



Implementation of NRCS-CN and Remote Sensing Technology for analysis of Rainfall-Runoff Relationship in Paghman Sub basin, Kabul, Afghanistan

P.Rajasekhara**, Folad Malwan*, P.Vimal Kishore*

Department of Civil Engineering/Osmania University

Osmania University

University college of Engineering, Osmania University, Hyderabad, Andhra Pradesh

INDIA

Abstract: Estimation of the runoff is required in order to determine and forecast its effects. Excessive runoff can cause floods with danger to life and property. Excessive runoff can washout the surface soil and because of this agricultural cycle of an area can be damaged forever. In a smaller scale, excessive runoff can disrupt life in residential areas and agriculture in rural areas. The runoff curve number (CN) is a key factor in determining runoff in the NRCS (National Resource Conservation Service) based hydrologic modeling method. The Soil Conservation Service Curve Number (SCS CN) also known as hydrologic soil group method was used in this study. This method is a versatile and popular approach for quick runoff estimation and is relatively easy to use with minimum data and it gives adequate result. From the study, monthly as well as annual rainfall and corresponding runoff were estimated.

The traditional NRCS-CN method for calculating the composite curve number is very tedious and consumes a major portion of the hydrologic modeling time. In most of cases, HSG and LULC maps were generated by graphical analyzing software such as ArcGIS, Imagin, and Civil 3D. Nowadays GIS and Remote Sensing is being used with NRCS-CN method highly, most of the researchers found that use of NRCS-CN with help of GIS gives very accurate results in determination of surface runoff.

The Paghman/Upper Kabul with an area of 348 km² and includes the urban population centers of western Kabul, and more rural lands in the western part of the area. For even more facilitating future analysis, Paghman sub basin was divided into five sections (Northern, Southern, Central, Eastern, and Western) parts. Values of Curve Number for each of above-mentioned sections were calculated and by using NRCS-CN equations. The Curve Number values for these sub basins are ranging from 62 to 71. Remote Sensing provided a powerful tool for estimating Curve Number values in Paghman sub basin.

Keywords: runoff, curve number, soil group, GIS&RS, NRCS-CN

I. Introduction

Surface water runoff is a step in the water cycle on Earth. When precipitation occurs, water only has a few locations where it can go. Water can infiltrate into the ground, evaporate, or become runoff. Runoff is the short way of saying surface water runoff. Water that does not get absorbed into the soil, or rise back into the atmosphere as water vapor, will run off surfaces collecting in varied locations (In low-lying areas, on floodplains, etc.). The environment in which water from precipitation lands will determine the likelihood of surface runoff. For instance, paved areas prevent water from infiltrating into the ground. The water will runoff the surface if evaporation does not take place. Flooding can occur if the amount of precipitation in an area exceeds the evaporation rate and infiltration capacity of the soil. Significant floods can also occur as water hits paved areas and has not chance to infiltrate into the ground.

Runoff occurs when part of the landscape are saturated or impervious. Two runoff concepts included infiltration-excess and saturation excess runoff. The infiltration-excess runoff paradigm assumes that overland flow occurs when the rainfall intensity is greater than the infiltration rate at the surface soil. The water in excess of that which infiltration through the soil surface, flows across the soil surface to nearby channels (Kirkby, 1985). This process has also been termed as Hortonian runoff. The following conditions must be satisfied to generate Hortonian flow. First, rain must fall on the landscape with enough intensity or rate to excess the permeability of the surface soil and secondly, the duration of rainfall must be longer than the time required saturating the surface. Hortonian runoff occurs less frequently except when, a) Distrusted or poorly vegetated areas that usually have a sub humid or semiarid climate, b) Clay dominated surface soil, c) Watersheds where bedrock surfaces are exposed and, d) Urban impervious surface.

Regardless of the conceptual or modeling approach to stream flow generation, the important catchment characteristics, topography soil type, vegetation cover, and depth to the water table usually vary at multiple

spatial scales, often resulting in a complex, nonlinear relationship between runoff and rainfall. As a result, slam plot studies will likely have different runoff characteristics compared to field-scale studies, and compared to watershed-scale studies.

