Estimation of Runoff 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 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 NCRS (National Resource Conservation Service) based hydrologic modeling method. 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, Imagine, 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.
Kabul basin cover an area of near 1800 Km^2 and is consist of five sub basins, namely Central Kabul, Shumali, Deh Sabz, Paghman and Logar sub basins. For even more facilitating future analysis and studies each of above-mentioned sub basins were 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 sections were calculated for most probable precipitation intervals. The Curve Number values for these sub basins are ranging from 65 to 71. Remote Sensing provided a powerful tool for estimating Curve Number values in Kabul basin and eventually values of runoffs for Kabul Basin.

Keywords – CN (Curve Number), Arc GIS, HSG, LULC maps

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. Modification of the land surface during urbanization changes the type and magnitude of runoff processes. Covering parts of the catchment with impervious roofs and concrete lots increases the volume and rate of Horton overland flow. Planners have to design detention ponds to accommodate increased runoff. The channels are straightened and lined with concrete to increase the efficiency, so that they transmit the flood wave downstream more quickly. A storm hydrograph after urbanization has larger peak flow and shorter lag time than before.

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:

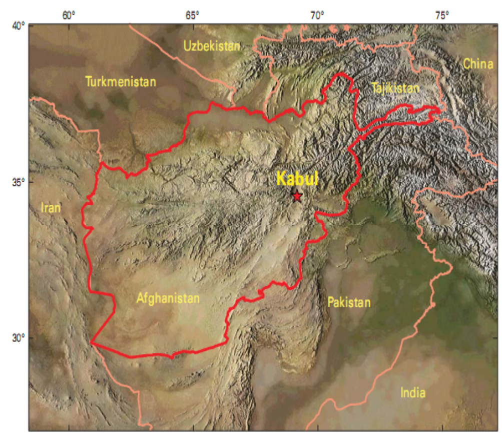
- Selecting satellite image for the studied area.
- Digital image Processing (DIP) for satellite images.
- Preparing a surface soil map for studied area.
- Preparing a (Land use & Land Cover) map for studied area.
- Generating Curve Number map for the studied area.

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.

(a)



(b)

Figure 1(a). Afghanistan location (b) Kabul basin location

A. Kabul basin

The study area encompasses about 1,800 km2 and includes the Kabul Basin. The city of Kabul is located along the confluences of the Kabul River, Logar River, and Paghman Stream (fig. 2), although in recent years these streams have been dry for much of the year. Paghman Stream joins the Kabul River at the western end of the city, just before the Kabul River enters central Kabul. Topography in central Kabul is relatively flat. The Kabul River flows eastward toward its confluence with the Logar River, then enters a steep canyon at the south-central end of the basin. Immediately north of Kabul, bedrock outcrops delineate surface-water divides beyond which ephemeral drainages discharge to the northeast from Shomali and to the northwest from DehSabz.Both of these areas eventually contribute flow to the Panjsher River. The Panjsher River joins the Kabul River approximately 100 km east of Kabul. (Torge Tunnermieir and Dr. George Houben, 2003).

B.Kabul sub basins

Kabul Basin is consisting of five major sub basins, namely Central Kabul, Paghman (Upper Kabul), Shomali, Deh Sabz and Logar Sub Basins. The accommodated area of Kabul basin is about 1800 km^2. (Torge Tunnermieir and Dr. George Houben, 2005).

The sub basins are namely as:

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.

The Paghman/Upper Kabul with an area of 348 km^2 and includes the urban population centers of western Kabul, and more rural lands in the western part of the area.

The Shomali ground-water area encompasses 785 km^2 and is a predominantly rural area that contains the largest irrigated agricultural area in the Kabul Basin.

The Deh Sabz area encompasses 464 km^2 and is a very rural area. There are no perennial rivers or streams in this area, although there are some ephemeral streams and some perennial springs that discharge from the base of the mountains on the east side of this area.

In addition, Logar sub basin has an area of 190 km^2 and includes both urban and rural lands.

III.METHODOLOGY

A.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:

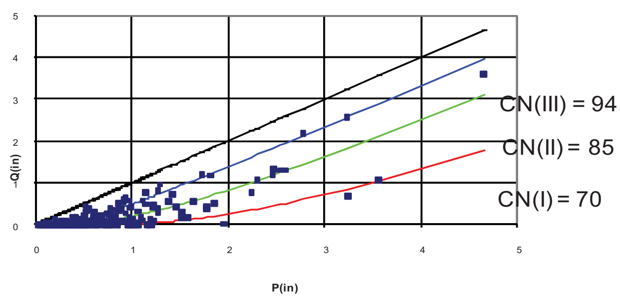


Figure 2. Rainfall and runoff sample curve, Nabraska "Donald, Rechard and others, 2005"

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

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:

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

Solving for Q in Eq.2 results in:

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

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:

$$Ia = \lambda * S \quad \text{....................................4}$$

Where = 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 is almost always suited well, therefore substituting Eq.4 in Eq.3 the main equation of CN becomes:

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

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

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

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.

