



INTERNATIONAL CONFERENCE ON WATER RESOURCES, COASTAL AND OCEAN  
ENGINEERING (ICWRCOE 2015)

**Modified SCS-CN and Green-Ampt Methods in Surface Runoff  
Modelling for the Kundahpallam Watershed, Nilgiris, Western  
Ghats, India.**

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**Abstract**

Kundapallam watershed is located in Nilgiris District of south India. This ungauged watershed has an areal extension of 14.37 km<sup>2</sup>. There are increasing numbers of rainfall induced landslide occurrences in this area. The causes of rainfall induced landslides require a thorough understanding of runoff characteristics of the watershed. In this respect, the runoff of the study area is estimated with two approaches such as modified Soil Conservation Curve Number (SCS-CN) and Green-Ampt loss method. By these approaches, the related thematic factors on runoff characteristics are prepared with satellite images by using ARCGIS and IDRISI image processing software. The catchment delineation is generated for the Kundapallam watershed to get watershed parameters by using HEC-GeoHMS extension in ARCGIS. Curve number is assigned based on Soil Wetness Index (SWI). Sixteen soil samples were collected from different localities for the determination of hydraulic conductivity, moisture content, wetting front capillary pressure, bulk density, porosity *etc.* The infiltration rate of sample locations is determined by using double ring infiltrometer. Then all the parameters are assigned to models applied in this study to determine runoff characteristics of the study area. The accuracy and goodness of fit of the model are tested by determining the correlation coefficient (SCS-CN = 0.979 and Green-Ampt = 0.985) and coefficient determination (SCS-CN = 0.958 and Green-Ampt = 0.97) and it indicates statically positive correlations and perfect fit between the results of the study. The results showed that the modified SCS-CN provides low runoff estimation compared than Green-Ampt loss method.

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Peer-review under responsibility of organizing committee of ICWRCOE 2015

*Keywords: Modified SCS-CN parameters; Kundapallam ungauged watershed; Soil Wetness Index; Rainfall-Runoff modelling.*

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## 1. Introduction

Among the different components of hydrological process, rainfall and runoff are the important elements that contribute more water to the various activities performed in a watershed. The technical understanding of relationship between rainfall and runoff makes the researchers to plan the effective distribution of water for improving the developmental activities. This effective management may be done by quantifying the runoff generated by a rainfall through modelling with the different parameters of watershed. The usual procedures involving in the prediction of runoff were consume more time, produce erroneous results and require additional cost to gather different data. Hence, the recent advanced techniques such as remote sensing and Geographic Information System (GIS) are engaged in the collection, storing and analysis of data with respect to spatial and temporal distribution. The several techniques are available to model the runoff that was done by the hydrologist (Frevert and Singh (2002), GUPTA et al. (2004), Mahboubeh et al. (2012), Ruslin (2011), Sharma et al. (2008)). One particular method to quantify runoff was chosen with respect to objective, nature of the study area and the data availability. Even though numerous models are available to simulate runoff, selection of a suitable rainfall runoff model for a particular watershed is important to make a proper planning and management of watersheds. The model choice is mainly based on the prediction capacity with actuality of a watershed.

Among the different modelling approaches, Beven and Krikby (1979) estimated the distribution of runoff yield by the technique called Variable Source Area (VSA) is a modified version of physically based modelling system and it is first developed by them with incorporating topographic index for identifying the fractional areas contributing runoff. By this technique the saturated and unsaturated zones of watershed can be delineated with the effects of land surface parameters. A full branch of VSA hydrology was developed by the scientists of Soil and Water Lab, Biological and Environmental Engineering, Cornell University, USA to understand the responses of different land surface parameters as well as runoff yield.

