



Analysis of Rainfall-Runoff relationship in Shomali sub-basin using NRCS-CN and Remote Sensing

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Abstract: Rainfall-runoff relationship is one of the most important phenomena in hydrology design of hydrological structures and drainage systems. 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 natural resources conservation services curve number (NRCS-CN) method is one of the most widely used methods for quick and accurate estimation of surface runoff from un-gauged watersheds, the traditional NRCS-CN method for calculating the composite curve number is very tedious and consumes a major portion of the hydrologic modeling time. Therefore, geographic information systems (GIS) are now being used in combination with the NRCS-CN method. In most of cases, HSG and LULC maps were generated by graphical analyzing software such as ArcGIS, Imagen, and Civil 3D.

Shomali sub basin cover an area of near 1800 Km². For even more facilitating future analysis and studies the above-mentioned sub basins was divided into five sections (Northern, Southern, Central, Eastern and Western) parts. Values of Curve Number for each of above-mentioned sections were calculated by using NRCS-CN equations. The Curve Number value for Shomali sub basins is about 70.5. Remote Sensing provided a powerful tool for estimating Curve Number values in Shomali sub basin.

Keywords: rainfall-runoff relationship, NRCS-CN method, Land use and land cover, GIS, Remote sensing.

I. Introduction

An understanding of runoff types is necessary to apply the method properly in different climatic regions. Four types are distinguished: channel, surface, lateral subsurface flow, and base flow. Channel runoff occurs when rain falls on a flowing stream. It appears in the hydrograph at the start of the storm and continues throughout the storm, varying with the rainfall intensity. This type of runoff is generally a negligible quantity in flood hydrographs and is ignored except in special studies. Surface runoff or overland flow occurs when the rainfall rate is greater than the infiltration rate. The runoff equation was developed for this condition. The runoff flows on the surface of the watershed and through channels to the point of reference. This type of runoff appears in the hydrograph after the initial demands of interception, infiltration, and surface storage have been satisfied. It varies during the storm and ends during or soon after the storm. The volume of surface runoff flowing down dry channels of watersheds in arid, semiarid, or sub humid climates may be reduced by transmission losses which could be large enough to eliminate the runoff. Subsurface flow occurs when infiltrated rainfall meets a subsurface horizon of lower hydraulic conductivity, travels laterally above the interface, and reappears as a seep or spring. This type runoff is often called quick return flow because it contributes to the hydrograph during or soon after the storm. Base flow occurs when there is a fairly steady flow from natural storage. Base flow must be considered in the design of the principal spillway of a floodwater retarding structure.

The runoff equation does not include base flow. All types of runoff do not regularly appear on all watersheds. Climate is one indicator of the probability of the types of runoff that will occur in a given watershed. In arid regions the flow on smaller watersheds is nearly always surface runoff. Subsurface flow is more likely in humid regions. A long succession of storms, however, may produce subsurface flow or changes in base flow even in arid climates, although the probability of this occurring is less in arid than in humid climates. In flood hydrology

base flow is generally dealt with separately, and all other types are combined into direct runoff, which consists of channel runoff, surface runoff, and subsurface flow in unknown proportions. The curve number method estimates this combined direct runoff.

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. 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. 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.

General Remote Sensing work can be summarized as follows:

- Selecting satellite image for the studied area.
- Digital image Processing (DIP) for satellite images.
- Preparing a surface soil map for studied area.
- Preparing a (Land use & Land Cover) map for studied area.
- Generating Curve Number map for the studied area.

NRCS-CN is used because of its i) simplicity, ii) predictability, iii) stability, iv) reliance in one parameter, v) its responsiveness.

