basin study where time and manpower also accessibility are limited. SCS-CN method also is widely use in prediction software as it taken into consideration of the effects of soil, properties, land cover and antecedent moisture. Curve Number is well developed in USA for the agriculture purpose with many investigations to validate and calibrate the values of curve number. It was applied in numerous river basins in temperate and other regions e.g. US, Argentina, India, China, South Korea, Palestine and Malaysia. However, the reliability of the CN in the tropics is doubtable due to different land use characteristics, soil type, climate, geological features and rainfall pattern and variability. Based on the reviewed conceptual and applications of SCS-CN in temperate and tropics, numerous studies found the SCS-CN method is reliable and practical for runoff estimation in tropics region.

Keywords: Different characteristics, SCS-CN, reliability, runoff estimation, tropics vs temperate, validation.

Introduction

Rainfall-runoff (P-Q) relationship is the fundamental information in the hydrology science and study from the design of hydraulic structure, environmental impact assessment, climate change evaluation, drainage and irrigation planning, flood forecasting, pollution abatement and watershed management. The pioneer rainfall-runoff study started by P. Perreault in the Seine River in Paris in 1674. He was comparing the measured annual rainfall (P_a) and the estimated annual streamflow (Q_e) (Linsley, 1982). There are several methods to measure rainfall (e.g. manual rain gauge and automatic rainfall sampler) and runoff (e.g. in-situ measurement, conventional method and modelling). The selection of the method depends on the objectives of the study and the accuracy of the output. Phetprayoon et al. (2009) explained an in-situ measurement is deliberated more accurate however cannot be functioned at anytime and anyplace. Hence, rainfall-runoff modelling can provide the runoff information with more accurate in convenient and less time-consuming for larger watershed analysis.

Up to date, numerous rainfall-runoff model (up to thousand) have been develop which included the unpublished models. Rapid technology advancement allows more modification and combination of the rainfall-runoff modelling and latest advance tools e.g. geographical information system, remote sensing and etc., subsequently enhance the quality and accuracy of the output produced. Several examples of modelling and method for estimating Q from the P particularly in ungauged watershed are Soil Conservation Service Curve Number (SCS, 2004), Rational Method (Guo, 2011), Geomorphological

Instantaneous Unit Hydrograph (Kumar et al., 2007), Artificial Neural Network (Hsu et al., 1995), Agricultural Non-point Source Model (Bhuyan et al., 2002), and Soil and Water Assessment Tool (Rostamian et al., 2008). Generally, the available P-Q models expressed in the form of a water budget (Q = P – L) (Mishra and Singh, 2013), where Q is the runoff amount, P is the rainfall amount, L is the amount of hydrologic abstractions e.g. interception, soil storage, surface detention, infiltration, evaporation and evapotranspiration. Out of that, SCS-CN is the most extensive and broadly used by various practitioners, hydrologists and researchers all over the world due to it is flexibility and simplicity, understandable, applicable and consider factors generating runoff e.g. soil characteristics, land use cover, hydrologic state and antecedent moisture condition (Nayak and Jaiswal, 2003; Ebrahimian et al., 2009; Mishra and Singh, 2013).

Although SCS-CN has been used to a wide range of environments, yet the suitability, adaptability and sensitivity of the SCS-CN methods for the other regions e.g. tropics is quite doubtable and questionable. This is due to the origin of SCS-CN was developed by Soil Conservation Service, United State Department of Agriculture (USDA) to assist in agriculture watershed planning for U.S. which are temperate region. Unfortunately, to our knowledge, scarce studies in literature on the suitability of the SCS-CN application in tropics region, where most of published studies focuses in temperate due to this method established for temperate. Thus, the purpose of this article is to review the literatures and researches on the application of SCS-CN methods in the other regions, as well as tropics to evaluate the suitability of the SCS-CN methods in tropics region.

Soil Conservation Service Curve Number (SCS-CN)

SCS-CN was formerly established by Soil Conservation Services, USDA in 1954 and recorded in National Engineering Handbook (NEH-4) Section 4 in 1956 (Mishra and Singh, 2013). The SCS-CN is the result of the exhaustive in-situ study by Mockus (1949), Sherman (1949), Andrews (1954), and Ogrosky (1956) which conducted since the late 1930s and early 1940s. The document has been revised several times in 1964, 1965, 1971, 1972, 1985, and 1993. SCS-CN method is broadly used for projecting runoff from a given rainfall event. SCS-CN model combines watershed (i.e. soil type, land cover and land condition) and climatic factors (initial abstractions) in one entity called the curve number (CN). Soulis and Valiantzas (2012) and Schiariti, P. (2012) describes SCS-CN is coefficient that runoff potential is produce from total precipitation after losses to evaporation, absorption, transpiration and surface storage. CN was derived from 199 experimental watersheds size ranged 0.0971 ha to 18,600 ha at 23 locations nationwide (India), using annual P and Q which collected from 1928 to 1954 with the thousands of infiltrometer tests (Mishra and Singh, 2006).

In most cases, the CN were determined as the maximum annual runoff using rainfall-runoff records derived from the gauged catchments (SCS, 1978), where the information on climate and watershed characteristics is available. The CN values ranging from 0 to 100, corresponding to various soil, land cover, land management conditions and moisture condition. The CN values is determined and selected from National Engineering Handbook, Section 4-Hydrology by SCS (1956, 1964, 1971 and 1985). A CN=100 indicate a zero potential retention condition (S=0) which is impermeable basin and in contrast, CN=0 represents a maximum potential retention ($S=\infty$) that an infinite abstracting basin. The higher CN value represent higher runoff potential with low infiltration, whereas the lower CN indicate low runoff potential with high infiltration. Even though the CN value ranged from 0-100 in theoretically, mostly CN value used to be range in 55-95 (Hawkin, 1998).

The steps to determine CN are based on NEH-4 as follow (McCuen, 1982): (i) identify the land use, treatment class, and soil type in the basin. A soil type can be classified based on the minimum infiltration rates; (ii) identify the antecedent moisture condition based on 5-day antecedent rainfall (SCS, 1985); (iii) determine the CN-value for each land use classes from table TR-55 and NEH-4 (SCS, 1986).

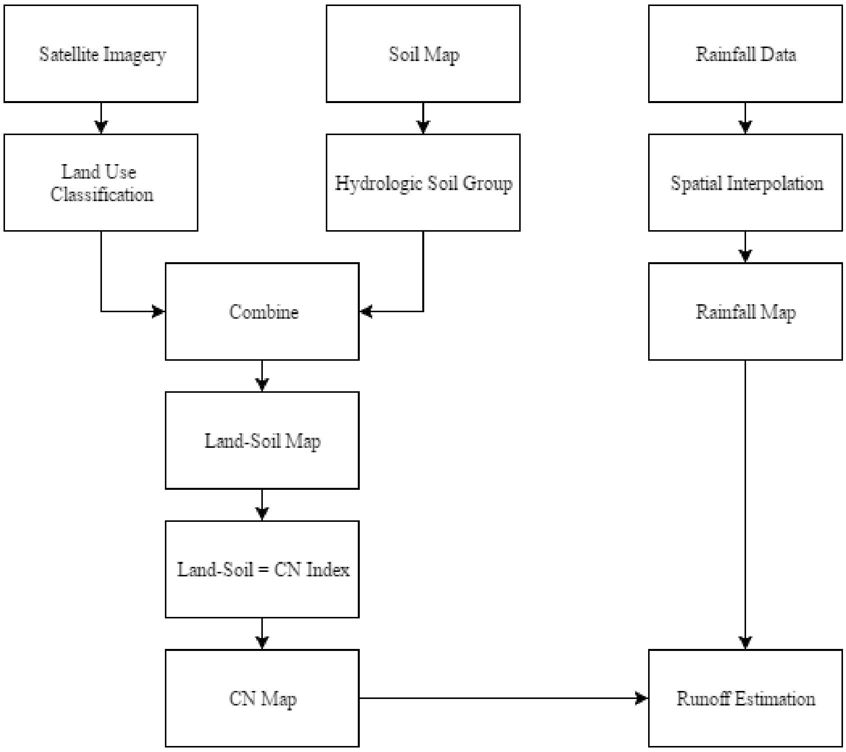

Figure 1: Process of runoff estimation using SCS-CN with GIS application

Procedure

Basically, the SCS-CN is a combination of the water balance and two fundamental hypotheses i.e. equality hypotheses and initial abstractions hypotheses. Hence, the SCS-CN methods consists of;

a) water balance equation

$P = I_a + F + Q$ Equation 1

b) equality hypotheses and

$Q / P - I_a = F / S$ Equation 2

The ratio of the actual direct runoff (Q) to total rainfall (P) to the ratio of actual infiltration (F) to the potential maximum retention (S)

c) I_a-S hypotheses

$Ia = \lambda S$ Equation 3

Relates the initial abstraction (I_a) to the potential maximum retention

Where P = rainfall; I_a = initial abstraction; F = cumulative infiltration excluding initial abstractions; Q = runoff; and S = potential maximum retention or infiltration, also described as the potential post initial abstraction retention (McCuen, 2002). Combination of equation 1 and 2, the popular form of SCS-CN method is:

