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ESTIMATION OF SURFACE RUNOFF USING SCS-CN METHOD IN GIS ENVIRONMENT: A CASE STUDY OF KHULNA CITY

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ABSTRACT

Estimation of Surface runoff, a very important measure of rain water distribution, is essential to manage proper water balance within an area. This study was conducted to estimate surface runoff using SCS (Soil Conservation Service) –CN (Curve Number) method within political boundary of Khulna City Corporation (KCC) area. Runoff curve number, the key factor to determine surface runoff of this method, was established with the environment of Geographic Information System (GIS). ArcGIS technique was used to determine curve number using topographic map, land use map and soil map of the study area. Satellite image of the study area was collected from USGS. The catchment area of Khulna city is 40.79 km.2 where 1926 mm per year average precipitation was observed. Within the catchment area different curve numbers were obtained from land use and soil types. Finally, a relationship was established between rainfall and surface runoff and it was found that about 19% of rainfall is subjected to surface runoff. That's why it is easy to find out and calculate flow direction, flow accumulation, adjoin catchment of this area. Integration of GIS with the traditional SCS-CN method has been proved as a strong analytical tool for surface runoff estimation and helped to evaluate several land use policy to manage it.

Keywords: *Geographic Information System (GIS), SCS-CN method, Curve Number, Surface runoff, Khulna City Corporation (KCC).*

1. INTRODUCTION

Surface runoff is water, from rain, snowmelt, or other sources, that flows over the land surface, and is a major component of the water cycle. Runoff that occurs on surfaces before reaching a channel is also called overland flow. A land area which produces runoff draining to a common point is called a watershed. Urbanization increases surface runoff, by creating more impervious surfaces such as pavement and buildings do not allow percolation of the water down through the soil to the aquifer. First of all, surface runoff highly depends on precipitation. Surface elevation, texture, soil characteristics are highly related with surface runoff. When surface elevation or steepness is high, a potential amount of precipitation subjected to runoff. Again soil permeability is highly related to runoff. Different soil has different percolation capacity. When percolation is no longer possible then runoff occurs.

Surface runoff is subjected to rainfall where rainfall-runoff relationship is very complex, influenced by various storm and drainage characteristics (Seth et al. 1997). Rainfall induced runoff is very important for water resources development and management such as flood control and its management, Irrigation scheduling, design of drainage network, hydro power generation etc. (Mishra et al. 2013). Again surface runoff plays an important role in natural water balance. Ground water recharge is inversely related with surface runoff. It is worth mentioning that over the past two decades, the use of Remote Sensing and Geographic Information System (GIS) technologies in run-off estimation from urban watershed has gained increasing land use planning and watershed management can be done effectively and efficiently using SCS-CN number method with GIS (Ahmad et al. 2015). The major advantage of employing GIS in rainfall-runoff modelling is that more accurate sizing and catchment characterization can be achieved. Furthermore, the analysis can be performed much faster, especially when there is a complex mix of land use classes and different soil types (Shadeed and Almasri, 2010).

1.1 Study Area

Khulna is the 3rd large city and 2nd largest coastal zone of Bangladesh. It is also moderately high precipitated zone because of its geographical location. The geographical location of this area 22°49′0″N 89°33′0″E which is the south-western part of Bangladesh. Khulna city is situated at the western bank of the river Bhairov over a length of around 15 km. As of the 2011 census, the city has a population of 751.23 thousand and its total area is 64.78 km^2 (BBS, 2011).