Beven and krikby (1979) were the originator of concept of physically based variable contributing area with considering flow accumulation and its direction on land surface. It is a modified version of SCS-CN equation called CN-VSA approach and simple method providing solution for heterogeneous character of land surface. As emphasized by Steenhuis et al. (1995) and Lyon et al. (2004), it is more accurate to identify saturation areas and their locations in the river catchment with the use of Geographical Information System (GIS) and geo statistical tools of grid-based approach of land surface. Therefore the modified SCS-CN approach is appropriate runoff model for well vegetated humid areas since the saturation of soil based on the topographic parameters and effective rainfall depth. Variable Source Area (VSA) hydrology and identification of saturation-excess processes of runoff generation in shallow soils were pursued by the team of the scientists of Biological and Environmental Engineering, Cornell University, Ithac (USA) Lyon et al. (2004), Schniederma et al. (2007).

Easton et al (2008) have re-conceptualized the Soil and Water Assessment Tool (SWAT) model to distribute overland flow with respect to VSA hydrology by modifying the CN and available water content. This new modeling approach is called SWAT-VSA. They have applied both SWAT and SWAT-VSA to a sub-watershed in the Cannonsville basin in upstate New York to compare model predictions of integrated and distributed responses, including surface runoff, shallowly perched water table depth, and stream phosphorus loads against direct measures. The distribution of runoff and shallowly perched water table depth was predicted better by SWAT-VSA than the SWAT. Event based dissolved phosphorus export from the watershed was also predicted better by SWAT-VSA. The results of these models can be used to evaluate and guide watershed management by predicting location of runoff generation to locate best management practices for controlling non-point source pollution.

Dahlke et al (2009) have applied a VSA interpretation of the SCS-CN runoff equation that allows the initial abstraction to vary with antecedent moisture conditions. They coupled this modified SCS-CN approach with a semi-distributed water balance model to predict runoff, and distribute predictions using a soil topographic index for the Town Brook watershed in the Catskill Mountains of New York State. The accuracy of predicted VSA extents using both the original and the modified SCS-CN equation were evaluated for 14 rainfall-runoff events through a comparison with average water table depths measured at 33 locations in Town Brook. The modified SCS-CN equation captured VSA dynamics more accurately than the original equation. The results of this study were

demonstrating the feasibility of integrating VSA hydrology into water quality models to reduce non-point source pollution. Based on these earlier studies, this paper evaluates the performance of the modified SCS-CN method for modelling rainfall-runoff relationship in ungaugedKundapallam watershed.

**2. Materials and methods**

*2.1 Description of the Study Area*

Nilgiris is the smallest district of Tamil Nadu situated along the junction of Eastern and Western ghats of the Sahyadri Hills. It is known as "The Queen of Hill Stations" and situated at an elevation of 900 to 2,636 meters above Mean Sea Level (MSL). Kundapallam is a micro watershed located within Nilgiris with an elevation ranging from 1,546 to 2,411 m, and has an aerial extension of 14.37 km2. This micro watershed is bounded by 11°14'17" to 11° 16' 54" North latitude and 76° 34' 45" to 76 ° 39' 7" East longitudes. The name of the watershed is derived from Kundahriver which divides the watershed into a larger eastern part and a comparatively smaller western part. Geologically, the area is covered by charnockiterock and the drainage is influenced mainly by joint patterns and foliation trends of the rocks. The minimum (19.98° C to 12.18° C) and maximum (33.21° C to 20.48° C) temperature in this basin combined with a humidity ranging from 49.39 % to 98.14 % makes this a unique environment to study its hydrological characteristics. The watershed hosts Kundahhydel power station and estimation of runoff characteristics of this watershed is important in the analysis of flooding, ecological degradation, and soil erosion.

*2.2 Data Sources*

The base map of the study area was prepared from 1:50,000 scale Survey of India (SOI) Toposheet No.58A/11 of 1972 (Figure1). Slope map and flow accumulation map of the study area was obtained by processing CARTOSAT-1 Digital Elevation Model (DEM) and it was shown in figure1, figure 2 and figure 3. The daily weather data for the period from 2001 to 2010 were obtained from the ISRO Automatic Weather Station (AWS) No.175 located (11° 24' 2.556" N and 76° 42' 59.5254" E) 15 km away from the study area. The soil survey of India and a survey of the soil profiles in the watershed were used to prepare the detailed soil depth map of the watershed (Figure 3). AWiFS satellite data was used to prepare the land use map (Figure 4).