II. Study Area

Afghanistan is a land-locked country (figure. 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: land-locked country of Afghanistan

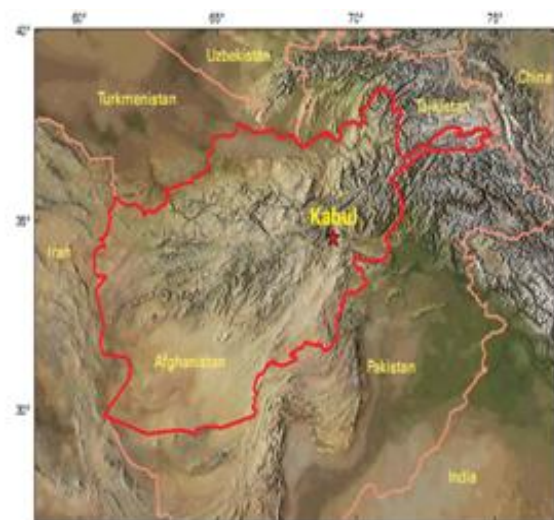


Figure 2. Kabul basin (including Shomali sub basin)

Shomali sub basin

Shomali Sub basin is in northern Kabul basin are less-populated, agricultural areas of the Kabul Basin that are largely irrigated from traditional surface water diversions. The Shomali ground-water area encompasses 785 km² and is a predominantly rural area that contains the largest irrigated agricultural area in the Kabul Basin. (Torge Tunnermeier and Dr. George Houben, 2003)

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:

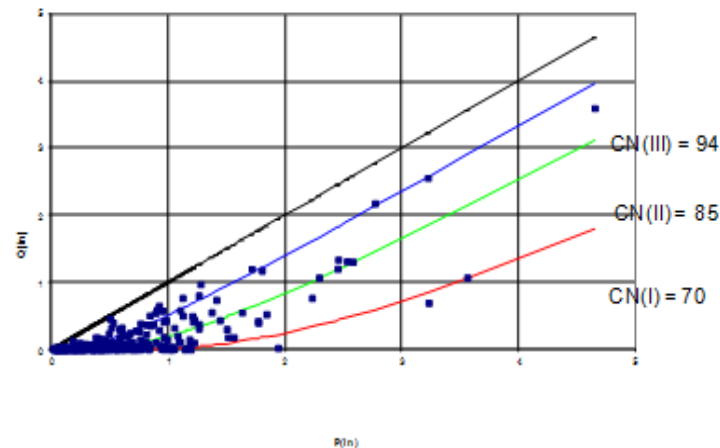


Figure 3. Rainfall and runoff sample curve, Nebraska “Donald, Rechar and others, 2005”

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

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 $0 \leq CN \leq 100$.

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/use Treatment

Land cover and 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 category.

VII. Collected Data

Satellite image of Shomali 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. Land Use and Land Cover Map for Shomali sub basin

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 all sub basins which was something to expect. Other types of LULC were residential, agricultural, natural forests, forests and water bodies.

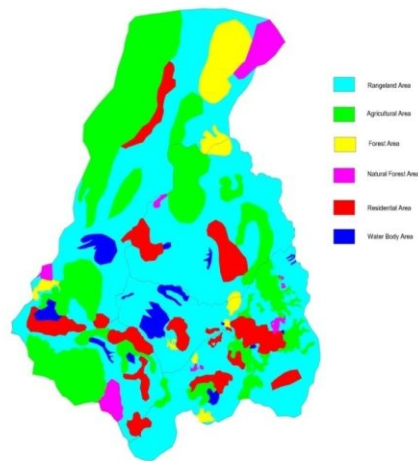


Figure 4: HSG map of Shomali sub basin

X. Curve Number Values for Shomali 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. Since Shomali sub basin is about 785 km² it was realized that it would be much more useable and genuine to calculate the Curve Number values for each sections namely as north, south, central, east and west. As figure 5 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 Numbers 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 in each basin. For Shomali sub basin the values are:

Table 1. CN values for Shomali sub basin

Sub Basins	Pixels	True CN values
Northern Shomali Sub Basin		
<i>Total Pixels</i>	<i>44544360</i>	
Av. CN		74.12895
Southern Shomali Sub Basin		
<i>Total Pixels</i>	<i>20098489.9</i>	
Av. CN		73.81007
Central Shomali Sub Basin		
<i>Total Pixels</i>	<i>26915924</i>	