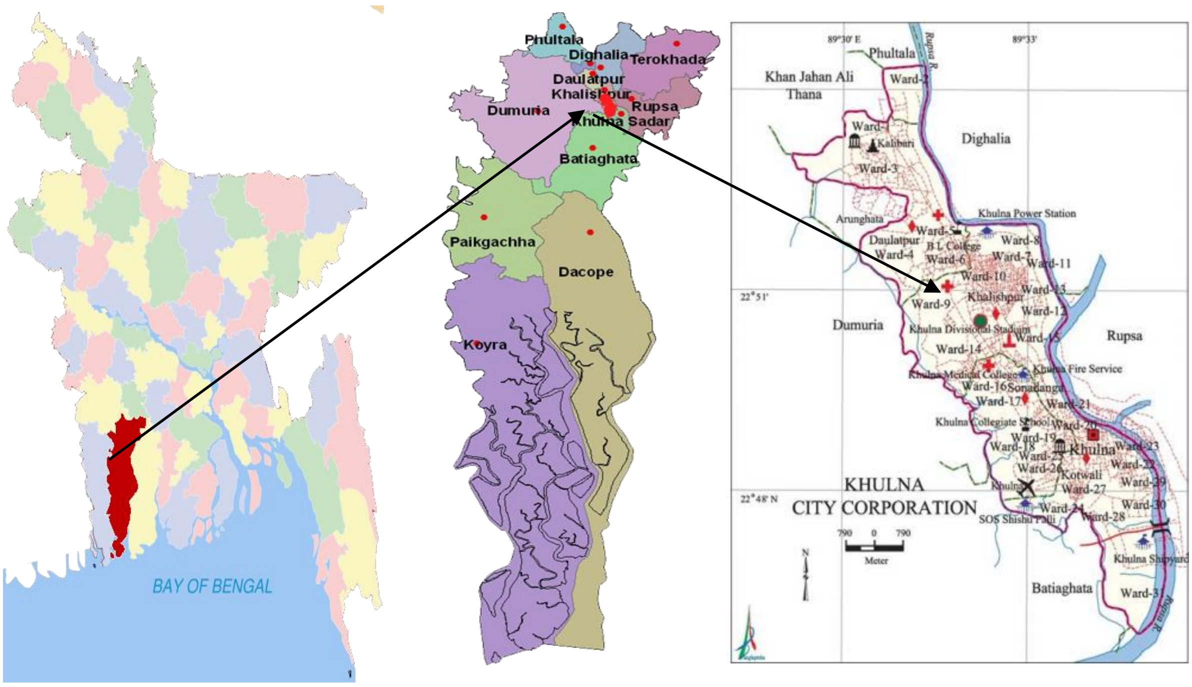


Figure 1: Study Map (Source: Google Map)

2. METHODOLOGY

2.1. Data Collection and Map Preparation

Data was collected from both primary and secondary sources. Most of the data required for the study were collected from the secondary sources. For the analysis purpose of GIS, data about topography, soil characteristics, study area image were collected from the secondary sources. Soil data of Khulna city was clipped from the soil map of Bangladesh and required topographic data was clipped from the DEM of Bangladesh. Data of land use and land cover was generated using ArcGIS through supervised classification and digitizing. Required study area image for that was collected from satellite image. Data of precipitation was collected from the meteorological station of Khulna in order to analyze the change of micro-climate. Different thematic map such as soil map, topographic map, land use and land cover map, CN map were prepared using ArcGIS.

2.2. Surface Runoff Calculation

The amount of surface runoff was estimated using SCS-CN method. The Soil Conservation Service Model also known as the Hydrologic Soil Cover Complex Model, is a widely used procedure for runoff estimation. The model uses a numerical value (Curve Number) varying between 0-100 to express runoff potentiality. The equation used for estimation of runoff depth is as follows,

$$Q = (P - .3S)^2 / (P + .7S) \qquad \text{Where} \quad S = 25400 / CN - 254$$

Here, Q = Runoff depth (mm). S = Maximum potential retention. CN = Curve Number. P = Rainfall depth (mm).

2.2.1. Computation of CN Value

Curve number depends on soil type, land use, Digital Elevation Model (DEM), Antecedent Moisture Condition of the study area.

2.2.2. Soil Map Generation

In the determination of CN, the hydrological soil classification was adopted. Here, soil was classified into three out of four classes named as A (Low Runoff Potential), B (Moderately Low Runoff Potential), C (Moderately High Runoff Potential), and D (High Runoff Potential). The classification was done based on runoff potential of different hydrological soil group.

2.2.3. Antecedent Moisture Condition (AMC)

Antecedent Moisture condition (AMC) refers to the moisture content present in the soil at the beginning of the rainfall-runoff event under consideration. It is well known that initial abstraction and infiltration are governed by AMC. For purpose of practical application three level of AMC are recognized by SCS as follows:

AMC-I: Soil are dry but not to wilting point. Satisfactory cultivation has taken place.

AMC-II: Average conditions.