$Q = (P-0.2S)^2 / (P+0.8S)$ for $P > I_a$ Equation 4

$I_a = \lambda S = 0.2S$ Equation 5

$S = 25400/CN - 254$ Equation 6

$$Q = [P-0.2(25400/CN -254)]^2 / [P+0.8(25400/CN -254)] \quad \text{Equation 7}$$

But when the P is less than 1, Q will be equal to 0. The initial abstraction, I_a is accounts for short-term losses e.g. interception, surface storage and infiltration. The parameter λ is normally regarded as a regional parameter dependent on climatic factors and geologic features (Bosznay, 1989; Ramasastri and Seth, 1985). The combination of soil type, vegetation cover and land use treatment (SVL complex) affect the infiltration potential of catchment. The magnitude of runoff (Q) depends on the infiltration potential (S) for a given rainfall (P). SCS-CN is well developed, modified and used by various agency and researchers around the globe to assist in their water resources study, planning and assessment. However, this method is established in US which temperate region and the characteristics of the factor affecting in the runoff estimation is contrast and differ with tropics and other region. Therefore, the rest of this article will review several study of runoff estimations in various region particularly in tropics region to evaluate the suitability and reliability of the SCS-CN methods in tropics region.

Factor affecting CN

Mockus (1949) proposed the runoff can be estimated from a combination of factors i.e. soil features, land use, areal extent and location, antecedent rainfall, storm date, duration and depth, as well mean annual temperature. The major watershed features and characteristics that affecting the S parameter and CN are hydrologic soil group, land cover type, land use treatment, hydrologic condition, antecedent moisture condition and climate condition of the catchment:

a) Hydrologic soil group, (HSG)

Soil textural i.e. sand, silt and clay of the grain size which affect the size of pore, subsequently affect the suction or surface tension and, therefore affect the rate of infiltration. The soil structure, soil hydraulic conductivity and initial moisture are the other major factor affecting the infiltration rates. For instances, a loose sandy soil allows more infiltration than tightly hold clay and the dry soil will exhibit more infiltration compare to wet soil. The SCS classified four main group of soil types based on the transmission and infiltration rates which named hydrologic soil group of A, B, C and D (Table 1). Infiltration means as the rate of water penetrate into the soil surface depends on the surface conditions. Meanwhile, the transmission defines as the rate of water movement in the soil which depend on the soil horizon.

Table 1: Characteristics of hydrologic soil group, HSG
(Source: McCuen, 1982; Mishra and Singh, 2013)

HSG	Characteristics	Minimum infiltration rate (mm/hr)
A	High transmission and infiltration rate, even in wet condition. Low runoff potential Deep, well to excessively drained sands or gravels.	7.62-11.43
B	Moderate transmission and infiltration rate when thoroughly saturated. Moderately deep to deep, moderately well to well drained soils with fine, moderately fine to moderately coarse textures e.g. shallow loess and sandy loam.	3.81-7.62
C	Low infiltration rate and slow transmission rate when thoroughly wetted. Contain a layer that impedes downwards movement of water. Moderately fine to fine texture e.g. clay loams, shallow sandy loam, soil with low organic contents	1.27-3.81

D	Very low infiltration rate when thoroughly wetted and very slow transmission rate. High swelling clay soils with, permanent high-water tables, soils with a clay layer at or near surface and thin soils over nearly impervious	0.0 – 1.27

In National Engineering Handbook-4 (NEH-4) by United State Department of Agriculture (USDA) Soil Conservation Service (SCS), there are more than 4000 soil types in United States of America was classified in the hydrologic soil group. These classifications originally corresponding on the P-Q data from infiltrometer plots and small agricultural catchment, and latest NEH-4 are classified based on judgement and experience of soil scientist. This classification assumes that soil surface are bare; maximum swelling; rainfall rates exceed infiltration rates. Therefore, the soil that have similar depth, organic content, structure and swelling when saturated will react same pattern during high rainfall intensities. In brief, soil type is significantly affect the runoff potential, higher runoff potential, as the increase of hydrologic soil group from A to D.

b) Land use and treatment classes (urban, agriculture, forest, and others)

Land use cover is the topmost surface which cover the catchment and has a definite bearing on infiltration e.g. vegetation, litter, mulch, fallow, water surface, roads, roofs and etc. The infiltration rate differ as the forest soil promotes more infiltration compare to pervious surface at urban area. Land treatment mainly for the agricultural land including the mechanical practices e.g. contouring and terracing; as well as management practices e.g. crop rotation. The NEH-4 table presents the combination of land use, treatment classes, hydrologic condition and hydrologic soil group, which can categorize into 4 major class i.e. urban, cultivated land, and woods and forests (Table 2). However, this table is based on the characteristics of the USA which is the temperate country.

Table 2: Runoff curve number for hydrologic complexes (AMC II and I_a=0.2S)
(Source: Mishra and Singh, 2006)

Land use description/ treatment	Hydrologic condition (%)	HSG			
		A	B	C	D
URBAN					
Residential: Average lot size-					
¼ acre	38	61	75	83	87
½ acre	25	54	70	80	85
1 acre	20	51	68	79	84
Paved parking lots, roofs, etc.		98	98	98	98
Street and roads:					
Paved with curbs and storms sewer		98	98	98	98
Paved, open ditches		82	89	92	93
Gravel (include ROW)		76	85	89	91
Dirt (include ROW)		72	82	87	89
Western deserts area:		63	77	85	88
Urban district:					
Commercial areas	85	89	92	94	95
Industrial areas	72	81	88	91	93
Developing areas: Newly degraded areas		77	86	91	94
Open areas, golf courses, cemeteries, etc.					
75% grass cover	Good	39	61	74	80
50% to 75% grass cover	Fair	49	69	79	84
AGRICULTURAL					

Cultivated lands:					
Fallow:					
Bare soil + SR		77	86	91	94
Crop residue cover	Poor	76	85	90	93
	Good	74	83	88	90
Row crops:					
Straight row	Poor	72	81	88	91
	Good	67	78	85	89
Crop residue cover + Straight row	Poor	71	80	87	90
	Good	64	75	82	85
Contoured	Poor	70	79	84	88
	Good	65	75	82	86
Crop residue cover + Contoured	Poor	69	78	83	87
	Good	64	74	81	85
Contoured & Terraced	Poor	66	74	80	82
	Good	62	71	78	81
Crop residue cover + Contoured & Terraced	Poor	65	73	79	81
	Good	61	70	77	80
Small grains:					
Straight row	Poor	65	76	84	88
	Good	63	75	83	87
Crop residue cover + Straight row	Poor	64	75	83	86
	Good	60	72	80	84
Contoured	Poor	63	74	82	85
	Good	61	73	81	84
Crop residue cover + Contoured	Poor	62	73	81	84
	Good	60	72	80	83
Contoured & Terraced	Poor	61	72	79	82
	Good	59	70	78	81
Crop residue cover + Contoured & Terraced	Poor	60	71	78	81
	Good	58	69	77	80
Close seeded legumes / rotation pasture:					
Straight row	Poor	66	77	85	89
	Good	58	72	81	85
Contoured	Poor	64	75	83	85
	Good	55	69	78	83
Contoured & Terraced	Poor	63	73	80	83
	Good	51	67	76	80
Uncultivated lands:					
Pasture or rangeland:	Poor	68	79	86	89
	Fair	49	69	79	84
	Good	39	61	74	80
Contoured	Poor	47	67	81	88
	Fair	25	59	75	83
	Good	6	35	70	79
Meadow-continuous grass, no grazing	Good	30	58	71	78
Brush-brush weed grass mixture	Poor	48	67	77	83
	Fair	35	56	70	77
	Good	30	48	65	73
Farmstead-buildings, lanes, driveways		59	74	82	86
WOODLANDS AND FORESTS					
Humid rangelands or uncultivated lands:					

Woodlands or forestlands	Poor	45	66	77	83
	Fair	36	60	73	79
	Good	25	55	70	77
Wood-grass combination (orchard or tree farm)	Poor	57	73	82	86
	Fair	43	65	76	82
	Good	32	58	72	79

c) Hydrologic surface conditions (poor, fair, good)

The hydrologic surface conditions are a percentage of the grass-cover in agricultural catchment. Good hydrologic surface conditions describe as the area with larger of grass-cover, the runoff potential is lesser and promote more infiltration. It is help protection to the catchment from the erosion for soil conservation purposes. In contrast, poor hydrologic surface condition is defined as lesser grass cover and increase the runoff potential. There are three category of the hydrologic surface condition which are good, fair and poor depending on the cover effectiveness of grass-cover extent or native pasture or range (Table 3). The value in CN will be higher for the poor and vice versa. The percentage of area with grass-covered and the intensity of grazing are estimated visually.