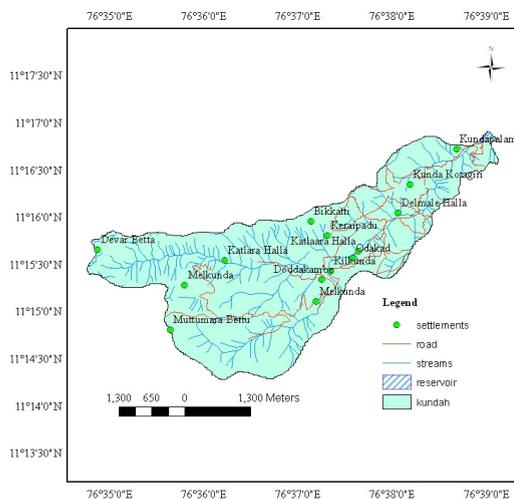


Figure 1. Base Map

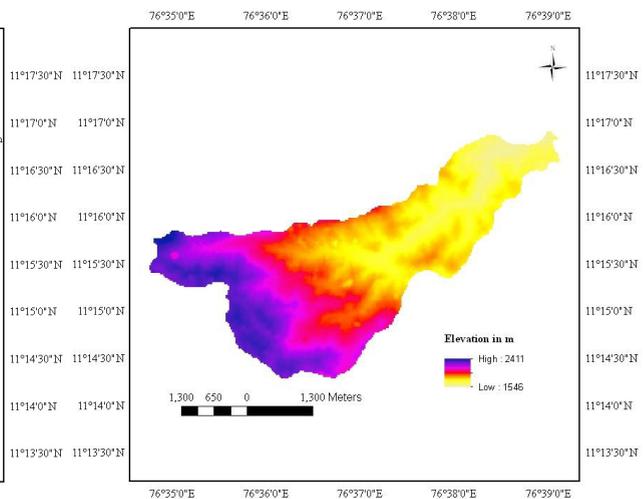


Figure 2. DEM

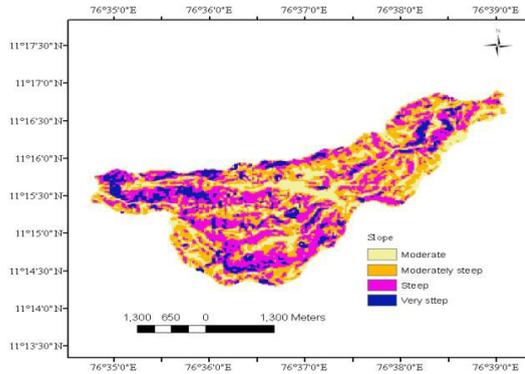


Figure 3. slope map

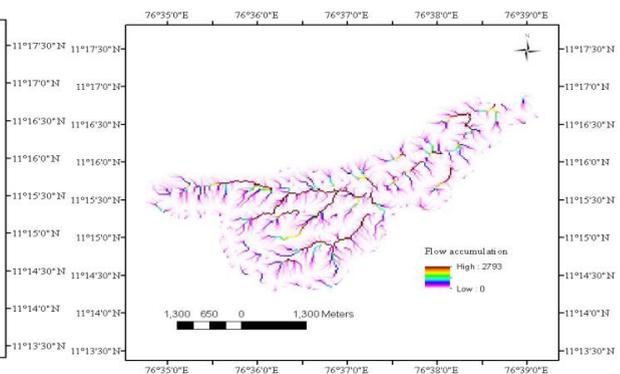


Figure 4. Flow accumulation map

2.3 Modelling runoff by modified NRCS-CN method

A rainfall runoff model by traditional NRCS-CN approach was developed for calculating flood flow volumes from ungauged small watersheds for hydraulic engineering design. Though this method was used in different water quality model such as SWAT Arnold and Allen (1993), AGricultural Non-Point Source (AGNPS) Young et al. (1989), Chemicals, Runoff and Erosion from Agricultural Management Systems (CREAMS) USDA (1980) and Generalized Watershed Loading Functions (GWLf) Haith and Shoemaker (1987), it does not predict the spatially distributed runoff generation areas and the calculation is prominently controlled by the land use and soil type. Also in this method, the hydrological and morphological characteristics were not included in the calculation of CN. Hence, the runoff from the traditional NRCS-CN has erroneous result that could not correlate with watershed characteristics. So the modified NRCS-CN equation developed by the Steenhuis et al. (1995) was used to predict the spatially distributed runoff by incorporating the concept of traditional NRCS-CN equation. By this method Runoff at a point in the watershed can be calculated with the equation 1 and 2

