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Rainfall-Runoff relationship in Central Kabul sub basin using NRCS-CN and Remote Sensing

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***Abstract*— Rainfall runoff is an important component contributing significantly to the hydrological cycle, design of hydrological structures and morphology of the drainage system. Estimation of the same is required in order to determine and forecast its effects. Estimation of Direct rainfall runoff is always efficient but is not possible for most of the location at desired time. Use of remote sensing and GIS technology can be used to overcome the problem of conventional method for estimating runoff caused due to rainfall. In this paper, modified National Resource conservation Service (NRCS) CN model is used for rainfall runoff estimation that considers parameter like slope, vegetation cover, area of watershed. Therefore, geographic information systems (GIS) are now being used in combination with the NRCS-CN method.NRCS-CN method is accepted and used worldwide because of 1). It's simplicity, 2).Predictability, 3). It's stability, 4). Because it relies only in one parameter and 5). It's responsiveness. In most of cases, HSG and LULC maps were generated by graphical analyzing software such as ArcGIS, Imagin, Civil 3D.**

Central Kabul sub basin covers an area of near 419 km^2. For even more facilitating future analysis and studies Central Kabul 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 values for runoff for sub basin and its respective sections were calculated for most probable precipitation intervals. The Curve Number values are ranging from 54 to 71. Remote Sensing provided a powerful tool for estimating Curve Number values in Central Kabul sub basin.

***Keywords*— Runoff, ArcGIS, Curve Number, Hydrological soil group, Antecedent soil Moisture.**

I. INTRODUCTION

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. It was first described by Harton (1933), two 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. Hartonian 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.

The second type of runoff generation also occurs where the soil surface is saturated and further rainfall, even at low intensities, generates runoff that contributes to stream flow. This more dominant process is termed as saturation-excess runoff generation. A rise in the water table occurs because of a large infiltration rate of water into the soil and down to the saturated subsurface. The variable spatial extent of the landscape saturated from below that fluctuates dynamically with watershed wetness is termed *the variable sources area* (freeze and cherry, 1979). *Variable source areas* typically develop near existing stream channels and in depressions or hollows and expand as more water infiltrates and moves down slope as saturated subsurface flow.

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.

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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.

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 (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 plateaux lie on the Amu in the north of the country.

Central Kabul sub basin - Central Kabul with an area of 419 km^2 and includes the primary population center of Afghanistan (the city of Kabul) in the western part of the area and more rural lands in the eastern part of the area.

Fig.1 Central Kabul Basin Location

III. Methodology and Experimentation

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 2.

The method of NRCS- CN assumes proportionality between retention and runoff such that:

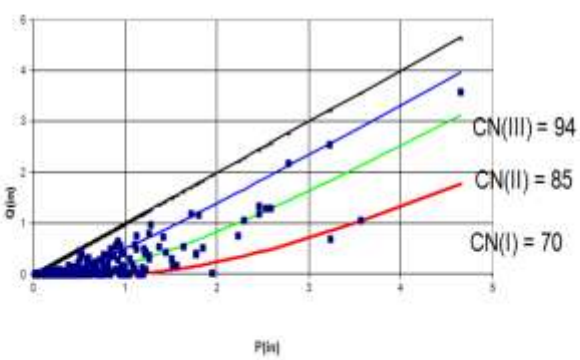

Fig.2 Rainfall and runoff sample curve, Nabraska "Donald, Rechard and others, 2005"

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$$\frac{F}{S} = \frac{Q}{P} \ldots\ldots\ldots\ldots\ldots\ldots\ldots..1$$

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:

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

Solving for Q in $Eq.2$ results in:

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

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:

$$Ia = \lambda * S \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots...4$$

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:

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

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

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

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=∞, that is an infinitely abstracting watershed.

Three important characteristics of each sub basins are also namely HSG, AMC and LULC/ LULT.

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 Soils 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 soils. It has low runoff potential and high infiltration rates even when thoroughly wetted. Group B is silt loam or loam. It has a 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, sandy clay, silty clay or clay. This HSG has the highest runoff potential. They have very low infiltration rates when thoroughly wetted and consist chiefly of clay soils with a high swelling potential, soils with a permanent high water table, soils with a clay pan or clay layer at or near the surface and shallow soils over nearly impervious material. (NEH-4).

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).

Antecedent Soil Moisture - 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.

Data Aquired - Satellite image of Central Kabul sub basin was selected from LANDSAT quadrangle mosaics with the six Landsat 7 ETM+ nonthermalbandsand 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.

Data Format Properites - LANDSAT imagery is provided to the user by Geoscientific 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 Geoscientific for LANDSAT imagery include a UTM projection and a WGS84 datum and ellipsoid.

Land Use nad Land cover Map – 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 type of LULC where residential, agricultural, natural forests, forests and water bodies.