Table 3: The classification of native pasture or range
(Source: SCS, 1971)

Hydrologic condition	Vegetation condition
Poor	Less than 50% of the area covered. Heavily grazed.
Fair	Less than 50% to 75% of the area covered. Moderately grazed.
Good	Cover on more than 75% of the area. Lightly grazed.

d) Antecedent moisture condition (AMC)

The AMC refers to the amount of moisture available in the soil and the degree of wetness and saturation of the soil surface before rainfall event. It is significantly affect the rainfall-runoff processes by influencing the infiltration process. For instance. If the soil is fully soaked during rainfall event, the whole rainfall will directly become the runoff without infiltration losses. In contrast, if the soil is fully dry during the rainfall event, there is possibilities of the rainfall infiltrates into the soil, thus no runoff will be occurred. According to Mishra and Singh (2006), there are three concepts to identify the AMC of the soil i.e. antecedent precipitation index (API), antecedent base flow index (ABFI), and soil moisture index (SMI).

The API is the most popular idea used to determine AMC based on antecedent rainfall amount which differs from preceding 5 to 30 days. Though, there are no clear guidelines to differ the antecedent rainfall at the definite period. The NEH-4 generally used 5-day rainfall as API for AMC which categorized into three categories based on the condition of the soil i.e. AMC I for the dry condition and dry CN or the lowest runoff potential, AMC II is for normal condition or average runoff potential, and AMC III to the wet condition of the soil and wet CN with highest potential of runoff (Table 4). In short, the higher AMC indicate higher CN which lead to higher potential of runoff (Hjelmfelt et al,. 1982). However, the table 4 data is based on the USA condition, SCS (1971) suggested for developing AMC standards for every single catchment using P-Q information to obtain the soil characteristics of the catchment itself. The advantages of API method is simple, convenient and applicable in field compare to ABFI and SMI approach.

Table 4: The 5-day antecedent rainfall for determination of AMC
(Source: Mishra and Singh, 2006)

AMC	Total 5-day antecedent rainfall (mm)	
	Passive seasons	Active seasons
I	< 13	< 36
II	13 to .8	36 to 53
III	> 28	> 53

Antecedent base flow index (ABFI) approach is based on the antecedent base flow and it is showed to be the better than API because it eliminates the selection of the antecedent duration problem. Though, there is problem to separate the base flow from the total runoff, since base flow mostly directed by the groundwater flow. The ABFI approach is rarely used in practices. Soil moisture index (SMI) concept is used when the soil moisture needs to take into account for water balance, commonly for long-term hydrologic simulation which apply evapotranspiration, and other climatic factors e.g. temperature, solar radiation, etc. (SCS, 1971).
The AMCs were differentiated based on the rainfall intensity during prior 5 days (P5) (Mays, 2005). Because of the different land use/cover of the watersheds, average composite CNs (CNII) were derived according to the standard NRCS table procedure documented in the National Engineering Handbook (NRCS, 2004), which corresponds to the normal (AMC-II) condition (Miliani et al., 2011; Mishra et al., 2014). The adjusted CNI for dry conditions (AMC-I) and the CNIII for wet (AMC-III) conditions can be obtained by using the formula suggested by Mishra et al. (2008).

e) Initial abstraction and climate

Initial abstraction (I_a) is an early process to reduce rainfall for becoming runoff directly (Mishra and Singh, 2013). It consists of interception loss by the tree canopy, surface detention, evaporation by the sunlight or heat and infiltration into the soil (Mein and Larson, 1971). Basically, the process of interception is the first abstraction to occur during a rainfall event and it is reduces the rainfall amount by retain a certain amount of rainfall which either absorbed by vegetation or another surface cover or eventually evaporated back to atmosphere. Though, not all the amount of rainfall is intercepted by surface cover, it depends on the rainfall events and intensity contribution. For instances, the interception process will reduce the amount of annual average rainfall by 25%. The light storms are abstracted significantly by interception. For moderate storms, Chow (1967) found that interception losses from 7 to 36% of total rainfall during growing season and from 3 to 22% during the remainder of the year. For heavy and long-duration storm, the losses by interception is likely to be small fraction of the rainfall. The excess water reaching ground after interception process by surface cover called as throughfall. In short, the interception depends on the rainfall characteristics (e.g. intensity, depth and duration), surface cover density (e.g. type of vegetation and seasons) and wind features (e.g. velocity, duration and direction) (Rutter et al., 1971).

For surface detention or depression, it refers to the amount of rainfall that can retain by the characteristics of the land surface e.g. surface unevenness, slope and length of catchment which lag time to provide more time for infiltration to occur. In the surface detention, the rainfall losses either by evaporates to atmosphere or infiltrates into the soil surface. Typically, the surface detention effect varies in time and rainfall duration, it is plays an active role in abstracting the rainfall in the beginning of rainfall, as time progresses, the storage is full-filled with the water and contribute to runoff. The evaporation is the process of the water on the land surface is converted to the water vapour and returned to atmosphere. It is affected by the meteorological and environmental factors e.g. solar radiation, sunshine hours, vapour pressure, relative humidity, air and water temperature, wind characteristics and atmospherics pressure. There are studies showed that evaporation rates are low in humid regions and high in the arid and semiarid regions. In brief, the process of interception, surface detention and infiltration will hold the water in the soil, while evaporation process will vaporise the water back to atmosphere. The higher amount of initial abstraction will lead to lower runoff potential and vice versa.

The initial abstraction ratio (λ) plays a significant role in the runoff estimation using SCS-CN (Baltas et al. 2007). The selection of λ varies with the climatic and regional conditions (Ponce and Hawkins 1996). The assumption of the λ=0.2 in the original SCS-CN was found to be indefinite, and many studies found that λ values between 0.01 and 0.05 are more realistic (Table 5). Thus, different regional and climatic conditions represent different value of initial abstractions and it is vital steps on determination of accurate λ value to obtain better output.

Table 5: The best initial abstraction ratio from several watersheds in temperate

No	Location	Initial abstraction ratio (λ)	Reference
1	307 U.S. watersheds	λ=0.05 is a better fit for real data as compared to 0.2	Woodward et al. (2003)
2	237 U.S. watersheds	best value of λ was 0.01	Mishra et al. (2004)
3	experimental watershed in Attica, Greece	average best-fit λ value of 0.014 a value of 0.037 for a sub-watershed	Baltas et al. (2007)
4	186 Australian watersheds	λ value was determined to be 0.05	Beck et al. (2009).
5	Three Gorges area of China	λ to range between 0.010 and 0.154 with a median of 0.048	Shi et al. (2009)
6	semiarid watersheds in southeastern Arizona	the best-fit values vary from 0.01 to 0.1	Yuan et al. (2014)

f) Rainfall characteristics

The rainfall characteristics e.g. amount and duration of rainfall affects the rainfall intensity which effects infiltration (Mein and Larson, 1971). The greater of rainfall intensity, the lesser rainfall duration which render lesser time for water retention on surface and infiltration to occur, leading to higher runoff produced. Besides, a high intensity rainfall will breakdown and erode the soil structure into smaller and fine particles which leads to the crust formation that delays and decrease infiltration rate by shrink the effective soil depth and soil porosity.

Advantages and Limitations of the SCS-CN

SCS-CN is the most popular method among the engineers, practitioners, hydrologist and researchers for runoff estimation. Due to its simplicity but well-established and documented, as well as the minimum information requirement, without excluding the factor affecting of runoff generation. For example, many researchers from India i.e. Rao et al. (1996), Sharma et al. (2001), Chandramohan and Durbude (2001) and Sharma and Kumar (2002) was applied SCS-CN to estimate and to investigate runoff in their basin study. In early establishment, the CN method is developed for small watershed (Tekeli et al., 2007), but it was well evolved through modification and advancement to be applicable for all size of watersheds. Nayak and Jaiswal (2003) acclaimed SCS-CN as the simple, flexible, widely used in small to medium basin. It was showed a good correlation between measured and estimated runoff (Shi et al., 2009; Kumar et al., 2010; Gajbhiye and Mishra, 2012). SCS-CN also adored by researchers due to its flexibility and compatibility to modify and to blend with the other factor affecting runoff e.g. slope and the other software e.g. Geographical Information System. Chatterjee et al. (2001) mentioned the better spatial resolution of remote sensing data on land use and hydrological parameters (e.g. land use cover, soils, geomorphology, drainage) will allow the use of CN method in larger watershed with better accuracy and results in short time.

