Runoff Estimation of Aralamallige Watershed, Bangalore Using Remote Sensing and GIS Approach

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Abstract: The area selected for the present study was Aralamallige Watershed in Dodaballapur Taluk, Bangalore Rural District located between 77° 25'and 77 °35'32.6'' E longitude and 13 °15' 21.54'' and 13° 23'2.27''N Latitude. The catchment comprises of an area of about 138.45 sq.km. Remote sensing provides the base informations on the land use/land cover, soil, drainage and other aspects. GIS softwares were used for database creation and other analysis. Runoff was estimated using soil conservation service(SCS) model and estimated to be 323.54mm, 188.64mm, 78.43mm, 22.27mm, 158.79mm and 42.16mm for the years 2000 and 2005 respectively. The study demonstrated the use of remotely sensed data in conjugation with GIS for better management of natural resources within the watershed.

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Introduction

Geomorphologists and hydrologists often view streams as part of drainage basin. A drainage basin is the topographical region from which a stream receives runoff through flow and groundwater flow. Drainage basins are divided from each other by topographic barriers called a watershed .Lillesand, T.M. and R.W. Kiefer (1994).

Horton and Strahler (1964) first initiated quantitative analysis in the field of hydrology early in 1940's and 1950's. Thereafter important contribution has been made by Strahler (1952, 1957), Morisawa (1959), Dilip G. Durbude (2001), Melton (1957), Schumn (1956) Akhouri Pramod Krishna, (1996), and Leopold and Miller (1956).

Estimation of runoff from a watershed is an important aspect for hydrologists and water resources planners. Accurate estimation of runoff rate and its volume is used for water supply forecasting, flood prediction and warning navigation, water quality management, hydropower production and many other water resources applications. Almost all rain water that falls on the earth's surface accounts for the surface runoff. As a result of this surface runoff, soil erosion occurs. Soil erosion is a major problem faced by many agricultural countries today. Hence, for the control of soil erosion and for the construction of various hydraulic structures like check dams, nala dams etc runoff estimation is necessary.

India is basically an agricultural country. Most of the agricultural lands in the country are rainfed. Monsoon being seasonal, there is a huge demand for supply of water throughout the year. The water stored in reservoirs, dams, etc. is used for irrigation purposes. This water is a result of collection of surface runoff. Estimation of runoff gives an abstract value of the volume of water that is available for various purposes such as water supply forecasting, water storage in dams, and many other water resources applications. Estimation helps in flood prediction also.

Surface runoff constitutes the hydraulic load that a structure should withstand. Surface runoff is a part of precipitation which, during and immediately after a storm event, appears as flowing water in the drainage network of a watershed. Such flow may result from various movements of water over a surface, precipitation in excess of abstraction demands, or it may result from emergence of soil water into waterways. Surface runoff occurs only when the rate of precipitation exceeds the rate of infiltration. After satisfaction of infiltration, water begins to fill the depressions. As the depressions are filled overland flow starts. The water depth builds up on the soil surface until it is sufficient to result in surface runoff in equilibrium wit the rate of precipitation less interception and infiltration. The role of remote sensing in runoff estimation is to provide input data or as an aid for estimating evaporation coefficients and model and parameters. In the present study, the information such as land use/land cover and hydrological soil group derived from remotely sensed data were overlaid through ARC/INFO GIS software to select the curve number on polygon wise to estimate surface runoff by SCS curve number method. (Singh, 2001). Figure7.1

shows the methodology adopted to estimate the surface runoff by SCS curve number model.

Physiography:

The study area chosen was Aralamallige watershed, Doddaballapur taluk, Bangalore rural district. The study are stretches geographically from 77° 25' and 77 °35'32.6'' E longitude and 13 °15' 21.54'' and 13° 23'2.27''N Latitude. The catchment comprises of an area of about 138.45 sq.km and is covered in the survey of India (SOI) toposheet numbers 57 G/7 and 57 G/11. The maximum length of and width of the watershed is watershed is 16.77 km and 11.41 km respectively. Physiographically the study area falls in the southern maiden region, which is characterized by undulating landscape with rather broad based valleys. The highest relief is formed at 940m above Mean sea level and lowest relief is obtained at 900m above MSL. The slope of the land is from northeast to southwest. The study area comprises of granite which occur as intrusive in the gneissic complex and vary in color, structure and texture. Ragi is an important grain crop of the taluk. Other crops include paddy, maize and cereals along wheat, jowar and millets. Area is rich in red loomy soils.