B.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).

C.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.

D.Data acquired

Satellite image of Kabul 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.

E.Data Format Properties

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.

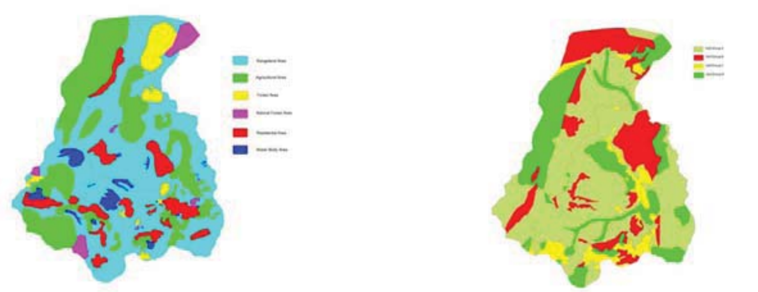
Each LANDSAT scene is available with bands as separate files, (.tiff format - split layers / files - BSQ Band Sequential Format). A Geo-TIFF file can be used as a TIFF file in any graphical software. The geo-reference formats employed by Geoscientific for LANDSAT imagery include a UTM projection and a WGS84 datum and ellipsoid.

F.Land Use and 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.

G.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. Table 4.6 shows the classification and data pack numbers. In each 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.



(a) (b)

Figure 3(a).LULC map of Kabul basin (b) HSG map of Kabul basin

IV.EXPERIMENT AND RESULTS

A. Curve Number Values for 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 Management Tool these data are collected and uploaded to ArcGIS for further calculation. Since Kabul basin is about 1800 Km^2 it was realized that it would be much more useable and genuine to calculate the Curve Number values for each sub basin to get a better look and realize the amount of runoff variation so, Curve Number values for each of five sub basins were calculated and analyzed.

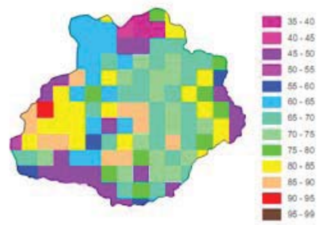
Recalling Eq.6 and solving for "S" (potential retention) we will have:

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

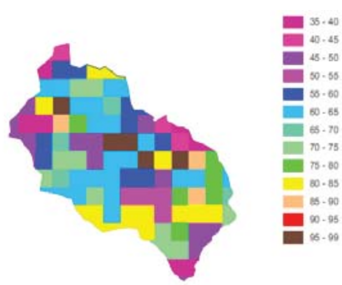
Where "S" is given in "centimeters".
Values of S for each Sub basin and their section and are calculated using Eq.7 and are shown in Table 1

(a)

(b)



(c)



(d)

(e)

Figure 4.Curve Number variation for (a) Central Kabul (b)Shumali (c)Deh Sabz (d)Paghman (e)Logar

Table 1. Potential Retention (S) values for Central Kabul sub basin (AMC I, II and III)

Basins Name	S* (AMC I)	S (AMC II)	S (AMC III)
Central Kabul	**281.08**	**122.46**	**50.30**
Shumali	**226.49**	**99.45**	**38.41**
DehSabz	**283.89**	**123.85**	**51.21**
Paghman	**296.75**	**130.16**	**55.31**
Logar	**234.79**	**103.93**	**41.47**

Using equation 5 the values for Runoff can be calculated for any precipitation amount in Kabul basin.

$$Q = \frac{(P - 0.2S)^2}{P + 0.8S} \quad \ldots\ldots\ldots\ldots\ldots 8$$

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.

V.CONCLUSION

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

Kabul basin is consist of five sub basins, namely Central Kabul, Shumali, Deh Sabz, Paghman and Logar sub basins. 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 Curve number values:

In summary the findings are:

- The Curve Number values for Kabul basin and its Sub basins are for AMC II (Average Condition)
    - Central Kabul sub basin = 67.47
    - Shumali sub basin = 71.86
    - Deh Sabz sub basin = 67.22
    - Paghman sub basin = 66.12
    - Logar sub basin = 70.96
- The Curve Number values for Kabul basin and its Sub basins are for AMC I (Dry Condition)
    - Central Kabul sub basin = 47.47
    - Shumali sub basin = 52.86
    - Deh Sabz sub basin = 47.22
    - Paghman sub basin = 46.12
    - Logar sub basin = 51.96
- The Curve Number values for Kabul basin and its Sub basins are for AMC III (Wet Condition)
    - Central Kabul sub basin = 83.47
    - Shumali sub basin = 86.86
    - Deh Sabz sub basin = 83.22
    - Paghman sub basin = 82.12
    - Logar sub basin = 85.96

- 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 70% of rainfall is returning as runoff.

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