The Geographical Information System (GIS) is the latest spatial technology that provide better data management, processing and analyzing, also enhance the accuracy of runoff estimation. Pandey and Sahu (2002), Huang and Zhan (2004), Gandini and Usunoff (2004), Mishra and Singh (2006) and Reshma et al. (2010) are among the researchers whose applied these GIS with SCS-CN. GIS also provide further and extended analysis to measure the impact of land use alterations on the P-Q relationship (Wehmeyer et al., 2011). Olivera and Maidment (1999) used grid-based GIS model which divide watershed into grid cells with spatially specific hydrologic parameters to overcome the deficiency of lumped and spatial distributed model. Zhan and Huang (2014) have been developed

ArcCN-Runoff using ArcGIS tool for estimating runoff through producing curve number and runoff maps. This is allows the runoff estimation to be performed in short-time and high accuracy of an output. Ebrahimian et al. (2012) found a positive correlation between the observed and predicted runoff depths for 35 rainfall-runoff events in the Kardeh watershed by using the modified SCS-CN equation of Huang et al. (2006). Deshmuhkh et al. (2013) gained good significant results by using the slope adjusted CN, as proposed by Sharpley and Williams (1990), in contrast to the conventional tabulated CN method.

In addition, SCS-CN also are applicable for other hydrology study e.g. sediment yield (Mishra et al., 2006), potential water harvesting sites (Ramakrishnan et al., 2009) and hydrologic forecasting (Geetha et al., 2008). Mishra et al. (2006) revealed the combination of SCS-CN and Universal Soil Loss Equation (USLE) by Wischmeier and Smith (1965) in computing of soil erosion potential in 12 small watersheds in India and USA found to be in good correlation of computed sediment yield with the observed values and shown it can considerable potential in field. In a different study, Ramakrishnan et al. (2009) examined the potential water harvesting sites in India using SCS-CN, GIS and remote sensing, as results, the potential sites was shown fairly accurate (80-100%) of the suitability after field investigation was carried out. Another study by Geetha et al. (2008) in hydrologic forecasting, the SCS-CN shown better signified the hydrologic behaviour of the catchments with different soil, vegetation, and climate than the Variable Source Area model (VSA).

Although SCS develop CN method in 1954 to manage and cope the flood problem in agricultural watershed (Rallison and Miller, 1982), and subsequently used in urban watershed (SCS, 1975). Nevertheless, the CN often estimates inaccurate runoff from forested watershed (Schneider and McQuen, 2005; McCutcheon et al., 2006). Soulis and Valiantzas (2012) explained that CN does not deliberate the influence of rainfall intensity and duration. SCS model does not effective for very small rainfall events (Shaw and Walter 2009; Buchanan et al. 2012; Cheng et al. 2014). According to Hawkins et al. (2009), only large and continuous storm of rainfall events (P>25.4 mm) were appropriated to minimize bias (Ajmal et al, 2016). Although it is very sensitive to change in single CN parameter, the original and traditional of SCS-CN does not consider the effects of spatial scale and the effect of antecedent moisture conditions as it assumed watershed as lumped model (Hawkins, 1993; McCuen, 2002; Michel et al., 2005; Ponce and Hawkins, 1996). Phetprayoon et al. (2009) elaborated that SCS-CN can be classified as lumped model which typically assumed the whole watershed have uniform rainfall and hydrologic factors. Thus, some of the local hydrological process might be missing.

In the standard SCS-CN model, the CN values for runoff estimation have been obtained experimentally from the measured P-Q data over a variation of geographic, soil, and land management conditions. Though, the slope and topography has been excluded which amongst an important factor influencing runoff within landscape (Huang et al. 2006). Quite a few researchers have studied the effects of the slope under either natural or synthetic rainfall. As results, under natural rainfall conditions for steep slope watersheds, the runoff increase as attributed to decrease of depression storage and ponding depth (De Ploey et al. 1976; Sharma et al. 1983; Dodds 1997). Huang et al. (2006) discovered the significant increase in the runoff as the slope increases, where the presence of a slope caused a 10% and 23% increase in the runoff depth in a pasture and alfalfa croplands, respectively in the Loess Plateau of China. In sugarcane plots, Mishra et al. (2014) found the 29.42% Q produced from rainfall at the 1% slope, 34.07% for a 3% slope, and 48.52% for a 5% slope, whereas the maize plots shown the 24.66%, 40.58%, and 51.53% were found for 1, 3 and 5% of slope, respectively. It can conclude that runoff increases as the slope increases and vary with the type of land use cover.

The following conclusions can be made as summarized by Ponce and Hawkin (1996) that proven advantages of the SCS-CN i.e. simplicity, predictability, stability, applicability, reliability on CN parameters and responsiveness to major runoff-producing properties i.e. soil type, land use treatment, surface condition, and antecedent condition. In opposing, the apparent disadvantages are sensitivity to curve number and unclear guidance on how to vary antecedent condition. In addition, lack of the method varying accuracy for different biomes and the absence of an explicit provision for spatial scale effects. As well as the setting of the initial abstraction ratio at λ=0.2, preempting a regionalization based on geologic and climatic setting.

CN Study in Temperate and Tropical

Temperate vs tropical region

The main contrasts of temperate and tropic are the localities, or actual latitudes, rainfall characteristics, temperature, humidity, and soil features. The tropics region is demarcated as the geographical area lying between 23.5ºN and 23.5ºS latitude, while the temperate regions are found above these parallels. Tropics can be characterized by warm to hot, wet and humid conditions whole years with a period of summer rainfall including thunderstorms and heavy rain and dry period. Average annual rainfall around 1500mm with the mean temperatures are rarely below 25ºC. Due to the warm temperature and moist air, decomposition occurs at a rapid rate in tropical rainforests. High levels of rainfall often allow the nutrients leached into soil, improving the fertility of the poor soil. In contrast, temperate climates vary from 25ºC – 35ºC in summer, yet drop down to 10ºC – 15ºC during winter, and much frostier at night down to zero. Average annual rainfall is 800- 1200mm and can happen in any month but frequently in winter and can be unpredictable with periods of droughts and floods. The climatic factor influencing initial abstraction (i.e. evaporation and infiltration), as for temperate is higher in temperature with lower rainfall than tropics, the probability of runoff generation to occur is lower.

Instead of climate, the vegetation cover varies in temperate and tropics, the tropics prevalent with the tropical rainforests which contain the greatest diversity of species of all biomes on Earth. Vegetation in the tropical rainforests is typically broad-leafed trees with over 25 meters tall. Other floras including ferns, vines, mosses, palms and orchids (Murphy and Lugo, 1986). In temperate, there are two types of forest which are deciduous and coniferous forest (Frelich, 2002). The deciduous forests are dominated by maple, oak and birch trees and characterize by the mosses, ferns and wildflowers, and the understory includes a variety of shrubs and ferns. In evergreen forests, the prominent speices are conifers, pines and fir trees. The high levels of precipitation and moderate temperatures provide long growing season, allow trees that grow very tall. Other dominant tree species found in temperate coniferous forests include cedar, cypress, Douglas fir, pine, spruce and redwood. The single species, straight boles and single layer of canopy temperate forest with needle-like leaves, cause the interception of rainfall not very effective compare to heterospecies with multi strata (canopy) with broad leaves. It improves the initial abstraction in tropical forest, due to reduce the capacity of an effective rainfall to interception, evapotranspiration, and infiltration.

In term of agriculture, reported experiments have shown that although in the tropics often produced higher yield per day, total crop growth season is shorter (Haws et al., 1983). Leaf area growth are quicker in the tropics due to higher temperatures during vegetative growth. Nonetheless, crop yields are consistently found to be higher in temperate regions than in the tropics (FAO, 1990), numerous factors contribute to this result e.g. humid tropics soils tend to be highly leached of nutrients, therefore unfertile because of too high temperatures, intense rainfall, and erosion. While, soils in the drier tropics are often vulnerable by salt accretions and lack of water (Barrow, 1987). In comparison, temperate soils are more favorable for agriculture as they contain a higher nutrient level. Though, there are exclusions in both regions, with high productive volcanic and fluvial soils found in the tropics, and poorly developed and infertile soils in temperate regions (Rosenzweig and Liverman, 1992). Crop production is also severely restricted in many humid tropical regions by the wide range of weeds, pests, and diseases that flourish in consistently warm and humid climates (Zhao et al., 2005). Some crops and varieties require long hours of daylight to growth and mature, is also limited by the persistent day lengths of the tropics. Solar radiation is lower in winter and higher in summer in temperate zones, which is necessary to plant growth, and whose intensity is controlled by the angle of the sun, day length, and cloudiness. While, solar radiation is often limited by cloudiness during the rainy seasons in the tropics.