Methodology and database:

Drainage map prepared for the study area using Survey of India (SOI) topomaps on 1:50,000 scale was updated with remotely sensed data are updated for streams and water bodies such as tanks developed using satellite data. Overlaying of these details was carried out on the post monsoon image and the extent of surface water spread during rabi and kharif season were demarcated using the respective season satellite image. The drainage map was used to understand the hydrological behaviour and there by estimate runoff. The drainage map of the study area is shown as (Fig 1.1).

Database creation:

The final thematic maps (spatial data) were scanned using A_0 scanner to create digital database. The scanned thematic maps were projected to polyconic projection using ERDAS IMAGINE (version 8.5) software. The thematic maps were digitised and labeled using Arc/Info (version 4.2) and Arc View GIS softwares. Thus the entire resource maps were converted into a set of digital layers. These layers were corrected by editing errors such as dangles, label of polygons, which were caused during digitisation (ESRI, 1989). Topology was established among the features of each theme by processes available in the software package (clean/build). All the data layers were transformed into real coordinate system in which the features of each data layer were identified with ground coordinates.

These individual layers were then converted in to shape files using ArcView software and further processed for coding of features and database creation. The database prepared was used for runoff estimation.

Soil Conservation Service (SCS) Curve Number Model

In this method, runoff was determined as a function of current soil moisture content, static soil conditions, and management practices. Runoff in deducted from the water available to enter the soil prior to infiltration.

The SCS curve number method was developed from many years of stream flow records for agricultural watersheds in several parts of the United States. The method is also called Hydrological soil cover complex number method. It is based on the recharge capacity of a watershed. The recharge capacity can be determined by antecedent moisture contents and by the physical characteristics of the watershed. Basically a curve number is an index that represents the combination of a hydrologic soil group and AMC.

The SCS approach is a popular method for runoff modeling for the following reasons.

- Its use has been mandated by the United States Department of Agriculture (USDA, SCS).
- It provides reasonable and useful results for average conditions.

There is a large user base available to assist new users and much is known about how to vary the parameters for non standard conditions and It is very easy to understand and requires few resources to use (Ravikumar, 2001).

7.2.1 Runoff volume

The SCS curve number method is based on the water balance equation and developed on the fundamental hypotheses.

Ratio of the actual direct runoff to the potential runoff is equal to the ratio of the actual infiltration to the potential infiltration.

The amount of initial abstraction is some fraction of the potential infiltration expressed mathematically, The first hypothesis is, where Q is the runoff and P is the rainfall.

$$\frac{Q}{P-I_a} = \frac{F}{S} \qquad (1)$$

The actual infiltration (F) is the difference between the potential and accumulated runoff. I_a is initial absorption, which represent all the losses before the runoff begins. it includes water intercepted by vegetation, and initial infiltration. This is highly variable but generally correlates with soil and cover parameters is the potential infiltration after the runoff begins (S>=F).

$F = (P - I_a) - Q$ (2)
substituting equation (2) in (1)
where F<=S and Q<= (P-Ia)

$$\frac{(P-I_a)-Q}{S} = \frac{Q}{(P-I_a)} \quad (3)$$

The retention S is constant for a particular storm because it is the maximum that can occur under existing conditions if the storm conditions continue without limit. The retention f varies because it is the difference between (P-Ia) and Q at any point on the mass curve.

The units of P, Q, Ia and F are the same (inches or mm). The factors in eq. 4 are best understood by the use of a mass curve, which shows the relation of Q versus P.

The volume of rainfall is separated into initial abstraction, retention and runoff. the initial abstraction consists of interception, infiltration and surface storage, all of which occur before the runoff begins. An empirical analysis was performed for development of SCS rainfall-runoff relation and the following formula was arrived at for estimating Ia.