AMC-III: Sufficient rainfall has occurred within the immediate past 5 days. Saturated soil condition prevails.

The limit of these three AMC classes, based on rainfall of the previous five days are given below,

Table 1: Antecedent moisture condition for determining the value of CN.

AMC Type	**Total Rain in previous 5 days**	
	Dormant Season	Growing Season
I	Less than 13 mm	Less than 36 mm
II	13 to 28 mm	36 to 53 mm
III	More than 28 mm	More than 53 mm

(Source: K. Subramanya, 2013)

2.2.4. Setting CN Look up Value

CN value is unique for different land use and land cover. After classifying the land use and land cover, there corresponding CN value was determined observing the hydrologic soil group. Increase in CN value denotes high runoff potential.

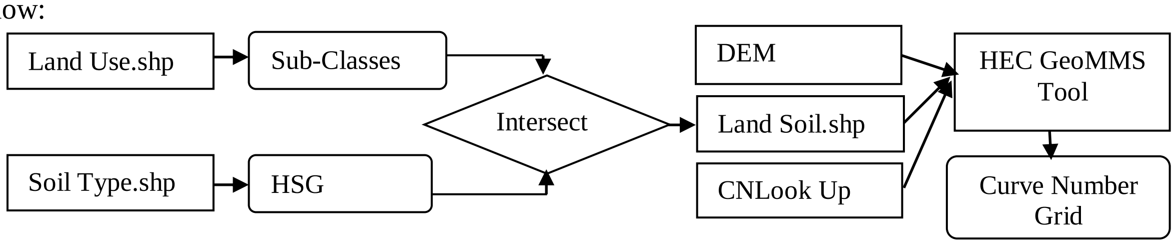
Table 2: CN value for different land use and soil type under AMC II.

Land Use and Land Cover	**CN value of Hydrologic soil group**			
	A	B	C	D
Agricultural Land	76	86	90	93
Vegetation	28	44	60	64
Open Space	49	69	79	84
Built Up Area	77	85	90	93
Water body and Wet land	0	0	0	0

(Source: K. Subramanya, 2013)

2.2.5. Curve Number Generation

HEcGeoMMS tool was used to generate curve number grid of the study area. After preparing all the needed criteria, Curve Number grid was obtained through the process shown in the flow diagram below:



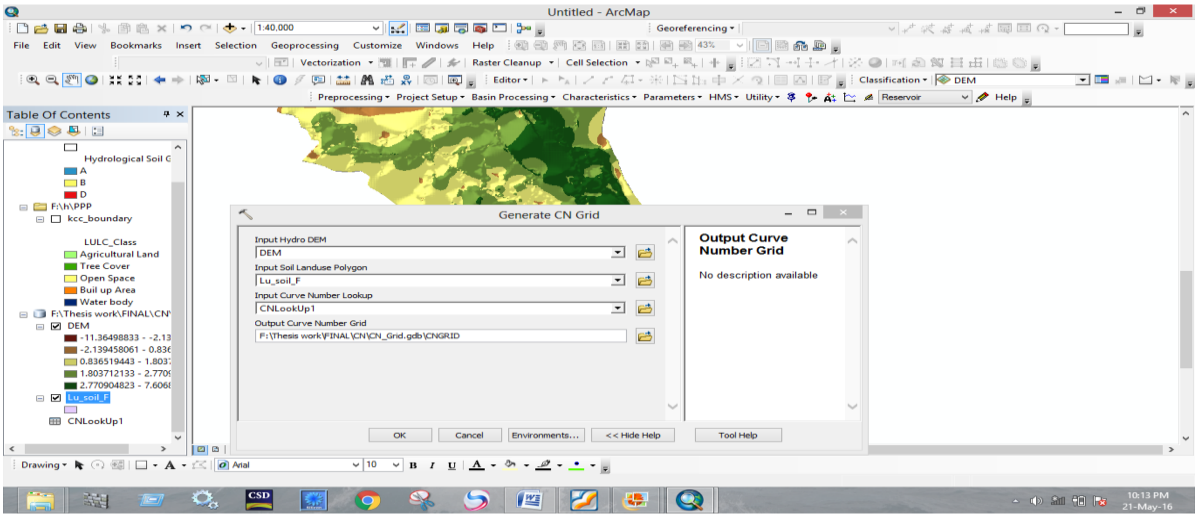


Figure 2: Curve Number Grid Generation through HEC GeoMMS Tool. (Source: Preparation on Arc GIS Environment)