Differences in farming systems, technology and economics also contribute to the produced yield in both temperate and tropical regions. Commonly in tropical regions, numerous farmers cannot afford inputs (i.e. advanced machinery) and governments cannot afford to subsidize them. In other parts of the tropics, traditional technologies e.g. multiple cropping and terracing, act to buffer the system against climate inconsistency, retain soil fertility, and increase crops outputs. To compare, temperate agriculture is characterized by high levels of inputs (e.g. quality seed stock, fertilizer, herbicides and pesticides), plus an advanced mechanization and high capitalization (Rosenzweig and Liverman, 1992).

CN in Temperate

Most of the CN studies were conducted in the temperate regions e.g. United States (Steenhuis et al., 1995; Tedela et al., 2011), Argentina (Cisneros et al., 2011), European (Okoński, 2007; Jenicek, 2007; Reshma et al., 2010), Spain (Conan et al., 2003), Palestin (Shadeed and Almasri, 2010) and South Korea (Ajmal et al., 2015). It has conclusively been shown the most common method for runoff estimation by researchers is SCS-CN due to simplicity, flexibility and reliability. Mostly, they applied the SCS-CN with the combination GIS and RS for quick and accurate assessment of runoff. For instance, Melesse and Shih (2002) study the response of land use to storm runoff distribution in Kissimmee River Basin in Florida, USA using integrated GIS and RS application. They observe the water and wetland covered areas are higher in 2000 compared to 1980 and 1990 due to recovering and restoration works. SCS-CN also useful tool to assist in the flood management and planning as found by Tan et al. (2002) in China Taipei, Olang and Furst (2011) in Kenya, Al-Ghamdi et al. (2012) in Saudi Arabia. As shown in Table 6 is the summary of the SCS-CN studies in temperate region, majority of the researchers agreed SCS-CN provide significant and effective method to estimate runoff with limited data used but in high accuracy of output.

Table 6: Comparative studies previous research on SCS-CN in temperate region

Catchment	Area (km^2)	Climate	Soil Type	Land Use Classification	Findings	References
15 watershed, South Korea	48.60-249.63	Mean P (52.19-85.37mm)	Mean Slope (7.50-48.13%)	n/a	Mean Observed Q (17.90-47.61mm)	Ajmal et al., (2015)
39 mountainous watersheds, South Korea	42.32-879.10	Min Max P (1000-1800mm) P-Q data 30-minutes intervals.	Mean Slope (7.50-53.53%) Loam, sandy loam and some fraction of silt loam	70% (forest e.g. conifer, deciduous, others), 20% (agriculture e.g. rice, other crops, orchards, plantations), 5% (urban e.g. residential, industrial, commercial, leisure, etc.) 1.6% (grasslands) 1.08% (bare land) 1.08% (water bodies) 0.3% (wetlands)	CN (52-78), CN_M (53-86) Increase of slope steepness, increased runoff generation, to compare with flat areas (with slopes less than 5%).	Ajmal et al., (2016)
Liudaogou, Loess Plateau, China	7.03	Semi-arid AAR (409mm) I_{60} (2.5-24.4mm h^{-1})	HSG A and D Sandy, loamy sand and sandy loam	Row crop, small grain, close-seeded crop, rangeland, brushland, deciduous forest, orchard, residential, open spaces	Ia/S value amplified slowly with increasing rainfall once the rainfall was less 50mm and increased quickly when the rainfall surpassed 50mm.	Bo et al. (2011)
Kissimmee Basin, USA	418.33	AR 190.50mm	HSG A, B, C, D	7 classes (1980,1990,2000)	larger water and wetland areas in 2000 compared to 1980 and 1990 due to recovering the restoration work of floodplain	Melesse and Shih (2002)
UC River, Kentucky, USA	970.00	AAR 155.4mm	n/a	Forest, urban, cropland and pasture, lakes and reservoir	NRCS-CN method was found to be most effective in prediction uncertainty for minimalizing flood	Harris and Hossain (2008)

Jobaru RB, Japan	72.8	AAR 2266mm	HSG A and C	Water, urban, forest (broadleaf, coniferous, bamboo, mix), paddy field, other agriculture, pasture, barren, other	different CN reflect different land uses with remarkably influenced peak flow decreasing of CN caused the reducing of peak flow	Sumarauw and Ohgushi (2012)
Makkah city, Saudi Arabia	80.02 (1990) 157.56 (2010)	AAR 102.6mm	HSG A, B, C, D	Urban, street, industrial and commercial	residential areas increased by 197%, as result, total flood volumes enlarged by 248%.	Al-Ghamdi et al. (2012)
Kardeh Watershed, Iran	448.20	AAR 296.4mm Event based Consider slope	HSG A, B, C, D	Farmland, forest, rangeland, orchard, settlement, rock	fair positive correlations was found between observed and estimated runoff ($r = 0.55$; $P < 0.01$) and slope-adjusted vs. observed runoff data ($r = 0.56$; $P < 0.01$)	Ebrahimian et al. (2009)
Balnice RB, Czech Republic	209.60	10, 20, 50, 100-years precipitation	n/a	Urban, arable land, pasture, agriculture, forest, shrub, inland water	intensifying flood extremity the influence by the forest cover decreases.	Jenicek (2009)
Zilberchai Basin, Iran	2612.02	AAR 278.8mm IDW Interpolation	18.35% slope	Pasture, rainfed farm, irrigated farm, residential, tree integrate	lands with inappropriate hydrologic group and low penetrability, have high runoff and discharge than the areas with suitable hydrologic group	Malekani et al. (2014)
Hojea RC, Southern Sweden	316.00	AAR 600mm 4 P simulation (4, 24, 40, 47mm)	HSG A, B, C, D	Building, trees, impermeable paving, permeable paving, mown grass, sedum roof	Q impact increases as building density increases, where additional tree cover is proven in reducing runoff	Sjöman et al. (2014)

*AR=annual rainfall; AAR=average annual rainfall

CN in Tropical

There are no extensive and unambiguous study or literature reviewed about the reliability, practicality and suitability of the SCS-CN method in tropical regions. Nevertheless, numerous researchers and practitioners in tropics region applied SCS-CN in their rainfall-runoff study as shown in Table 5. Most of study found in India e.g. in identifying water harvesting sites (Ramakrishnan et al., 2009), sediment yield modelling (Mishra et al., 2006; Tyagi et al., 2008), simulation for hydrologic forecasting (Geetha et al., 2008), estimating soil moisture (Reshmidevi et al., 2008; Durbude et al., 2011), simulating turbidity removal (Ojha, 2011) and flood modelling (Kurothe et al., 2001; Deskmukh et al., 2012; Ningaraju and Surendra, 2016). Mishra and Vijay are the most active and prominent researcher and reviewer of SCS-CN method with more than 20 publications on the SCS-CN application, methodology, simulation, and modification. It is indicated the high interests on the SCS-CN shown the reliability of the model for used in tropical regions.

Other study by Phetprayoon et al. (2009), to investigate runoff using grid-based CN (30m x 30m grid cell) in the Upper Lam Phra Phloeng basin (786 km2) know as most active agricultural areas in Thailand. The study found the calibrated grid-based CN can be applied with reasonable accuracy for runoff estimation. Besides, there are studies used SCS-CN to investigate the impact of the land use changes to the runoff generated in the basin scale e.g. Santillan et al. (2010) in Taguibo Catchment, Philippines, Hernandez-Guzman et al. (2008) in Rio San Pedro River Basin in Mexico and Vannasy and Nakagoshi (2016) in Mark-Hiao, Laos. They found the significant increase on runoff volume as results of the increasing area of urbanization and agriculture, and reduction of the natural and forest cover. Further study by Olang and Furst (2011) to simulate the land use change to predict the impact of runoff volume generated and revealed the peak discharge and flood runoff volume increases with the expansion of deforestation and agriculture areas.

