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Runoff Estimation in Banaras Hindu University using GIS

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Abstract—*Urban run-off increases significantly due to increased impervious area and reduced drainage network [1]. Runoff is the most basic and important data needed when planning water control strategies. For any hydrological studies on an un-gauged watershed, a methodology has to be selected for the determination of runoff at its outlet.*
Estimation of surface runoff using Soil Conservation Service - Curve Number (SCS-CN) developed by Natural Resources Conservation Service is one of the most widely used method. In the present study Banaras Hindu University drainage system is taken as case study for highlighting the role of GIS and RS in estimation of runoff. 23 years daily rainfall data was acquired from Indian Metrological Department. The study reveals that the SCS-CN method can be used to estimate runoff when adequate hydrological information is not available. In the study, hydrologic soil groups and land use has been generated using GIS tools. To generate CN values map, the CN values from NRCS Standard Tables were allotted to intersected hydrologic soil groups and land use maps and then to estimate runoff [2] . The results can be used in drainage system management and conservation purposes.

Keywords: - *SCS CN, Runoff estimation, AMC, NRCS, GIS, RS.*

1. INTRODUCTION

Varanasi experiences fluctuating levels of rainfall throughout the year; precipitation patterns are distinguished by periods of short yet extreme rainfall during the monsoon seasons, due to the severity of intense rainfall events coupled with the urban extent of the city-state, many areas often experience significant flash flooding. Banaras Hindu University overwhelms by flash floods after every rain, causing major disruption to the activities of students and teaching staff as their usual walkways became 'flowing rivers' [3].

Runoff is the flowing of precipitated water in the catchment area through a channel after satisfying all surface and sub surface losses. Accurate estimation of runoff from rainfall is important for land and water resource management. The information regarding runoff generation on the particular geo environment is needed in dealing with many watershed development and management problem. In this context, there has been a growing need to study, understand and quantify the impact of major land use changes on hydrologic regime, both water quantity and quality[2].

In BHU, the availability of accurate information on Runoff is scarcely available. However, for development of proper drainage system and its management has necessitated the runoff information. Advances in computational power and the growing availability of spatial data have made it possible to accurately predict the runoff.

The Curve Number method is versatile and widely used procedure for runoff estimation. This method includes several important properties of the watershed namely soil permeability, land use and antecedent soil water conditions which are taken into consideration. In the present study, the runoff from BHU watershed was estimated using SCS-CN method with the help of GIS.

Remote sensing Techniques are more reliable, up-to-date, and faster than conventional techniques. It plays a vital role in acquisition of data in the different aspects of land use and soil cover, which are essential parameters in the field of watershed runoff estimation. GIS is capable of handling spatial and non-spatial data when compared to conventional information system. It also identifies the spatial relationships between map features. The use of GIS technology as a spatial data management and an analysis tool provides an effective mechanism for hydrologic/ hydraulic studies.

Thus remote sensing along with GIS application aid to collect, analyze and interpret the data rapidly is very much helpful for watershed planning. Remote sensing technology can augment the conventional method to a great extent in rainfall-runoff studies. In this study SCS CN modified for Indian condition has been used for generation of runoff of the watershed [4].

2. STUDY AREA

Banaras Hindu University is located in Varanasi, Uttar Pradesh. Established in 1916, BHU is one of the largest residential universities in Asia. The university's main campus spread over 1,300 acres.BHU is organized into 4 institutes and 14 faculties (streams) and more than 140 departments. Total student enrolment at the university exceeds 20,000. It has over 60 hostels for resident students. Also it has 1440 residential Quarters and apartments for the faculties and staff of BHU.

The study area shown in Fig. 1, lies between latitude 25°19′46″N to 25°36′ N and longitude 83°02′40″E to 82°7′ E. The maximum and minimum elevation of the basin is 85 m and 72 m respectively.