Theissen polygons were established for each identified rain gauge station. For each theissen cell, area weighted CN (AMC II) and also CN (AMC I) and CN (AMC III) were determined. CN for AMC II is shown in Table 2. Area weighted composite curve number for various conditions of land use and hydrologic soil conditions were computed as follows:

$$CN = \sum_{i=1}^{i=n} \frac{CNi \times Ai}{A_i}$$

Weighted Curve Number,

Where Ai=A1, A2, A3, …., An represent areas of polygon having CN values CN1, CN2, CN3,…..,CNn respectively and Ai is the total area.

After calculation CN value for AMC II condition, CN value for AMC I and AMC III were obtained by the following equations:

$$CN_I = \frac{CN_{II}}{2.281 - 0.0128 CN_{II}} \qquad CN_{III} = \frac{CN_{II}}{.427 + 0.0128 CN_{II}}$$

Table 3: Curve Number and Soil Retention under Antecedent Moisture Condition.

Antecedent Moisture Condition	Weighted Curve Number	Maximum Retention (S)
AMC I	(CNI)= 47.60	279.57
AMC II	(CNII)= 67.45	122.56
AMC III	(CNIII)= 82.92	52.34

(Source: Derived from SCS-CN method)

3. ANALYSIS AND FINDING:

3.1. Precipitation Change of the Study Area

Khulna city has homogeneous climatic characteristics. The city area is small enough therefore the climatic variation at a particular time in different places is negligible. Normally Increase of precipitation means increase in run off. Figure 5.2 shows the change in precipitation within last ten years (2005-2015). The amount of yearly precipitation was as much as 1926 mm for the year 2015 and as low as 801 for year 2010.

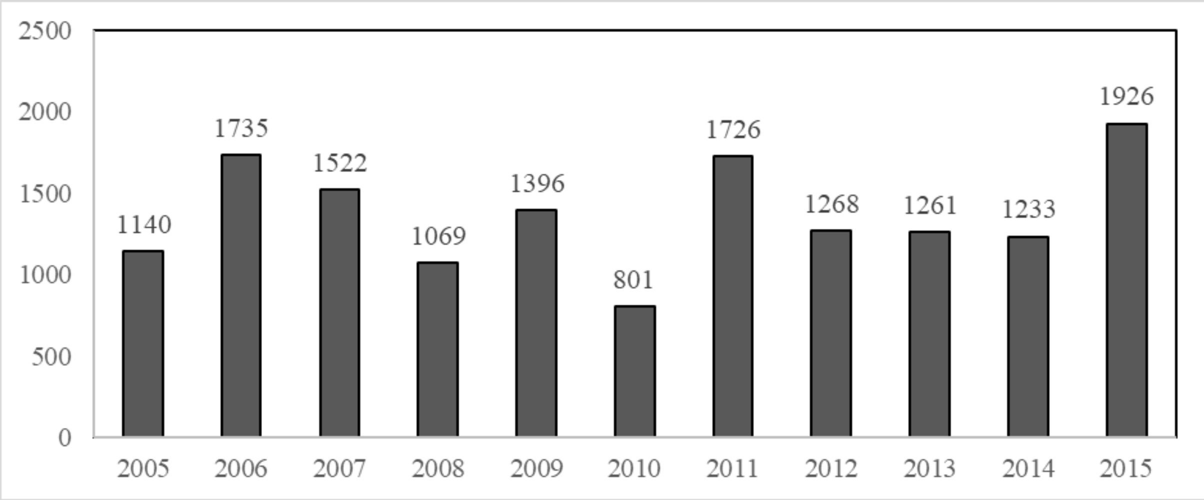


Figure 3: Change in precipitation (Source: BMD, 2016).