In general, these findings suggest that SCS-CN method is the best method to estimate runoff in tropical region with the satisfying accuracy of output compared to other models and methods. Most of the study used and applied the SCS-CN method using the published reference by SCS (1956, 1964, 1965, 1971, 1972, 1985, 1993) and Mishra et al. (2002, 2006, 2013). There are some modification and suggestion to enhance the output of the runoff estimation by considering the slope into the account. They found the runoff volume was increased with slope e.g. Sharpley and Williams (1990); El-Hassanin et al. (1993); Dodds (1997); Shafiq and Ahmad (2001); Huang et al. (2006); and Garg et al. (2013).

Table 7: Comparative studies on SCS-CN in tropics region

Catchment	Area (km^2)	Climate	Soil Type	Land Use Classification	Findings	References
Upper Lam Phra Phloeng, Thailand	786.26	AAR (1117mm) 11 stations 18 storms events in 2008 (10 for observed calibration, 8 for model validation)	15 types of soil series	Forest e.g. dense and disturbed evergreen forest, dense and disturbed deciduous forest, forest plantations (25%), crop e.g. maize, sugarcane, cassava (42%)	Modified-CN using grid-based method can be applied in Q simulations with acceptable accuracy	Phetprayoon et al. (2009)
Klang, Malaysia	674.00	AAR (2400mm)	HSG A, B and D	Agriculture (9%), forest (37%), mining, cleared area, pasture, swamps, urban (50%), water body	Both SCS-CN and Green Ampt have no significant difference in Q	Kabiri et al. (2013)
Bantimurung, South Sulawesi, Indonesia	20.25	AR 123mm	HSG C and D	Montane forest, stony land, grassy sorhoun land, pavement road, urban, rice cultivation	Overestimate Q of 22,92 % with the actual value obtained	Musa et al. (n.d.)
Huong RB, Vietnam	2830.00	AAR 2500mm coastal 3500mm hilly	n/a	n/a	increases of temperature and rainfall significantly affect discharges and water levels	Van Dau and Kuntiyawichai (2015)

Taguibo, Mindanoa, Philippines	75.53	n/a	HSG B and D	Barren area, built-up, forest, grassland, mixed vegetation, water	reduction in forest and mixed vegetation to grasslands and barren areas cause significant increase in runoff volumes during rainfall events	Santillan et al. (2010)
Rio San Pedro, Mexico	3000.00	AR 700-2000mm	HSG C and A	Aquatic surface, mangrove, saltmarsh, agriculture, succession, exposed soil, villages	landscape alterations are changing the runoff conditions	Hernandez-Guzman et al. (2008)
Darewadi, India	35.69	Min Max P (500-550mm) AT (7.3-44°C)	n/a	n/a	Average CN (pre=85; post=75.88) 5-days AMC (44.82-80.72mm)	Dhawale (2013)
Narmada, India	98796.00	n/a	n/a	n/a	Increases agriculture, increase 20-40% Q	Nayak et al. (2012)
Mark-Hiao, Laos	11.75	n/a	HSG A, B and D	Agriculture, marsh and swamp, built-up, forest	increase in runoff co-efficient and runoff depth due to increases of urbanization and reduction of other land cover types	Vannasy and Nakagoshi (2016)
Barureva, Sher and Umar watershed, Narmada Basin, India	1488.00	Daily Q 1977-2002	HSG C and D	Agriculture, badland, barren land, forest, settlement, water body	n/a	Deskmukh et al. (2012)

Kharadya Milli, India	23.95	AR 2003-2013 (400.50-1202.60mm)	HSG A, B and D	Agriculture w/o conservation, shrub, bare land, degraded land, forest plantation, settlement,	AQ (35.47-240.16mm)	Ningaraju and Surendra (2016)
Nyando RB, Kenya	3550.00	AAR 1300mm	n/a	Agriculture, forest, shrub land, wetland and water	Simulation of land cover changes have increased peak discharges and flood runoff volumes. More severe within the upstream areas where higher rates of deforestation and agricultural expansion.	Olang and Furst (2011)

*AR=annual rainfall; AAR=average annual rainfall

Conclusion

SCS-CN in Tropics: Is It Reliable?

In brief, based on the following reviewed literatures and studies on SCS-CN conceptual, applicability, and reliability. It has shown that CN application in the tropic region is still reliable and accepted for runoff estimation. These current findings add substantially to our understanding of CN application particularly on estimating runoff. Most of study found that SCS-CN is most suitable method with the minimum data used and produced good accuracy of the output compared to the other methods especially in ungauged and large watershed. Its advantages e.g. simplicity, predictability, stability, flexibility and responsiveness to major runoff-producing properties have risen it popularity is high among the hydrologists and researchers. However, it is fundamental to adapt and modified the SCS-CN particularly in initial abstraction values and antecedent moisture condition that suited for every research areas due to variation of the regional, geologic, climate and hydrologic conditions. In addition, the integration of advanced technology and software e.g. GIS and RS allow the proper database management, as well the enhancement the accuracy of land use classification subsequently increased the precision of the runoff estimation.

The review suggests that the application of SCS-CN method for particular study area should be calibrated and validated due to different characteristics and features for every site in order to enhance the accuracy of the runoff estimation. Further research and investigation in field is recommended especially on antecedent moisture condition and initial abstractions of the rainfall e.g. infiltration, soil storage capacity, evapotranspiration and etc. in the different type of land uses (e.g. rubber, oil palm, paddy, forest plantation and etc.), soil type and climate particularly in the tropic region. It would be of great help to establish a greater accuracy on the CN consequently in runoff estimation particularly in tropics.

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References

Adornado, H. A., & Yoshida, M. (2010). GIS-based watershed analysis and surface run-off estimation using curve number (CN) value. *Journal of Environment Hydrology*, 18, 1-10.

Ajmal, M., Moon, G. W., Ahn, J. H., & Kim, T. W. (2015). Investigation of SCS-CN and its inspired modified models for runoff estimation in South Korean watersheds. *Journal of Hydroenvironment Research*, *9*(4), 592-603.

Al-Ghamdi, K. A., Elzahrany, R. A., Mirza, M. N., & Dawod, G. M. (2012). Impacts of urban growth on flood hazards in Makkah City, Saudi Arabia. *International Journal of Water Resources and Environmental Engineering*, *4*(2), 23-34.

Amutha, R., & Porchelvan, P. (2009). Estimation of surface runoff in Malattar sub-watershed using SCS-CN method. *Journal of the Indian Society of Remote Sensing*, *37*(2), 291-304.

Andrews, R. G. (1954). The use of relative infiltration indices for computing runoff. Unpublished. Soil Conservation Service, Fort Worth, Texas. (pp. 6)

Barrow, C. (1987). Water Resources and Agricultural Development in the Tropics. Longman, London UK. (pp. 356).

Bosznay, M. (1989). Generalization of SCS curve number method. *Journal of Irrigation and Drainage Engineering*. A.S.C.E., 115(1), 111-116.

Chandrmohan, T. & Durbude, D. G. (2001). Estimation of runoff usings small watershed models, *Hydrology Journal*. 24(2). 45-53.

Chatterjee, C., Jha, R., Lohani, A. K., Kumar, R., & Singh, R. (2001). Runoff curve number estimation for a basin using remote sensing and GIS. Asian-Pacific Remote Sensing and GIS Journal. (14). (pp. 1-8).

Chow, V. T. (1964). Handbook of Applied Hydrology. McGraw Hill, New York.

Cisneros, J. M., Grau, J. B., Antón, J. M., de Prada, J. D., Cantero, A., & Degioanni, A. J. (2011). Assessing multi-criteria approaches with environmental, economic and social attributes, weights and procedures: A case study in the Pampas, Argentina. *Agricultural Water Management*, *98*(10), 1545-1556.

Conan, C., de Marsily, G., Bouraoui, F., & Bidoglio, G. (2003). A long-term hydrological modelling of the Upper Guadiana river basin (Spain). *Physics and Chemistry of the Earth, Parts A/B/C*, *28*(4), 193-200.

Dawod, G. M., & Koshak, N. A. (2011). Developing GIS-based unit hydrographs for flood management in Makkah metropolitan area, Saudi Arabia. *Journal of Geographic Information System*, 3(02), 160.

Dhawale, A. W. (2013). Runoff estimation for Darewadi watershed using RS and GIS. *International Journal of Recent Technology and Engineering*, 1(6), 46-50.

Dodds, W. K. (1997). Distribution of runoff and rivers related to vegetative characteristics, latitude, and slope: a global perspective. *Journal of the North American Benthological Society*, 162-168.

Durbude, D. G., Jain, M. K., & Mishra, S. K. (2011). Long-term hydrologic simulation using SCS-CN-based improved soil moisture accounting procedure. *Hydrological Processes*, *25*(4), 561-579.