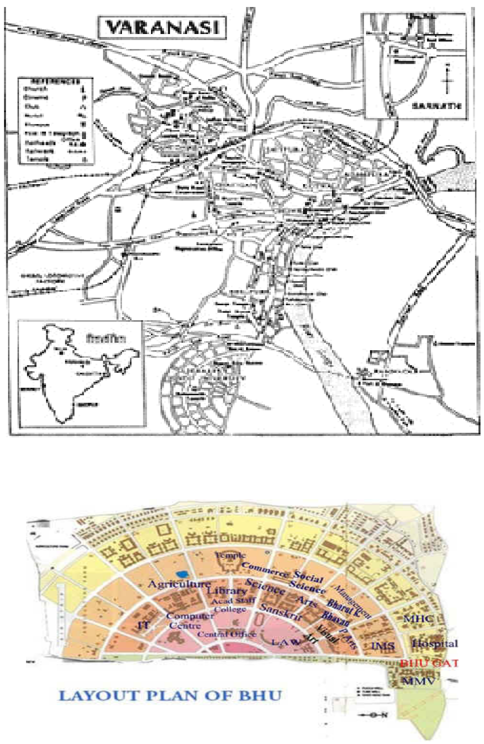

Fig. 1: Study area

3. DATA USED

3.1 Satellite imagery

The details of primary data in the form of digital data (procured from NRSC) for interpretation and analysis of satellite imagery is given in Table 1. The entire catchment area of watershed was covered in one tile.

Table 1: Satellite data used

Satellite Imagery	Sensor_id	Resolution	Tiles	Acquisition date
Landsat 7	ETM+	5.8m x 5.8m	Path 102 & Row 54	2014-05-25

Land use/land cover mapping of the BHU watershed was carried out by standard methods like digital image processing (DIP) supported by ground truthing were achieved at computer GIS Lab, using Erdas Imagine 9.0 of Leica Geosystems.

3.1 Meteorological Data

Daily rainfall data is required for estimating surface runoff generated from study area and this Meteorological data (daily rainfall data) for the study area from 1st Jan 1980 to 31st December 2004 was brought from Indian Meteorological Department (IMD).

3.2 Soil Data

The runoff generation is based on the application of the saturation excess overland flow method. As the rainfall input continues, the storage capacity of the soil is filled and once filled, excess rainfall on that part of the catchment becomes surface runoff. Saturated soils may be subject to subsurface flow which may later come back to the surface as return flow. The return flow can cause the runoff to continue even after the rainfall ends. Soil map was prepared in ArcGIS 10 through various field visits of study area and pre information available on ICAR National Bureau of Soil Survey and Land Use Planning (NBSS & LUP) department.

4. METHODOLOGY

The typical process for estimating the Runoff for watershed is shown in below flow chart in Fig. 2:

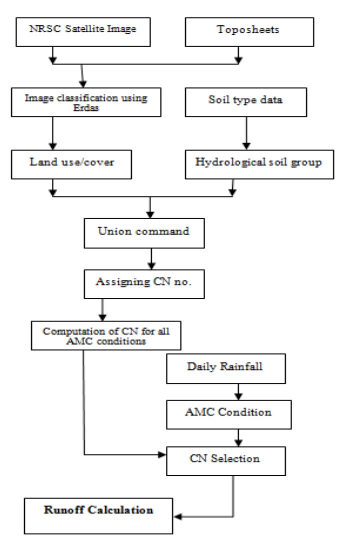

Fig. 2: Flow chart showing methodology

4.1 Define and map the watershed.

Satellite image of 5.8m resolution was procured from NRSC as primary data to be used for which curve number(s) will be calculated. This satellite image was subset using Erdas imagine tool. The subset image is shown in Fig. 3 and a shape file for showing Drainage System of BHU was prepared by digitizing using ArcGIS 10.0.The drainage system is shown in Fig. 4.