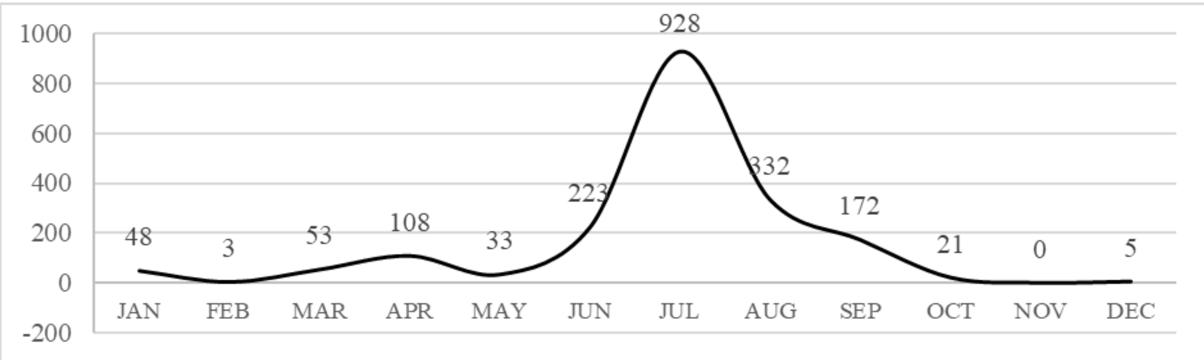


Figure 4: Variation of monthly precipitation in the study year (2015) (Source: BMD, 2016).

From the Figure 4, the potential precipitation amount was observed for only four months from June to September. Figure 4 also shows the negligible amount of precipitation for the months of October to February where precipitation of study year is as much as 928 mm for the month of July.

3.2. Analysis of Surface Runoff

Surface runoff was estimated using SCS-CN method. Surface runoff is highly related to the amount of precipitation, land use and land cover and topographic condition. All these parameter was evaluated in GIS environment which are described below.

3.2.1. Evaluation of Land Use of Khulna City

Land use plays an important role for identification of surface runoff. Khulna is an emerging city which land use is being changed with each passing year which will influence surface runoff potentiality.

Table 4: Land use of Khulna city.

Land use	Area (sq. m)	Percentage(%)
Agricultural Land	3686773.67	8.136225
Vegetation	7564165.85	16.69312
Open Space	5109758.83	11.27657
Built up Area	23920398.68	52.78918
Water body	5031975.95	11.10491