The rate of runoff is required for the design of drains, canals and other channels, and for the prediction of water levels in streams and rivers. Quantity of runoff is required when storage is involved for irrigation, power generation, river transport, not to mention the need to prevent soil erosion and sediment transportation.

Remote sensing can be used to determine watershed geometry, drainage network, and hydrologic input parameters such as soil moisture delineated land use classes that are used to define runoff coefficients. Soil is considered as a basic element in civil engineering fields; therefore, the soil is classified by traditional method and remote sensing techniques.

II. Study Area

Afghanistan is a land-locked country (Fig 1) lying in the south of Asia between Iran and Pakistan. It extends from the 61st to the 74th longitude east and from the 29th to the 38th latitude north. The lowest point in the country is at Amuat + 258 m ASL, and the highest point is at Nowshak at + 7485 m ASL. With an area of 647,500 km², Afghanistan is almost twice as large as Germany. The borders of the country have a total length of 5529 km, of which 76 km with China, 936 km with Iran, 2430 km with Pakistan, 1206 km with Tajikistan, 744 km with Turkmenistan, and 137 km with Uzbekistan. Afghanistan is dominated by high ranges of mountains. Several mountain ranges extend eastwards from the Pamir and Hindukusch mountain chains in the south-east. A few plateaus lie on the Amu in the North of the country.

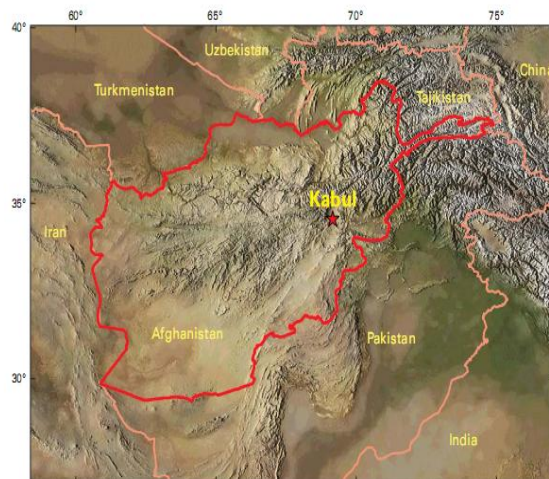


Figure 1: Afghanistan location

Paghman/Upper Kabul sub basin

Paghman/Upper Kabul with an area of 348 km² and includes the urban population centers of western Kabul, and more rural lands in the western part of the area.

III. NRCS-CN Method

Basis for the generalized SCS runoff equation can be expressed as follows: when the accumulated natural runoff is plotted versus accumulated natural rainfall, runoff starts after some rainfall has accumulated and the line of relation curves and becomes asymptotic to a 1:1 line, as shown in figure 3. The method of NRCS- CN assumes proportionality between retention and runoff such that:

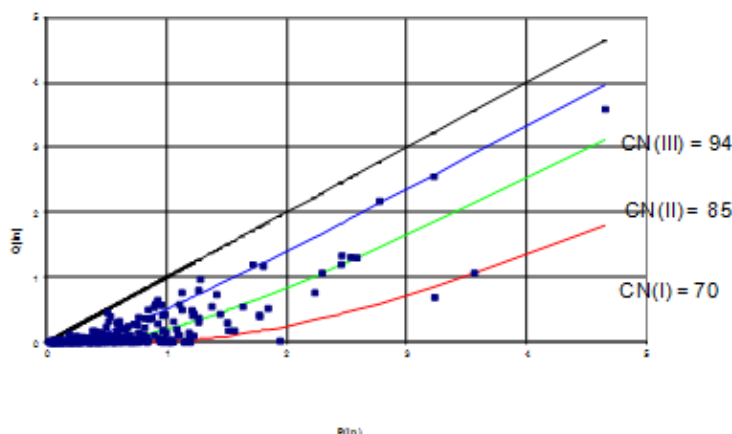


Figure 2: Rainfall and runoff sample curve, Nebraska “Donald, Rechar and others, 2005”

$$\frac{F}{S} = \frac{Q}{P} \dots\dots\dots 1$$

Where $F=P-Q$ =actual retention, S =potential retention, Q =actual runoff, P =potential runoff (total rainfall). The values of "P", "Q" and "S" are given in depth dimensions. Originally, these values were developed in U.S customary units (in) but an appropriate conversion to SI units (cm) is very much possible. Runoff "Q" is the total depth of direct runoff resulting from rainfall "P". Potential retention "S" is the maximum depth of rainfall that could potentially be abstracted by a given site.