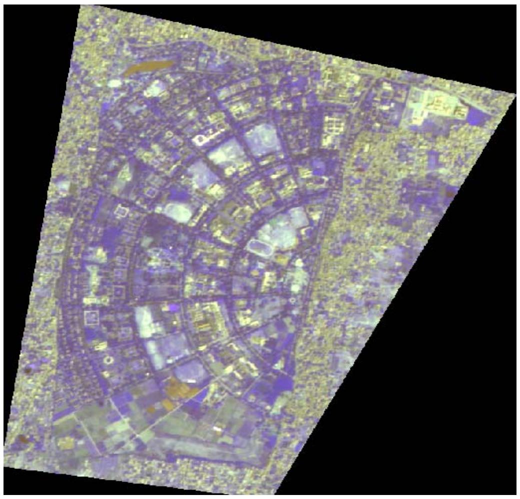

Fig. 3: Subset image of BHU

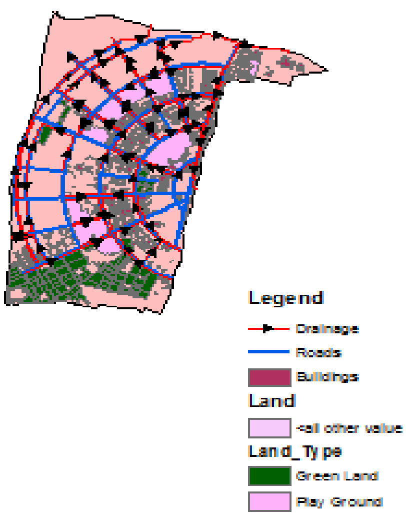

Fig. 4: Drainage System of BHU

4.2 Map the land cover/use for the area of interest.

The patterns of vegetation on land surface give areas with different runoff generating characteristics. The vegetation cover density and the spatial configuration will both affect the discharge from the hill slope. As the vegetation density increases, the average infiltration rate will increase, thus leading to a reduction in discharge. However, as the cover becomes more fragmented, there are a greater number of pathways from the runoff source areas to the channel base. This increases connectivity and consequently increases hill slope discharge. Moreover, different land use types have different evapotranspiration rates, because different plants have different vegetation cover, leaf area indices, root depths and albedo. Land use also influences the infiltration and soil water redistribution process, because especially saturated hydraulic conductivity is influenced by plant roots and pores resulting from soil fauna (Ragab & Cooper, 1993). An extreme example is the influence of build up areas and roads on overland flow. Finally, land use and land management influences surface roughness, either by the land use type itself or by its management, which affects the overland flow velocity and floodplain flow rate.

For finding out the Land use/cover of the watershed supervised image classification was done using Erdas imagine tool of GIS. Land use/cover map of BHU is shown in Fig. 5 and the classes on bases of which the classification was done is shown in Fig. 6

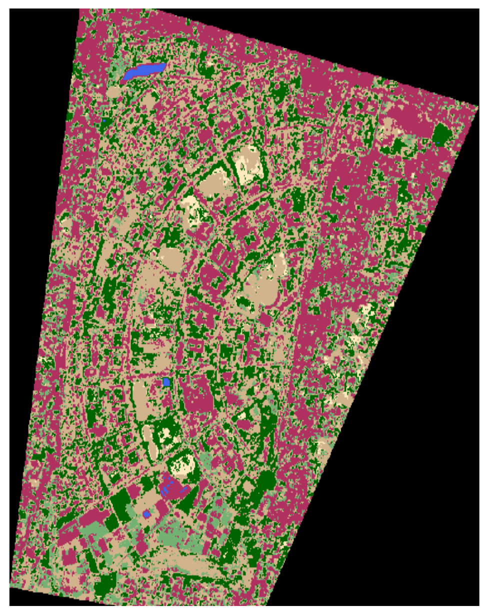

Fig. 5: Land Use/Cover of BHU

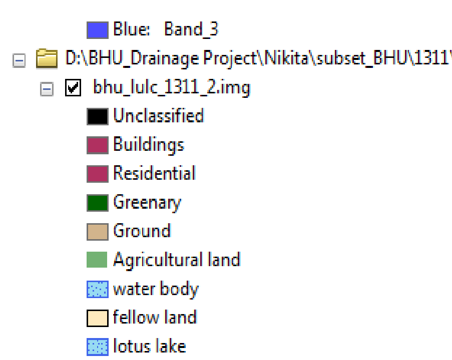

Fig. 6: Classes of image classification

4.3 Determine the soil types and hydrologic soil groups from the soil type data.

The ability of the soil to transmit and retain water influences the rate of runoff during a storm and the rate at which the soil dries out between storms. For example, sandy soils allow for more infiltration of rain water than do heavier clay soils. Therefore, the soil constituents are important to the accurate modeling of runoff. As the area of BHU is small the soil type does not vary a lot. The basic soil type of this area is clay type.

Soils are classified into hydrologic soil groups (HSG's) to indicate the minimum rate of infiltration obtained for bare soil after prolonged wetting. The HSG's, which are A, B, C, and D, are one element used in determining runoff curve numbers. The infiltration rate is the rate at which water enters the soil at the soil surface. It is controlled by surface conditions. HSG also indicates the transmission rate—the rate at which the water moves within the soil.

Group A soils have low runoff potential and high infiltration rates even when thoroughly wetted. Group B soils have moderate infiltration rates when thoroughly wetted and consist chiefly of moderately deep to deep, moderately well to well drained soils with moderately fine to moderately coarse textures. Group C soils 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 texture. Group D soils have high 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 [4]. We used the Table 2 referred from NRCS technical report 55 to determine the HSG according to texture of the soil.