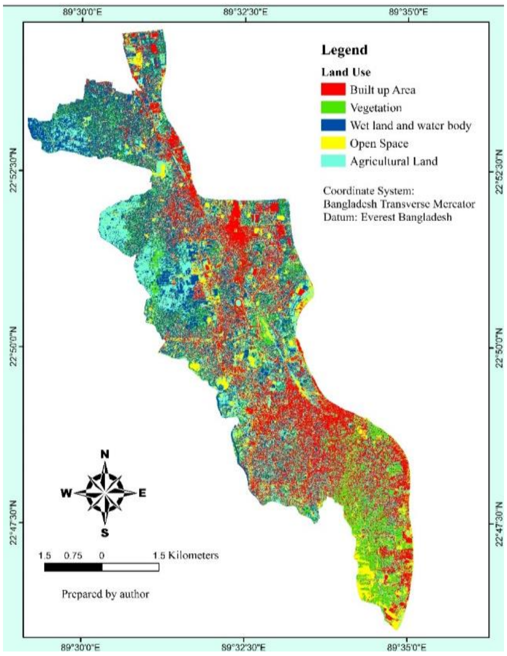


Figure 5: Land Use and Land Cover Map

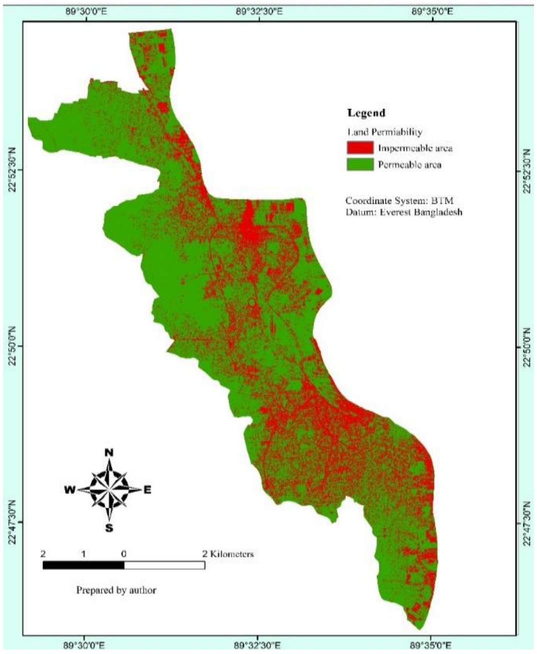


Figure 6: Permeable and impermeable area

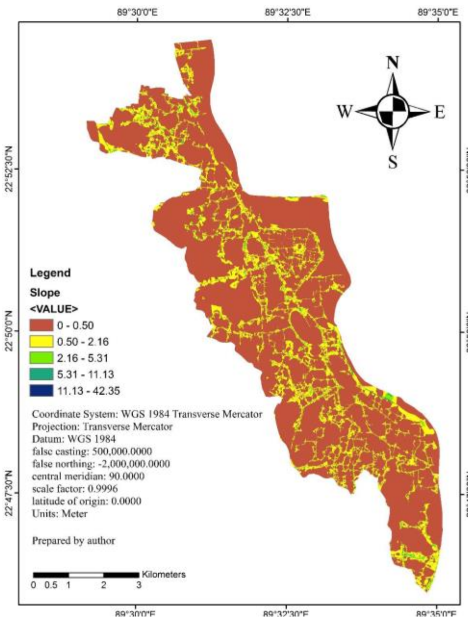


Figure 7: Topographic Map

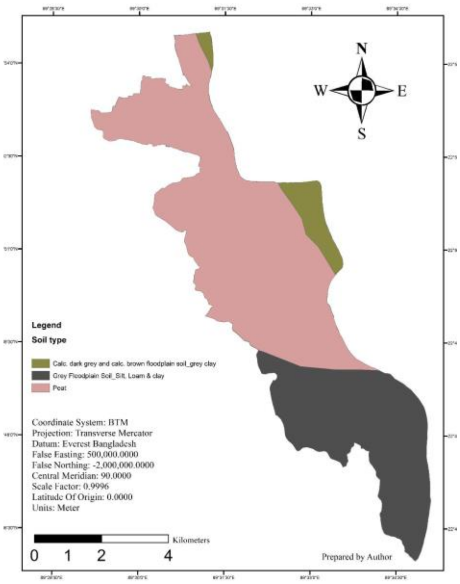


Figure 8: Soil Map

(Source: Preparation on ArcGIS Environment)

As per Table 4, 53 % area of Khulna city is covered by built up area which includes low and high density and 28.31% is impermeable.

3.2.2. Evaluation of Topographic Condition and Soil Characteristics of Khulna City

Variation of topography has impact on the runoff potentiality of an area. Topographic variation of Khulna city is not too much. Khulna is almost a flat area. Different soil type exist in Khulna city. Observed hydrological soil groups of Khulna city are A, B and D. Soil group A contains sand, loamy sand most of which found in peat soil. Within this soil type it is possible to maximize groundwater recharge. Soil group B contains silt loam or loam. Soil group D contains clay and is found on the bank of river at the outer part of the city corporation area.

Table 5: Hydrologic Soil type of Khulna city.

HSG	Area (sq m)	Percentage (%)
A	28247600	62.33
B	14786500	32.63
D	2278970	5.02

(Source: Calculation has done by Arc GIS tools.)

3.2.3. Runoff Curve Number of Khulna City

Curve number was calculated to find out the soil retention in the process of estimating surface runoff. The higher the value of curve numbers the higher the value of surface runoff. The highest range of curve number is 100.

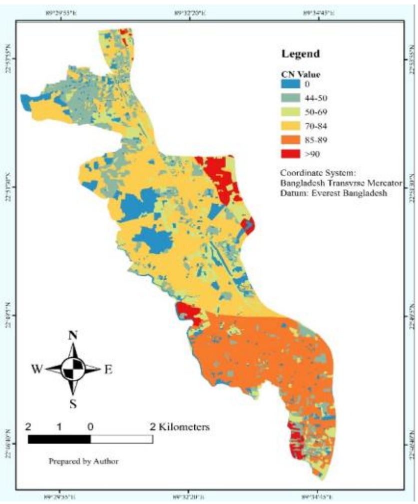


Figure 9: Curve Number Map (Source: Preparation on ArcGIS Environment)

Figure 9 shows the curve number map of Khulna city. Most of the area of the Khulna city has curve number around 70 to 85. This is because this area contain hydrologic soil group D which has highest runoff potential and also the topographic variation is noticeable here.