$$q = P_e - \sigma_e \text{ for } P_e > \sigma_e \tag{1}$$

$$q = 0 \text{ for } P_e \leq \sigma_e \tag{2}$$

Where,

q = runoff at a point location in mm

$P_e$  = depth of effective rainfall after runoff begins in mm

$\sigma_e$  = depth of local effective available storage after runoff begins in mm

Depth of effective rainfall and local effective available storage after runoff begins were calculated by the equation 3

$$P_e = P - I_a \tag{3}$$

The depth of local effective available storage after runoff begins within each area was determined by the equation 4

$$\sigma_e = \frac{2S_e(\sqrt{1-A_{s,i}} - \sqrt{1-A_{s,i+1}})}{(A_{s,i+1} - A_{s,i})} - S_e \tag{4}$$

Where,

$S_e$  = depth of effective available storage in mm and it is calculated by equation 5

$$S_e = 254 \left( \frac{100}{CN_{II} - 1} \right) \tag{5}$$

$A_{s,i}$  = area of the watershed that has lower local moisture storage in  $m^2$

$A_{s,i+1}$  = area of the watershed that has higher local moisture storage in  $m^2$

$CN_{II}$  = curve number for average watershed moisture content

The curve number was chosen based on the soil wetness index and land use characteristics of the watershed. The soil wetness index of the watershed can be calculated by the equation 6 Lyon et al. (2004)

$$SWI = \ln \left( \frac{\alpha}{T \tan \beta} \right) \tag{6}$$

Where

$\alpha$  = upslope contributing area for the cell per unit of contour line in m

$\tan \beta$  = topographic slope of the cell

T = transmissivity of the uppermost layer of the soil in m<sup>2</sup>/day

The total runoff of the watershed can be expressed as

$$Q = \sum_{i=1}^n q_i (A_{s,i+1} - A_{s,i}) \tag{7}$$

By using the map algebra tool in ArcGis 10, the flow accumulation map prepared from the flow direction map of the watershed was multiplied with the cell area to get an upslope contributing area and the slope map in degrees was converted into radians. Then the tan slope map was multiplied with the saturated hydraulic conductivity map and soil depth map. This product was divided with the flow accumulation map for getting the SWI map.

The SWI map was then classified according with the number HSG present in the watershed. The lower index has less probability to saturate and produce less runoff and the higher index has more probability to saturate and produce more runoff. Hence lower index was assigned as HSG A and the higher index was assigned as HSG D. Then the classified SWI map was given as input instead of soil map and the Hydrological Response Units (HRU) were prepared with the intersection of SWI map and the land use map of the watershed. The CN values were assigned for each HRU i.e. it was defined manually for the different land use and SWI class combination. After assigning the CN values, the runoff depth for the Kundapallam watershed was calculated by using the equation 1.

### 3. Testing of performance of model

In order to test the performance of the model, the degree of dependence between the rainfall and runoff was assessed through the Pearson product moment correlation coefficient analysis developed by theKarl Pearson.

$$r = \frac{n \sum xy - (\sum x)(\sum y)}{\sqrt{n(x^2) - (\sum x)^2} \sqrt{n(y^2) - (\sum y)^2}} \tag{8}$$

Where,

$n$  is the number of pairs of data

$x$  is the rainfall in mm

$y$  is the runoff in mm

If a correlation greater than 0.8 then the linear relationship between the variables was explained as strong and a correlation less than 0.5 was explained as weak. The coefficient of determination,  $r^2$  explains the variation between dependable and undependable variables and it varies from 0 to 1.