Ia = 0.2S (5)

$$Q = \frac{(P-0.2S)^2}{(P+0.8S)} \quad (6)$$

Eq. shows that the factor affecting I_a, would affect S, substituting eq 5.5 in eq 5.1 leads

While eq.1 has two unknowns I and S, eq. 5 has been reduced to an equation with one unknown S. The volume and rate of runoff depends on both meteorological basin characteristics and the estimation of runoff requires an index to represent these two factors. The precipitation volume is probably the single most important meteorological characteristic in estimating the volume runoff the soil type, land use and hydrological condition of the land cover are the basin factors that will have the most significant impact in estimating the volume of runoff. The antecedent soil moisture conditions (AMC) will also be an important determinant of runoff volume.

7.2.2 Curve number

$$CN = \frac{25400}{S+254} \quad (7)$$

$$or\ S = \frac{25400}{CN} - 254 \quad (8)$$

The potential maximum retention storage of watershed is related to curve number. Curve number is dimensionless and its value ranges from 0 to 100. For convenience, in evaluating antecedent rainfall, soil conditions and land use practice the cure number CN is given by (SCS, 1972) where S is in mm.

Thus, the rainfall-runoff relationship of eq has one unknown, and has been replaced with another relationship with one unknown i.e., CN. The CN is a relative measure of retention of water by a given soil vegetation complex and takes on values from 0-100. This number is derived from the character of the soil, vegetation; including crops, and the land use of that soil, as well as intensity of use.

When CN = 100, S becomes zero. This leads to Q = P.

When S = infinity, CN = infinity. This leads to Q = P.

When S = infinity, CN = infinity. This yields Q = 0 for all P when S=infinity and C=0

7.2.3 Determination of Curve Number (CN)

A curve number is an index that represents a combination of hydrologic soil group and antecedent moisture conditions. The CN value is determined from hydrological soil group and antecedent moisture conditions in the basin. The CN values were obtained after overlaying the land use / land cover map and hydrologic soil group map which were prepared from IRS satellite imagery

Table 7.1 curve number for AMC II hydrologic soil cover complex.

S. No	Land Use	Hydrologic Soil Group			
		A	B	C	D
1	Agricultural land without conservation (Kharif)	72	81	88	91
2	Double crop	62	71	88	91
3	Agriculture Plantation	45	53	67	72
4	Land with scrub	36	60	73	79
5	Land without scrub (Stony waste/ rock out crops)	45	66	77	83
6	Forest (degraded)	45	66	77	83
7	Forest Plantation	25	55	70	77
8	Grass land/pasture	39	61	74	80
9	Settlement	57	72	81	86
10	Road / railway line	98	98	98	98
11	River / stream	97	97	97	97
12	Tanks without water	96	96	96	96
13	Tank with water	100	100	100	100

(Source: Ven The Chow, 1982)

7.2.4 Hydrological soil group classification

Soils are classified into four hydrological soil groups, namely as A, B, C, D according to their minimum infiltration rate, which is obtained for bare soil after prolonged wettings. The hydrologic soil groups, as defined by SCS soil scientists are; (Table 7.2).

Table 7.2 Classification of Soil group

Hydrologic Soil Group	Description	Soil Characteristics	Minimum Infiltration Rate (Cm/Hr)
Group-A	High infiltration rates. Soils are deep, well drained to excessively drained sands and gravels	Deep sand, deep loess and aggregated silts	0.76
Group-B	Moderate infiltration rates. Deep and moderately deep, moderately well and well drained soils with moderately coarse textures.	Shallow loess and sandy loam	0.38-0.76
Group-C	Slow infiltration rates. Soils with layers impeding downward movement of water, or soils with moderately fine or fine textures.	Clay loam, shallow sandy loam, soil in organic content and soils usually high in clay	0.13-0.38
Group-D	Very slow infiltration rates. Soils are clayey, have a high water table, or are shallow to an impervious layer.	Soils that swell upon wetting heavy plastic clays and certain saline soils	0.0-0.13

The identification of the particular SCS soil group at a site can be done by one of the following three ways:

a) Soil characteristics
b) Country soil surveys
c) Minimum infiltration rates

Soil analysis can be used to estimate the minimum infiltration rates, which can be used to classify the soil using the following values.