Usually a certain amount of rainfall, referred to as "initial abstraction" is abstracted as interception, infiltration and surface storage before runoff begins. In the curve number method the initial abstraction "Ia" is subtracted from rainfall P which yields:

$$\frac{P - Ia - Q}{S} = \frac{Q}{P - Ia} \dots\dots\dots 2$$

Solving for Q in Eq.2 results in:

$$Q = \frac{(P - Ia)^2}{P - Ia + S} \dots\dots\dots 3$$

Which is valued for $P > Ia$, that is after runoff begins; and $Q=0$ otherwise.

There are two parameters in Eq.3, "S" and "Ia". To remove the necessity for an independent estimation of initial abstraction a linear relationship between "Ia" and "S" was suggested where:

$$Ia = \lambda * S \dots\dots\dots 4$$

Where λ = initial abstraction ratio.

NEH-4 reported that limits for the value of λ are equal to 0 up to 0.3. Later studies showed that a value of $\lambda=0.2$ is almost always suited well, therefore substituting Eq.4 in Eq.3 the main equation of CN becomes:

$$Q = \frac{(P - 0.2S)^2}{P + 0.8S} \dots\dots\dots 5$$

Only when $P > 0.2S$, and $Q=0$ otherwise.

The equation now contains only one parameter, potential retention "S", which varies between zero and infinity. For convenience a practical application, S is mapped into a dimensionless parameter CN, the curve number, which varies in a more appealing range. The mapping equation is given as

$$CN = \frac{25400}{254 + S} \dots\dots\dots 6$$

A $CN=100$ represents a condition of zero potential retention ($S=0$), that is, an impermeable watershed. Conversely a $CN=0$ represents a theoretical upper bound to the potential retention $S=\infty$, that is an infinitely abstracting watershed. Three important characteristics of each sub basins are also namely HSG, AMC and LULC/ LULT.

IV. Hydrological soil group

Soils are classified by the Natural Resource Conservation Service into four Hydrologic Soil Groups based on the soil's runoff potential. The four Hydrologic Soil Groups are A, B, C and D. Where A's generally have the smallest runoff potential and D's the greatest. Group A is sand, loamy sand or sandy loam types of soil. It has low runoff potential and high infiltration rates even when thoroughly wetted. Group B is silt loam, it has moderate infiltration rate. Group C soils are sandy clay loam, they have low infiltration rates when thoroughly wetted and consist chiefly of soils with a layer that impedes downward movement of water and soils with moderately fine-to-fine structure. Group D soils are clay loam, silty clay loam, and sandy clay, this HSG has the highest runoff potential and they have very low infiltration rates when thoroughly wetted and consist of clay soils with a high swelling potential, soils with a permanent high water table, soils with a clay pan at or near the surface and shallow soils over nearly impervious material (NEH-4)

V. Land cover/Treatment

Land use/treatment is another important property of watershed, which connects the physical relationship of a watershed with CN. The land use and treatment classes like agricultural, range, forest, urban and etc... can have huge impacts on the Curve Number -determination. Since land use/ cover changes year-by-year most of the countries have a program for tracking this LULC changes, in theory researches with this method only should

last for some amount of years due to rapid change of surface cover, but recent researches have shown that changes in LULC is very steady and it doesn't effect in CN changes in short term. (Jeffrey and Koichire 2012), (Nayak, Verma and Hema, 2007).

VI. Antecedent Soil Moisture (Antecedent Runoff Condition)

Antecedent Soil Moisture (Antecedent Runoff Condition) is one of the most important parameters in CN determination is AMC (Antecedent Soil Moisture) condition. However, determination of antecedent soil moisture content and classification into the antecedent moisture classes AMC I, AMC II and AMC III, representing dry, average and wet conditions, is an essential matter for the application of the SCS curve number procedure that is without a clear answer yet. Antecedent rainfall tables (NEH-4, 1964). The appropriate moisture group AMC I, AMC II and AMC III is based on a five-day antecedent rainfall amount and season catagory.