### 4. Results and Discussion

#### 4.1 Hydrological characterization of watershed

The sub-watershed and their relevant hydrological characteristics were generated from the Cartosat-1 DEM by completing required process in the GIS environment. The smoothing and filling functions were applied by HEC-GeoHMS in ArcGIS extension to remove the null and noise of DEM. Flow direction, flow accumulation and stream definition functions were run to produce the drainage network of DEM. Finally catchment delineation function in HEC-GeoHMS generated 21 sub-watersheds and their morphological characteristics were presented in table1.

Table 1.sub watershed characteristics

Subbasin	Area in m <sup>2</sup>	Latitude	Longitude	Elevation in m	Elevation Minimum in m	Elevation Maximum in m
1	42.96915	11.27715	76.64238	1632.625	1546	1770

2	34.86001	11.27599	76.63523	1696.837	1572	1814
3	74.47365	11.2715	76.63897	1679.19	1569	1774
4	35.23284	11.26788	76.6254	1770.608	1669	1925
5	64.59354	11.2687	76.63193	1720.831	1640	1817
6	50.42584	11.2627	76.63441	1752.353	1658	1844
7	44.36728	11.26454	76.61916	1796.983	1699	1936
8	66.92375	11.26256	76.62678	1747.525	1663	1861
9	25.81877	11.25824	76.59974	2039.022	1872	2283
10	147.6424	11.2603	76.5911	2142.792	1872	2380
11	14.91337	11.26122	76.60376	1891.55	1826	2011
12	77.1767	11.26103	76.60907	1842.095	1735	1970
13	70.37247	11.25952	76.61624	1783.523	1687	1958
14	14.54054	11.25974	76.6217	1731.814	1697	1799
15	37.65626	11.25488	76.61293	1863.01	1740	2009
16	52.1968	11.25337	76.60494	2022.018	1861	2278
17	65.33921	11.25284	76.59682	2115.247	1825	2313
18	30.85204	11.25008	76.60507	2084.535	1858	2283
19	101.7838	11.252	76.61969	1864.491	1706	2083
20	35.13963	11.24397	76.61432	2037.387	1900	2174
21	153.9806	11.24593	76.60542	2105.105	1892	2314

4.2 SWI, CN and runoff maps of the watershed

The SWI map was generated in GIS environment having their relevant properties. The five classes of SWI were generated and their percentage of coverage was shown in figure 5. Since the three hydrological soil groups B, C and D were found in the Kundapallam watershed, the SWI was classified into three groups according with HSG. The CN values corresponding to SWI (figure 6) were assigned based on standard SCS curve number table. It is noted that the lowest CN value was found to be 40 in dense forest and highest CN value was found to be 85 in built-up land. From the CN, hydrological properties and rainfall intensity, the spatially distributed runoff depth for the Kundapallam watershed were generated for a rainfall event of December 2010 and it was shown in figure 7.