Table 6: Curve number and Surface retention value for different soil condition.

Soil Condition	AMC I	AMC II	AMC III
Curve Number	47.60	67.45	82.92
Surface Retention	279.5736	122.5662	52.33578

3.2.4. Monthly Surface Runoff of Khulna City

Using SCS-CN equation daily surface runoff was estimated for the year 2015. Surface runoff is highly related to the amount of precipitation. But the relation between precipitation and the surface runoff is a complex issue to evaluate. However, integration of Geographic information system with the traditional soil conservation service is proved very effective to find out the curve number in the process of runoff estimation. The relation between runoff and precipitation is shown in the figure 10 below,

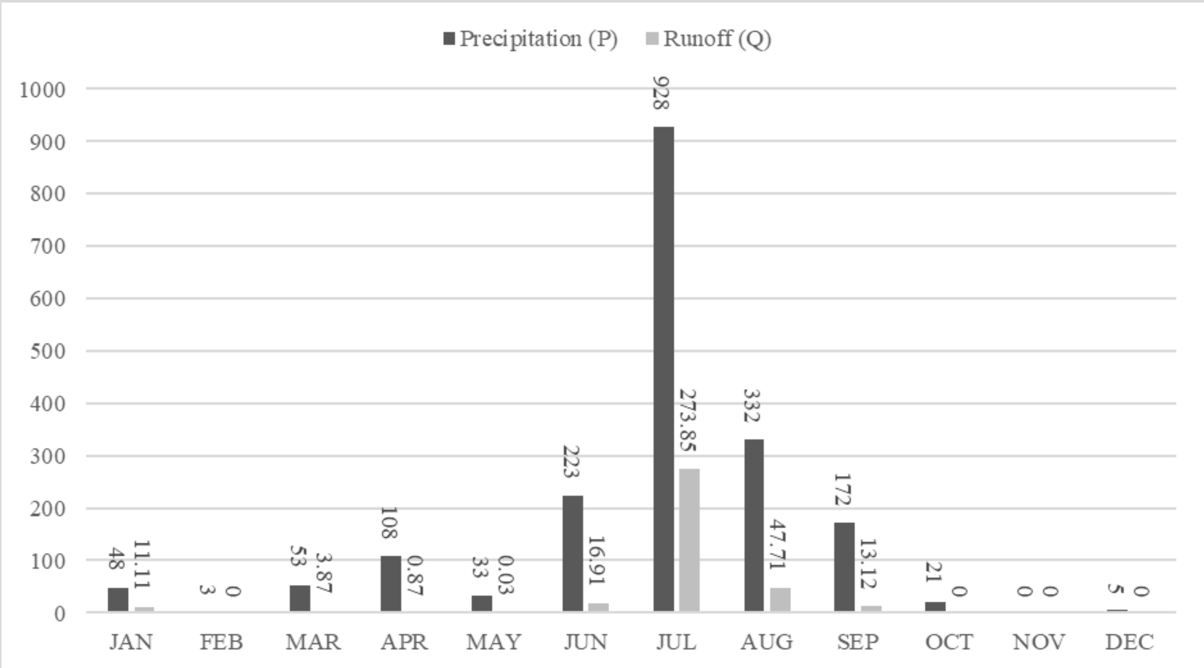


Figure 10: Surface runoff with respect to precipitation.

The total amount of runoff is 367.473753 (mm) in the respect of 1926 (mm) precipitation which is 19.08% of the total precipitation in the study year.

4. CONCLUSION

Runoff is the most imporant and the most challenging parts to estimate water cycle. It was observed that surface runoff is highly related with land use, topography and soil type. SCS-CN method was used with the integration of GIS for evaluating surface runoff. GIS technique is a very reliable alternative or a dependable support system to our conventional way of surveying, investigation, planning, monitoring, modelling, data storing and decision making process. However estimated surface runoff was about 19.08% of total precipitation. The volume of runoff can be used for the planning of land use and the careful management of soil, water and vegetation resources.

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