Av. CN		69.71504
Eastern Shomali Sub Basin		
<i>Total Pixels</i>	<i>14019424.9</i>	
Av. CN		67.4662283
Western Shomali Sub Basin		
<i>Total Pixels</i>	<i>18605698</i>	
Av. CN		70.756

Total Average CN for Shomali Sub Basin = 71.8631398

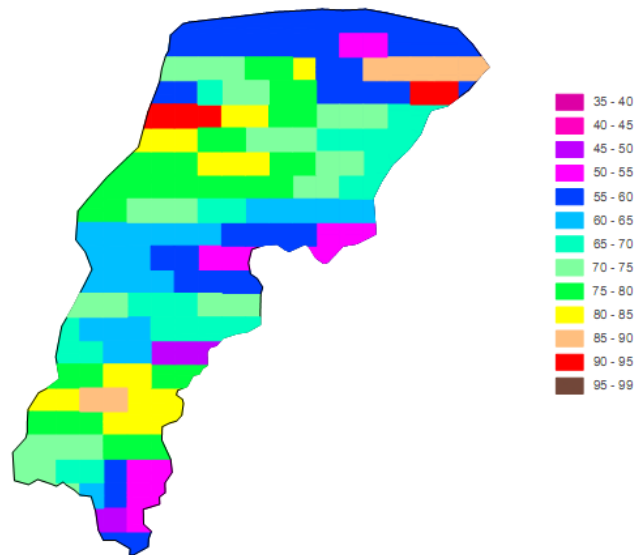


Figure 5: Shomali Basin Curve Number Variation

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 Shomali sub 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. Shomali 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 Shomali sub basin (from December till February). The derived curve numbers in summery are listed in (Table 2) for Shomali sub basin and their sections:

Table 2. CN values for Shomali Basin (AMC II condition)

Basins Name	Curve Numbers *
Shomali	71.8631398
• North	• 74.12895
• South	• 73.81007
• Central	• 69.71504
• East	• 67.4662283
• West	• 70.756

**The above Curve Numbers are for AMC II (average condition)*

From Table 2, it is clear that the variation of Curve Number between sub basin are small, but when divided into smaller sections (north, south, central, east and west) the variation 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 Shomali sun basin (AMC I and AMC III Conditions)

Basins Name	Curve Numbers (AMC I) *	Curve Numbers (AMC III) **
Shomali	52.8631398	86.8631398
• North	• 55.12895	• 88.12895
• South	• 54.81007	• 87.81007
• Central	• 50.71504	• 84.71504
• East	• 47.4662283	• 83.4662283
• West	• 51.756	• 85.756
*,** The values are changed from AMC II to AMC I and AMC III using table 10-1 of NEH-4		

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 4.

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

Basins Name	S* (AMC I)	S (AMC II)	S (AMC III)
Shomali	226.49	99.45	38.41
North	206.74	88.65	34.21
South	209.42	90.13	35.26
Central	246.84	110.34	45.83
East	281.12	122.48	50.31
West	236.76	104.98	42.19
The unit for "S" is Cm unless mentioned otherwise.			

Using equation 7 the values for Runoff can be calculated for any precipitation amount in Shomali sub 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.

XI. Conclusions

Analysis for determining the amount of runoff for Shomali 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 Shomali sub basin, HSG map, Curve Number map for Shomali sub basin was created and values of Curve Number was calculated for the whole region of Shomali sub basin, reliable data were collected from field trip to Shomali sub basin in data collection period and used during analysis whenever needed. For even more facilitating future analysis and studies Shomali 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. In summery the findings are:

- The Curve Number values for Shomali sub basin AMC II (Average Condition) is:
 - Shomali sub basin = 71.86
- The Curve Number values for Shomali sub basins for AMC I (Dry Condition) is:
 - Shomali sub basin = 52.86
- The Curve Number values for Shomali sub basin for AMC III (Wet Condition) is:
 - Shomali sub basin = 86.86
- Values of Curve Number between 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 88.
- 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 88%.
- Such runoffs can cause floods, disruption to life and economy, damage and losses to property and life and can wash out surface soil.

XII. References

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