VII. Data acquired

Satellite image of Paghman sub basin was selected from LANDSAT quadrangle mosaics with the six Landsat 7 ETM+ non-thermal bands and a resolution of 14.25 m. The original 28.5-m resolution of the six bands was enhanced to 14.25-m resolution using the panchromatic image data that was "noise removed." The reflectance values were originally 16-bit values. In order to make the data useable to a wide array of applications and users, the data is converted into the 16-bit values to 8-bit values by multiplying the 16-bit reflectance values by 0.0255 (or 255/10,000); each 8-bit value represents 0.39% reflectance. Band numbers consists of 1 through 5 and 7. Band 6 is the thermal infrared band and is not included in these data because it is rarely useful. Soil data were obtained from MoAIL.

VIII. Data Format Properties

LANDSAT imagery is provided to the user by Geo-scientific in a specific series of formats, all of which are designed for maximum coverage of users who have access to basic graphical software such as ArcGIS or any other graphical analyzing software. Each LANDSAT scene is available with bands as separate files, (.tiff format - split layers / files - BSQ Band Sequential Format). A Geo-TIFF file can be used as a TIFF file in any graphical software. The geo-reference formats employed by Geo-scientific for LANDSAT imagery include a UTM projection and a WGS84 datum and ellipsoid.

IX. Paghman sub basin LULC

Land-use and land-cover information is used in hydrologic modeling to estimate surface roughness or friction values, since it affects the velocity of the overland flow of water. Land-use information, coupled with the hydrologic characteristics of soils on the land surface, can also provide measures of expected percolation and water-holding capacity. The amount of expected runoff from vegetated land- use types, such as forest, is not only affected by the surface and soil physical properties, but also by the uptake capacity of the vegetation present, (Lynn; 2009). Therefore, Land use and land cover are important characteristics of the runoff process that affects infiltration, erosion, and evapotranspiration. Hydrologic models, distributed models in particular, need specific data on land use and its location within the basin. Land use describes how a parcel of land is used (such as for agriculture, residence or industry) whereas the land cover describes the materials (such as vegetation, rocks...etc.) that present on the surface. The land cover for an area may be evergreen forest, but the land use may be recreation, oil extraction or various combination of activity (Jalil, 2002). One type of LULC which was dominant throughout all sub basins is the rangeland class. Rangeland class continued to have the highest number of pixels in Paghman sub basins which was something to expect. Other type of LULC where residential, agricultural, natural forests, forests and water bodies.

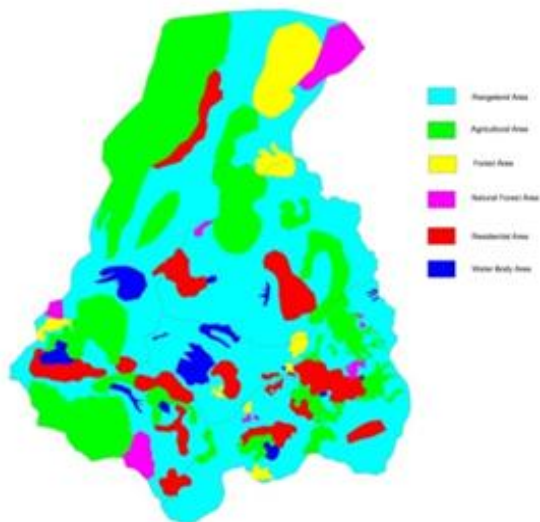


Figure 3: Paghman sub basin LULC map

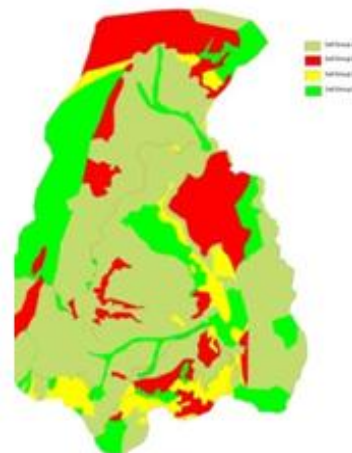


Figure 4: Paghman sub basin HSG map

X. Paghman HSG Map

Hydrological Soil Group map for each sub basin is created using Supervised Classification Tool. The amounts of pixels were calculated using all six bands of the image and soils were classified. The amount of pixels for each sub basin was calculated using data packs.