Ebrahimian, M., See, L. F., Ismail, M. H., & Malek, I. A. (2009). Application of natural resources conservation service–curve number method for runoff estimation with GIS in the Kardeh watershed, Iran. *European Journal of Scientific Research*, *34*(4), 575-590.

Elhakeem, M., & Papanicolaou, A. N. (2009). Estimation of the runoff curve number via direct rainfall simulator measurements in the state of Iowa, USA. *Water Resources Management*, 23(12), 2455-2473.

El-Hassanin, A. S., Labib, T. M., & Gaber, E. I. (1993). Effect of vegetation cover and land slope on runoff and soil losses from the watersheds of Burundi. *Agriculture, ecosystems & environment*, *43*(3), 301-308.

Food and Agriculture Organization. (1990). FAO Yearbook. Production. Vol. 44. Food and Agriculture Organization of the United Nations. Rome. 1991.

Frelich, L. E. (2002). *Forest dynamics and disturbance regimes: studies from temperate evergreen-deciduous forests*. Cambridge University Press.

Gandini, M. L., & Usunoff, E. J. (2004). Curve Number Estimation Using Remote Sensing NDVI in a GIS Environment. *Journal of Environmental Hydrology*, 12.

Garg, V., Nikam, B. R., Thakur, P. K., & Aggarwal, S. P. (2013). Assessment of the effect of slope on runoff potential of a watershed using NRCS-CN method. *International Journal of Hydrology Science and Technology*, *3*(2), 141-159.

Geetha, K., Mishra, S. K., Eldho, T. I., Rastogi, A. K., & Pandey, R. P. (2008). SCS-CN-based continuous simulation model for hydrologic forecasting. *Water Resources Management*, *22*(2), 165-190.

Harris, A., & Hossain, F. (2008). Investigating the optimal configuration of conceptual hydrologic models for satellite-rainfall-based flood prediction. *IEEE Geoscience and Remote Sensing Letters*, *5*(3), 532-536.

Hawkins, R. H. (1993). Asymptotic determination of runoff curve numbers from data. *Journal of Irrigation and Drainage Engineering*, 119(2), 334-345.

Haws, L.D., Inoue, H., Tanaka, A. & Yoshida, S. (1983). Comparison of crop productivity in the tropics and temperate zone. In Potential Productivity of Field Crops Under Different Environments International Rice Research Institute. Los Banos, Philippines. (pp. 403-413).

Hernández-Guzmán, R., Ruiz-Luna, A., & Berlanga-Robles, C. A. (2008). Assessment of runoff response to landscape changes in the San Pedro sub basin (Nayarit, Mexico) using remote sensing data and GIS. *Journal of Environmental Science and Health Part A*, *43*(12), 1471-1482.

Hjelmfelt, A. T. Jr., Kramer, K. A., & Burwell, R. E. (1982). Curve number as random variables. Proceeding International Symposium on Rainfall-Runoff Modelling. In: V. P. Singh (Ed.). Water Resources Publicatio, Littleton, Colo. 365-373.
Holman-Dodds, J. K., Bradley, A. A., & Potter, K. W. (2003). Evaluation of hydrologic benefits of infiltration based urban storm water management1.
Huang, M., & Zhang, L. (2004). Hydrological responses to conservation practices in a catchment of the Loess Plateau, China. *Hydrological Processes*, 18(10), 1885-1898.
Huang, M., Gallichand, J., Wang, Z., & Goulet, M. (2006). A modification to the Soil Conservation Service curve number method for steep slopes in the Loess Plateau of China. *Hydrological processes*, *20*(3), 579-589.
Huang, M., Gallichand, J., Dong, C., Wang, Z., & Shao, M. (2007). Use of soil moisture data and curve number method for estimating runoff in the Loess Plateau of China. *Hydrological Processes*, 21(11), 1471-1481.
Jenicek, M. (2007). Effects of land cover on runoff process using SCS CN method in the upper Chomutovka catchment. *Integrated catchment management for hazard mitigation*, 42.
Jeníček, M. (2009). Runoff changes in areas differing in land-use in the Blanice river basin-application of the deterministic model. *Journal of Hydrology and Hydromechanics*, *57*(3), 154-161.
Kadam, A. K., Kale, S. S., Pande, N. N., Pawar, N. J., & Sankhua, R. N. (2012). Identifying potential rainwater harvesting sites of a semi-arid, basaltic region of Western India, using SCS-CN method. *Water resources management*, *26*(9), 2537-2554.
Kumar, P. S., Babu, M. R. K., & Kumar, T. P. V. (2010). Analysis of the Runoff for Watershed Using SCS-CN Method and Geographic Information Systems. *International Journal of Engineering Science and Technology*, *2*(8), 3947-3654.
Kurothe, R. S., Goel, N. K., & Mathur, B. S. (2001). Derivation of a curve number and kinematic-wave based flood frequency distribution. *Hydrological sciences journal*, *46*(4), 571-584.
Malekani, L., Khaleghi, S., & Mahmoodi, M. (2014). Application of GIS in Modeling Zilberchai Basin Runoff. *The International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences*, *40*(2), 181.
McCutcheon, S. C. (2006). Rainfall-runoff relationship for selected eastern U.S. forested mountain watershed: Testing of curve number method for flood analysis. Technical Rep. West Virginia Division of Forestry, Charleston, WV.
McQuen, R. H. (1982). A guide to hydrologic analysis using SCS methods. Prentice Hall, Englewood Cliffs, New Jersey 0763
McQuen, R. H. (2002). Approach to confidence interval estimation for curve numbers. *Journal Hydrologic Engineering*, Volume 7, No. 1, 43-48.
Mein, R. G. & Larson, C. L. (1971). Modelling the infiltration component of the rainfall-runoff process, WRRC Bull. 43. Water Resources Research Center, University of Minnesota, Minneapolis, Minnesota.
Melesse, A. M., & Shih, S. F. (2002). Spatially distributed storm runoff depth estimation using Landsat images and GIS. *Computers and Electronics in Agriculture*, *37*(1), 173-183.
Michel, C., Andréassian, V., & Perrin, C. (2005). Soil conservation service curve number method: How to mend a wrong soil moisture accounting procedure? *Water Resources Research*, 41(2).
Mishra, S. K., & Singh, V. (2013). *Soil conservation service curve number (SCS-CN) methodology* (Vol. 42). Springer Science & Business Media.
Mishra, S. K., & Singh, V. P. (2006). A relook at NEH-4 curve number data and antecedent moisture condition criteria. *Hydrological Processes*, 20(13), 2755-2768.
Mishra, S. K., Tyagi, J. V., Singh, V. P., & Singh, R. (2006). SCS-CN-based modeling of sediment yield. *Journal of Hydrology*, *324*(1), 301-322.
Mockus, V. (1949). Estimation of total (peak rates of) surface runoff for individual storms. Exhibit A of Appendix B. Interim Survey Report Grand (Neosho) River Watershed. USDA.
Murphy, P. G., & Lugo, A. E. (1986). Ecology of tropical dry forest. *Annual review of ecology and systematics*, 67-88.

Musa, R., Pallu, M. S., Samang, L., & Putra, M. (n.d.) Experimental Study of Estimation Model for Direct Run-off Volume with Soil Conservation Service (SCS) Model (Case Study of Bantimurung Catchment Area in Maros Regency of South Sulawesi).

Nayak, T. R., & Jaiswal, R. K. (2003). Rainfall-runoff modelling using satellite data and GIS for Bebas River in Madhya Pradesh. *Journal of the Institution of Engineers. India. Civil Engineering Division*, 84(mai), 47-50.

Nayak, T., Verma, M. K., & Bindu, S. H. (2012). SCS curve number method in Narmada basin. *International Journal of Geomatics and Geosciences*, 3(1), 219-228.

Ojha, C. S. P. (2011). Simulating turbidity removal at a river bank filtration site in India using SCS-CN approach. *Journal of Hydrologic Engineering*, *17*(11), 1240-1244.

Ogrosky, H. O. (1956). Service objectives in the field of hydrology. Unpublished. Soil Conservation Service, Lincoln, Nebraska. (pp. 5)

Okoński, B. (2007). Hydrological response to land use changes in central European lowland forest catchments. *Journal of Environmental Engineering and Landscape Management*, *15*(1), 3-13.

Olang, L. O., & Fürst, J. (2011). Effects of land cover change on flood peak discharges and runoff volumes: model estimates for the Nyando River Basin, Kenya. *Hydrological Processes*, *25*(1), 80-89.