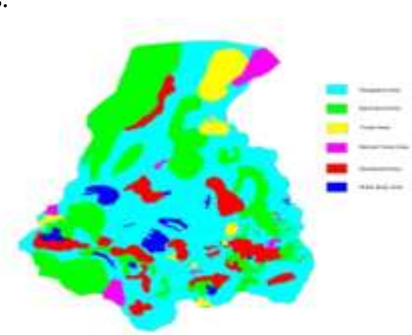

Fig.3 LULC Classification

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Kabul 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. In Central Kabul sub basin, some small amount of pixels could not be analyzed and their classes were not clear, but due to very small number of pixels (largest percentage was about $6.494137*10^{-4}$ %) their existence were simply ignored

CN Values for Central Kabul Basin - For creating a Curve Number map in ArcGIS some need for extra tools are necessary. Since ArcGIS in its original version doesn't 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 Agreeder, Fill sink, Fill direction are done and from Data Managemen Tool these data are collected and uploaded to ArcGIS for further calculation. It was realized that it would be much more useable and genuine to calculate the Curve Number values, Central Kabul sub basin was divided into another 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 in each basin. For Central Kabul sub basin the values are:

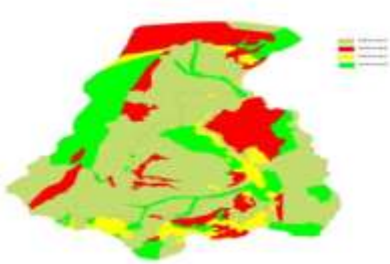

Fig.4 HSG Classification

TABLE I
CN VALUES OF CENTRAL KABUL

Sub Basins	Pixels	True CN values
Central Kabul Sub Basin (South)		
Total Pixels	13991752	
Av. CN		**65.6748**
Central Kabul Sub Basin (North)		
Total Pixels	11813288	
Av. CN		**54.855202**
Central Kabul Sub Basin (Center)		
Total Pixels	13856394	
Av. CN		**75.39379**
Central Kabul Sub Basin (East)		
Total Pixels	10453567.9	
Av. CN		**67.64155**
Central Kabul Sub Basin (West)		
Total Pixels	16173112	
Av. CN		**71.33691**

Average

$$CN = \frac{\sum(\text{Average CN for each part of sub basin} * \text{Total DP Pixels})}{\sum(\text{Total Amount of DP pixels})}$$

Total Average CN for Central Kabul Sub Basin = 67.4698238.

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Figure 6 : Central Kabul 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 Central Kabul 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.

Central Kabul 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 Central Kabul sub basin (from December till February).

The derived curve numbers in summery are listed in (Table 2) for each sub basin and their sections:

TABLE III
CH VALUES OF KABUL (AMC II CONDITION)

Basins Name	Curve Numbers *
Central Kabul • North • South • Central • East • West	**67.4698238** • 54.855202 • 65.6748 • 75.39379 • 67.64155 • 71.33691
*The above Curve Numbers are for AMC II (average condition)	

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 IIIII
CH VALUES OF KABUL (AMC I AND AMC III CONDITION)

Basins Name	Curve Numbers (AMC I) *	Curve Numbers (AMC III) **
Central Kabul • North • South • Central • East • West	**47.4698238** • 34.855202 • 45.6748 • 57.39379 • 47.64155 • 52.33691	**83.4698238** • 73.855202 • 82.6748 • 88.39379 • 83.64155 • 86.33691
*,** *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:

$$S = \frac{25400}{CN} - 254 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 7$$

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 IVV
CH VALUES OF KABUL (AMC I AND AMC III CONDITION)

Basins Name	S* (AMC I)	S (AMC II)	S (AMC III)
Central Kabul	**281.08**	**122.46**	**50.30**
North	474.73	209.04	89.92
South	302.11	132.75	53.23
Central	188.56	82.90	33.35
East	279.15	121.51	49.68
West	231.32	102.06	40.20
The unit for “S” is Cm unless mentioned otherwise.			

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

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

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.

IV. CONCLUSIONS

Analysis for determining the amount of runoff for Central Kabul sub basin was the objective and for an ungagged 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 Central Kabul sub basin region, HSG map, Curve Number map for Central Kabul sub basin was created and values of Curve Number was calculated for the whole region of Central Kabul sub basin, reliable data were collected from field trip to Kabul basin in data collection period and used during analysis whenever needed.

For even more facilitating future analysis and study of Central Kabul 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 values for runoff for each sub basins and their respective can be determined.

In summery the findings are:

- The Curve Number value for Central Kabul sub basin for AMC II (Average Condition) is:
    - Central Kabul sub basin = 67.47
- The Curve Number value Central Kabul sub basin for AMC I (Dry Condition) is:
    - Central Kabul sub basin = 47.47
- The Curve Number value for Central Kabul sub basin for AMC III (Wet Condition) is:
    - Central Kabul sub basin = 83.47
- Values of Curve Number between parts 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 89.
- The amount of Runoff in Wet Conditions are very high. In some cases even more then 70% of rainfall is returning, as runoff, and the heights is 89%.

Such runoffs can cause floods, disruption to life and economy, damage and losses to property and life and can wash out surface soil.

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