XI. Curve Number Values for Paghman sub basin

For creating a Curve Number map in ArcGIS some need for extra tools are necessary. Since ArcGIS in its original version does not provide any tool for calculating the Curve Number values, three add-on are essential to add to ArcGIS program, namely, Arc Hydro, HEC-HMS and Hec-GeoHMS. These three tools are available in ESRI website for updating ArcGIS.(Amy Hillier, 2011). The necessary data are HSG map and LULC map. Using ArcGIS, Arc Hydro tool calculation of preliminary analysis are done for instance calculation of Agreeeder, Fill sink, Fill direction are done and from Data Management Tool these data are collected and uploaded to ArcGIS for further calculation. To make this even simpler to read, understand and use, Paghman sub basin is divided into five parts, namely as north, south, central, east and west. As Figure.6 shows, the CN values are determined and are shown as they appear in the map. Legends on the right are the values of curve numbers starting from 35 up to 99 in intervals of five values. Each legends show an interval of five Curve Number by a specific color, where this color is also reflected in the same map. This map can give the reader/analyzer a good understanding of variation of curve number for Paghman sub basin:

Table 1. CN values for Paghman sub basin

Sub Basins	Pixels	True CN values
Northern Paghman Sub Basin		
Total Pixels	10960811	
Av. CN		65.936316
Southern Paghman Sub Basin		
Total Pixels	11822675	
Av. CN		67.3316
Central Paghman Sub Basin		
Total Pixels	16000000	
Av. CN		62.8
Eastern Paghman Sub Basin		
Total Pixels	8166161.04	
Av. CN		71.36617
Western Paghman Sub Basin		
Total Pixels	9681672.8	
Av. CN		65.9047

Total Average CN for Paghman Sub Basin = 66.1190752

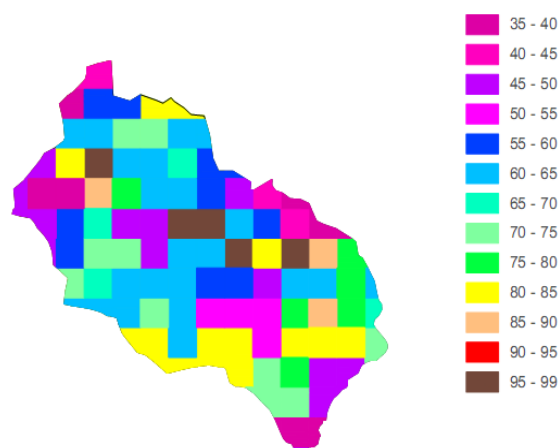


Figure 5: Paghman Basin Curve Number Variation

It is noted that the variation of curve number in all five basins are small and at most differs about six values. This shows that throughout the Kabul basin almost same hydrological and geological condition exist. It is also important to remember that the above Curve Number values are applicable only for AMC II (Average Condition). Moreover, in the latest version of NEH-4 the table for AMC Conditions is omitted and the choice of selecting AMC is left to Engineer/ Hydrologist judgment, experience and moisture condition of surface.

Paghman sub basin every year experiences all four seasons (each season usually lasts 3 months). The Dry Condition (AMC I) will apply for the summer season (starts from June till August); the AMC II (average condition) will be applicable for two seasons namely spring and autumn (from March to May for spring and

from September to November for autumn) and AMC III (wet condition) will mostly be applicable in winter season throughout Paghman sub basin (from December till February).
The derived curve numbers in summery are listed in (Table 6) for each sub basin and their sections:

Table 2. CN values for Paghman sub basin (AMC II condition)

Basins Name	Curve Numbers *
Paghman	66.1190752
• North	• 65.936316
• South	• 67.33160
• Central	• 62.80000
• East	• 71.36617
• West	• 65.90470
<i>*The above Curve Numbers are for AMC II (average condition)</i>	

From Table 2, it is clear that the variation of Curve Number when divided into smaller sections (north, south, central, east, and west) grows larger and for analysis and design purposes is much feasible.
The above Curve Numbers are applicable for AMC II condition. For AMC conditions, I and II the values would be as stated in (Table 3).