Olivera, F. & Maidment, D. (1999). Geographical Information System (GIS)-based spatially distributed model for runoff routing. *Water Resources Research*. 35(4). (pp. 1155-1164).

Pandey, A., & Sahu, A. K. (2002). Generation of curve number using remote sensing and geographic information system. In *Water Resources, Map India Conference*.

Phetprayoon, T., Sarapirome, S., Navanugraha, C., & Wonprasaid, S. (2009, October). Surface runoff estimation using grid-based curve number method in the upper Lam Phra Phloeng Watershed, Thailand. In *30th Asian Conference on Remote Sensing* (pp. 18-23).

Ponce, V. M., & Hawkins, R. H. (1996). Runoff curve number: Has it reached maturity?. *Journal of Hydrologic Engineering*, 1(1), 11-19.

Rallison, R. E., & Miller, N. (1982). Past, present and future SCS runoff procedure. Rainfall-runoff relationship. In: V. P. Singh (Ed.). Water Resources Publication, Littleton, CO. 353-364.

Ramakrishnan, D., Bandyopadhyay, A., & Kusuma, K. N. (2009). SCS-CN and GIS-based approach for identifying potential water harvesting sites in the Kali Watershed, Mahi River Basin, India. *Journal of Earth System Science*, *118*(4), 355-368.

Ramasastri, K. S. & Seth, S. M. (1985). Rainfall-runoff relationship. Rep. RN-20. National Institute of Hydrology, Roorkee-247 667, Uttar Pradesh, India.

Rao, K. V., Bhattacharya, A. K. and Mishra, K. (1996). Runoff estimation by curve number method-case studies. *Journal of Soil and Water Conservation.* 40. 1-7.

Reshma, T., Kumar, P. S., Babu, M. R. K., & Kumar, K. S. (2010). Simulation of runoff in watersheds using SCS-CN and Muskingum-Cunge methods using remote sensing and geographical information systems. *International Journal of Advanced Science and Technology*, 25(31).

Reshmidevi, T. V., Jana, R., & Eldho, T. I. (2008). Geospatial estimation of soil moisture in rain-fed paddy fields using SCS-CN-based model. *Agricultural Water Management*, *95*(4), 447-457.

Rosenzweig, C., & Liverman, D. (1992). Predicted effects of climate change on agriculture: A comparison of temperate and tropical regions. *In Global Climate Change: Implications, Challenges, and Mitigation Measures. In SK Majumdar (Ed.) The Pennsylvania Academy of Sciences. Pennsylvania*, 342-61.

Romero, P., Castro, G., Gómez, J. A., & Fereres, E. (2007). Curve number values for olive orchards under different soil management. *Soil Science Society of America Journal*, 71(6), 1758-1769.

Rosenzweig, C., & Liverman., D. (1992). Predicted effects of climate change on agriculture: A comparison of temperate and tropical regions. In *Global climate change: Implications, challenges, and mitigation measures*. In S. K. Majumdar. (Ed.). 342-61.

Rutter, A. J., Kershaw, K. A., Robins, P. C., & Morton, A. J. (1971). A predictive model of rainfall interception in forests, 1. Derivation of the model from observations in a plantation of Corsican pine. *Agricultural Meteorology*, *9*, 367-384.

Santillan, J. R., Makinano, M. M., & Paringit, E. C. (2010). *Detection of 25-year land-cover change in a critical watershed in southern philippines using LANDSAT MSS and ETM+ images: importance in watershed rehabilitation*. na.
Schiariti, P. (2012). Basic Hydrology–Runoff Curve Numbers. *Mercer County Soil Conservation District*.
Schneider, L. A., & McQuen, R. H. (2005). Statistical guideline for curve number generation. *Journal Irrigation and Drainage Engineering*. 131(3). 282-290.
Sjöman, J. D., & Gill, S. E. (2014). Residential runoff–The role of spatial density and surface cover, with a case study in the Höjeå river catchment, southern Sweden. *Urban Forestry & Urban Greening*, *13*(2), 304-314.
Shadeed, S., & Almasri, M. (2010). Application of GIS-based SCS-CN method in West Bank catchments, Palestine. *Water Science and Engineering*, *3*(1), 1-13.
Shafiq, M., & Ahmad, B. (2001). Surface runoff as affected by surface gradient and grass cover. *Journal of Engineering and Applied Sciences (Pakistan)*.
Sharma, T., Kiran, P. S., Singh, T. P., Trivedi, A. V., & Navalgund, R. R. (2001). Hydrologic response of a watershed to land use changes: a remote sensing and GIS approach. *International Journal of Remote Sensing*, 22(11), 2095-2108.
Sharma, D. & Kumar, V. (2002)**.** Application of SCS model with GIS data base for estimation of runoff in an arid watershed. *Journal of Soil and Water Conservation*: 30(2). 141-145
Sharpley, A. N., & Williams, J. R. (1990). EPIC-erosion/productivity impact calculator: 1. Model documentation. *Technical Bulletin-United States Department of Agriculture*, (1768 Pt 1).
Sherman, L. K. (1949). The unit hydrograph method. In: O. E. Meinzer (Ed.) *Physics of the Earth*. Dover Publication Inc. New York, NY (pp. 514-525).
Soil Conservation Service (SCS) (1956, 1964, 1965, 1971, 1972, 1985, 1993). Hydrology, National Engineering Handbook, Supplement A, Section 4, Chapter 10, Soil Conservation Services, USDA, Washington, D.C.
Soil Conservation Service (SCS) (1986). Urban hydrology for small watersheds. Technical Release No. 55. Soil Conservation Services, USDA, Washington, D.C.
Soulis, K. X., & Valiantzas, J. D. (2012). Variation of runoff curve number with rainfall in heterogeneous watersheds. The Two-CN system approach.*Hydrology and Earth System Sciences*, 16(3), 1001-1015.
Steenhuis, T. S., Winchell, M., Rossing, J., Zollweg, J. A., & Walter, M. F. (1995). SCS runoff equation revisited for variable-source runoff areas. *Journal of Irrigation and Drainage Engineering*, *121*(3), 234-238.
Sumarauw, J. S. F., & Ohgushi, K. (2012). Analysis on curve number, land use and land cover changes and the impact to the peak flow in the Jobaru River Basin, Japan. *International Journal of Civil & Environmental Engineering IJCEE-IJENS, 12 (02): 17, 23*.
Tan, C. H., Melesse, A. M., & Yeh, S. S. (2002). Remote sensing and geographic information system in runoff coefficient estimation in CHINA TAIPEI. *GISdevelopement.net*, *6*.
Tedela, N. H., McCutcheon, S. C., Rasmussen, T. C., Hawkins, R. H., Swank, W. T., Campbell, J. L., ... & Tollner, E. W. (2011). Runoff Curve Numbers for 10 small forested watersheds in the mountains of the Eastern United States. *Journal of Hydrologic Engineering*, *17*(11), 1188-1198.
Tekeli, T. I., Akgul, S., Dengiz, O., & Akuzum, T. (2007). Estimation of flood discharge for small watershed using SCS curve number and Geographical Information System. In *International Congress on River Basin Management*.
Van Dau, Q., & Kuntiyawichai, K. (2015). An Assessment of Potential Climate Change Impacts on Flood Risk in Central Vietnam. *European Scientific Journal*. pp 667-680.
Vannasy, M., & Nakagoshi, N. (2016). Estimating Direct Runoff from Storm Rainfall Using NRCS Runoff Method and GIS Mapping in Vientiane City, Laos. *International Journal of Grid and Distributed Computing*, *9*(4), 253-266.
Wehmeyer, L. L., Weirich, F. H., & Cuffney, T. F. (2011). Effect of land cover change on runoff curve number estimation in Iowa, 1832–2001. *Ecohydrology*, *4*(2), 315-321.

Wischmeier, W.H., Smith, D.D. (1965). Predicting Rainfall-Erosion Losses from Cropland East of Rocky Mountains, USDA Agricultural Handbook No. 282, Washington, DC.

Xiao, B., Wang, Q. H., Fan, J., Han, F. P. and Dai, Q. H. 2011. Application of the SCS-CN model to runoff estimation in a small watershed with high spatial heterogeneity. *Pedosphere*. 21(6): 738–749.

Zhan, X., & Huang, M. L. (2004). ArcCN-Runoff: an ArcGIS tool for generating curve number and runoff maps. *Environmental Modelling & Software*, 19(10), 875-879.

Zhao, Y., Wang, C., Wang, S., & Tibig, L. V. (2005). Impacts of present and future climate variability on agriculture and forestry in the humid and sub-humid tropics. In *Increasing Climate Variability and Change* (pp. 73-116). Springer Netherlands.