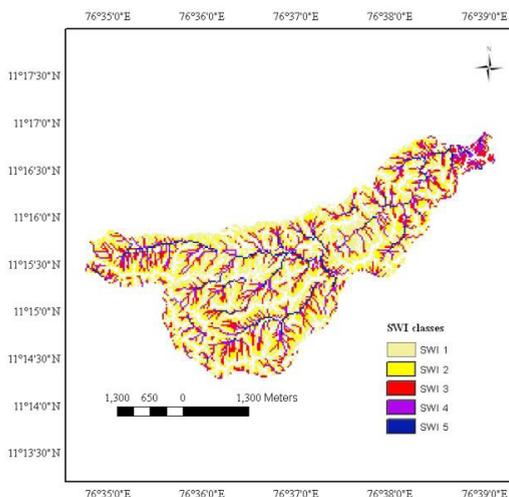


Figure 5. SWI classes

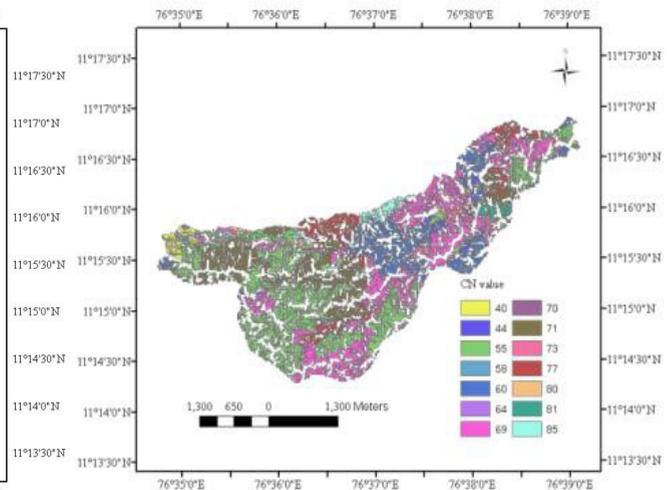
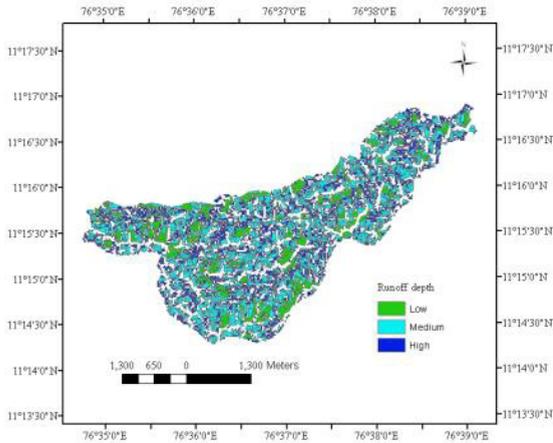


Figure 6. CN with respect to SWI



**Figure 7. Runoff depth**

**5. Evaluation of modified SCS-CN Equation**

An evaluation and applicability of modified SCS-CN method to the Kundahpallam watershed was assessed by determining the correlation coefficient and coefficient of determination between rainfall event and runoff depth for the years of 2001 to 2010. The three monthly rainfall depths such as low, medium and high were used to test the performance of the model and also it was compared with the results of Green-Ampt method (Grimaldi 2013) and presented in table 2. Green-Ampt model provided the best simulation of runoff in the catchment with the coefficient of determination ( $r^2$ ) equal to 0.97.

Table 2. comparisons of performance of model

Rainfall depth in mm	Runoff by modified SCS-CN in mm	Runoff by Green-Ampt in mm	correlation coefficient (r)			Coefficient of determination ( $r^2$ )	
			modified SCS-CN	Green-Ampt		modified SCS-CN	Green-Ampt
23.41(Dec 2010)	0.13	2.37					
159.12(Sep 2010)	75.32	123.53	0.979	0.985	0.958	0.97	
173.71(Nov 2010)	85.07	138.12					

**6. Conclusion**

GIS based Green-Ampt and modified SCS-CN model shall be supportive to the investigators for protection of water resources and water quality in watersheds. For defining the efficiency and suitability of models to an ungauged Kundahpallam watershed, a comparison was conducted on the results of both models and the best method was chosen based on the least difference between the results. Since Kundahpallam ungauged watershed is a thickly vegetated and moderate to highly steep sloped area, the major losses such as evaporation and infiltration were basically less. The key parameters for the Green-Ampt were infiltration and other soil inbuilt properties. Hence runoff depth calculated by Green-Ampt was more than the modified SCS-CN approach. From the assessment, Green-Ampt is the best method to simulate the runoff for the watershed. Ten year rainfall data were used for the computation of runoff. The results showed that 42% of rainfall got infiltrated into the ground and remaining 58% of rainfall flowed over the land as runoff. Since the infiltration capacity is lower than the rainfall intensity, infiltration excess runoff is the dominant process responsible for the observed runoff in this watershed than the saturation excess runoff. The estimated runoff shows that the watershed has a very good surface runoff potential. Based on the

results obtained from this study, the Green-Ampt method can be effectively applied to generate spatially distributed soil physical properties and runoff for the ungauged Kundapallam watershed by using the geographic information system.

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