Table 2: Hydrological Soil group [5]

Soil Texture	Hydrological Soil Group
Sand, loamy sand, or sandy loam	A
Silt loam or loam	B
Sandy clay loam	C
Clay loam, silty clay loam, sandy clay, silty clay, or clay	D

As BHU is a small area and mainly clay soil is present in this area, according to the above table (Table 4.1) the HSG of the BHU is Group D.

4.4 Assign a curve number based on standard SCS curve number tables.

A curve number is an index that represents the combination of a hydrologic soil group, land use and treatment classes. The curve number method requires individual storm rainfall, land use type, hydrologic soil group and antecedent moisture condition of watershed as input. In this method, the potential maximum retention storage of watershed is related to a discrete number called curve number. Curve number is dimensionless and its value varies from 0 to 100. The Curve Numbers given in table 3 correspond to Antecedent Moisture Condition II (AMC II). The AMC is the moisture state of the soil due to preceding five days rainfall. The values of the CN are obtained from chapter 9 of the NEH–National Engineering Handbook for different land uses and soil groups. These values were taken from data on floods, annual rainfall and runoff values from scientific literature for a large variety of catchments (USDA-SCS, 1985).

Table 3: Runoff Curve Numbers for (AMC II) for the Indian Conditions [6]

S. No	Land use	Treatment/Practice	Hydrologic condition	Hydrologic soil group			
				A A	B	C	D
1	Cultivated	Straight row	---	76	86	90	93
		Contour	Poor	70	79	84	88
			Good	65	75	82	86
		Contour and terraced	poor	66	74	80	82
			Good	67	75	81	83
		Bundled	poor	59	69	76	79
			Good	95	95	5	95
		Paddy(rice)	----				
2	Orchards	With under stony cover	----	39	53	67	71
		Without under stony cover	----	41	55	69	73
3	Forest	Dense	----	26	40	58	61
		Open	----	28	44	60	64
		Shrubs		33	47	64	67
4	Pasture	----	Poor	68	79	86	89
		----	Fair	49	69	79	84
		----	Good	39	61	74	80

4.5 Calculating Runoff.

The SCS Runoff Curve Number (CN) method is described in detail in NEH-4 (SCS 1985). The SCS runoff equation is

$$Q = (P\text{-}Ia)^2/(P\text{-}Ia)+S \quad \text{[eq. 4-1]}$$

Where,
Q = runoff (in)
P = rainfall (in)
S = potential maximum retention after runoff begins (in) and
Ia = initial abstraction (in)

Initial abstraction (Ia) is all losses before runoff begins. It includes water retained in surface depressions, water intercepted by vegetation, evaporation, and infiltration. Ia is highly variable but generally is correlated with soil and cover parameters. Through studies of many small agricultural watersheds, Ia was found to be approximated by the following empirical equation:

$$Ia = 0.2S \quad [eq. 4-2]$$

By removing Ia as an independent parameter, this approximation allows use of a combination of S and P to produce a unique runoff amount. Substituting equation 4-2 into equation 4-1 gives:

$$Q = (P-0.2S)^2/(P+0.8S) \qquad [eq. 4-3]$$

S is related to the soil and cover conditions of the watershed through the CN. CN has a range of 0 to 100, and S is related to CN by:

$$S = (1000/CN) - 10 \quad [eq. 4-4]$$

Table 4.2 is used for the CN values and Runoff is calculated for the range of rainfall [4].

5. RESULT AND CONCLUSION

When Curve Number values and the amount of rainfall have been determined for the study area, Runoff can be calculated using equations 4-1, 4-3 and 4-4 and Table 4.2.The Runoff value is generally rounded to the nearest hundredth of an inch.

The Rainfall versus Runoff graph can be generated after calculation Runoff for each year.

The rainfall-runoff relationship is one of the most complex hydrological phenomena due to the tremendous spatial-temporal variability of the watershed characteristics and unpredictable rainfall pattern. In this study Erdas imagine, a GIS tool is used for image sub-setting and classification and to find out the Land Use/Cover map. ArcGIS 10.0 is used for digitization and other calculation. SCS-CN method is based on empirical principles, the small number of parameters and the ease in obtaining these parameters makes this method a very good choice for the purpose of this study. However, there are some limitations of SCS-CN method as well, like runoff from melting snow or rain on frozen land cannot be estimated. Also the CN procedure is less accurate when runoff is less than 0.5 inch [5]. This study has proved that GIS and Remote Sensing is very beneficial for determining runoff in large and un-gauged catchments.

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