Table 3. CN values for Kabul basin (AMC I and AMC III Conditions)

Basins Name	Curve Numbers (AMC I) *	Curve Numbers (AMC III) **
Paghman	46.1190752	82.1190752
• North	• 45.936316	• 82.936316
• South	• 47.33160	• 83.33160
• Central	• 42.80000	• 79.80000
• East	• 52.36617	• 86.36617
• West	• 45.90470	• 82.90470
<i>*,** The values are changed from AMC II to AMC I and AMC III using table 10-1 of NEH-4</i>		

Recalling equation 6 and solving for "S" (potential retention) we will have:

$$S = \frac{25400}{CN} - 254 \dots \dots \dots .7$$

Where "S" is given in "centimeters".

Values of S for each Sub basin and their section and are calculated using Eq.7 and are shown in table 8.

Table 4. Potential Retention (S) values Paghman sub basin (AMC I, II and III)

Basins Name	S* (AMC I)	S (AMC II)	S (AMC III)
Paghman	296.75	130.16	55.31
North	298.94	131.22	52.26
South	282.64	123.24	50.81
Central	339.46	150.46	64.30
East	231.05	101.91	40.10
West	299.32	131.40	52.38
<i>The unit for "S" is Cm unless mentioned otherwise.</i>			

Using equation 7 the values for Runoff can be calculated for any precipitation amount in Kabul basin.

$$Q = \frac{(P - 0.25)^2}{P + 0.85} \dots \dots \dots .5$$

Here the units for "Q" (runoff) are in "centimeters" as in depth. To find the volume of runoff the value of "Q" must be multiplied to the area under analysis.

XII. Conclusions

Analysis for determining the amount of runoff for Paghman sub basin was the objective and for an un-gauged watershed, the only and most reliable method is NRCS-CN method. With help of Remote Sensing and using the powerful software (ArcGIS 10.1) Soil map for Paghman sub basin region, HSG map, Curve Number map for Paghman sub basin was created and values of Curve Number was calculated for the whole region of Paghman

sub basin, reliable data were collected from field trip to Paghman sub basin in data collection period and used during analysis whenever needed.

In summery the findings are:

- The Curve Number values for Paghman sub basin for AMC II (Average Condition) is
 - Logar sub basin = 70.96
- The Curve Number values for Paghman sub basin for AMC I (Dry Condition) is
 - Paghman sub basin = 46.12
- The Curve Number values for Paghman sub basin for AMC III (Wet Condition) is
 - Paghman sub basin = 82.12
- Values of Curve Number between sub basin sections does not differ a lot, at most the difference is about 6 values.
- A high value of Curve Number is present in AMC III condition in some areas. The highest value is about 86.
- The amount of Runoff in wet conditions is very high. In some cases even more then 85% of rainfall is returning, as runoff, and the heights is 86%.
- Such runoffs can cause floods, disruption to life and economy, damage and losses to property and life and can wash out surface soil.

XIII. References

- [1] Kirkby, M.J. 1985. Hillslope hydrology. In Hydrological forecasting, M.G. Anderson and T.B. Burt, eds. John Wiley and sons, New York, New York, 37-75
- [2] Harton, R.E 1933. The role of infiltration in the Hydrologic cycle. Transactions of the American geophysical union, 14: 446-460.
- [3] Mockus (1949) and Andrews (1954), National Engineering Handbook, Section 4, Department of agriculture, United States of America
- [4] Freeze, R. A. 1980. A stochastic- conceptual analysis of rainfall-runoff processes on a hill slope. Water resource research 16(2): 391-408.
- [5] Torge Tunnermeir and Dr. George Houben, 2003. Hydrology of the Kabul Basin, Part I, Geology, aquifer characteristics, climate, and hydrology.
- [6] Nayak, Verma and Hema, 2012 "SCS curve number method in Narmada basin", INTERNATIONAL JOURNAL OF GEOMATICS AND GEOSCIENCES , Volume 3, No 1, 2012, p: 219-228
- [7] Jeffry and Koichiro, 2012 "Analysis of CN, land use and land cover changes in the Jobaru river basin, Japan", ARPN Journal of Engineering and Applied Science, Vol. 7, No.7 pp.787-793, July 2012
- [8] Amy Hillier, 2011. Manual for working with ArcGIS 10.