7.2.5 Antecedent moisture conditions:

The antecedent moisture conditions (AMC) is the index of watershed wetness, which is determined by total rainfall in 5-day period preceding a storm. An increase in the index means an increase in the runoff potential. Such indices are only rough estimates because they do not consider the effects of evapotranspiration on watershed wetness. The levels of AMC are:

- AMC I soils are dry but not at wilting point, satisfactory cultivation has taken place
- AMC II average conditions
- AMC III heavy rainfall or light rainfall and low temperature occurred with in last five days which saturates the soils.

The following table gives the seasonal rainfall units for the AMC classification

The curve numbers for average antecedent moisture condition (AMC II) were obtained by combining the land use/land cover and hydrological soil group maps on SCS Table. From the AMC II condition, the values of curve numbers for AMC I

AND III were obtained either from the following equations (chow et.al.1988) are picked up from table.

Table 7.3: AMC Classification

AMC CLASS	TOTAL FIVE DAY ANTECEDENT RAINFALL	
	Dormant season	Growing season
I	< 0.5 inches (< 12.7 cm)	<1.4 (<32.5 mm)
II	0.5 -1.1 inches (12.7-32.5 cm)	1.4-2.1 (35-52.5 mm)
III	> 1.1 inches (> 32.5 cm)	>2.1 (52.5 mm)

Results And Analysis

The watershed is characterized by low rainfall, with irregular and erratic rainfall pattern. No perennial source of water is available for the watershed other than the tanks is fed by rainwater. Surface runoff, the important parameter in the water balance equation, other than rainwater and infiltration (recharging factor to the soil as soil moisture), is necessary for efficient planning and management of the available water. The SCS Curve number method uses, minimum data as input, and gives reliable output, using the remote sensing and GIS techniques in most efficient way. Minimum runoff was recorded in the year 2003 with 22.27mm and maximum runoff in the year 2001 with 323.54 mm. The purpose of this study is to evaluate the performance of the procedure using land cover database from remotely sensed data. The study also serves as an input for the management of the watershed with available water resources.

Table 7.4 weighted average curve number for the watershed.

Curve Number	Weighted Average CN
CN I	53.54
CN II	72.45
CN III	86.05

Table7.5 Monthly rainfall & runoff of Aralamallige watershed

Month	2000		2001		2002		2003		2004		2005	
	R	Q	R	Q	R	Q	R	Q	R	Q	R	Q
Jan	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Feb	17.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mar	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3	0.0	0.0	0.0
Apr	82.6	23.15	151.4	48.46	8.6	0.0	6.8	0.0	35.6	0.38	39.2	0.0
May	40.5	0.20	26	0.0	190.1	76.22	35.8	7.41	154.3	25.35	53.6	0.0
Jun	135.1	37.63	7.4	0.0	111.8	2.14	29.4	0.0	66.2	32.08	47.2	0.0
July	78.6	0.0	102.7	23.54	9	0.0	30	0.0	136.4	29.32	94.7	0.0
Aug	215.2	29.78	69.8	0.0	3.3	0.0	76.4	0.0	37.6	0.0	206.2	9.06
Sept	265.4	135.01	302.1	99.17	57.6	0.0	102.6	3.54	152	33.24	106.7	0.45
Oct	299.5	97.77	117.6	17.47	59.8	0.07	57	8.70	145.4	32.01	233.0	32.65
Nov	9.2	0.0	17.8	0.0	22.4	0.0	44.8	2.62	43	6.41	30.5	0.0
Dec	22.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table 7.6 Annual rainfall and runoff (mm) of Aralamallige watershed

Year	Rainfall(P)	Runoff(Q)
2000	1166.2	323.54
2001	771.7	188.64
2002	462.6	78.43
2003	382.8	22.27
2004	773.5	158.79
2005	810.6	42.16

Table 7.4 shows the weighted curve number estimated for watershed. All the three AMC conditions were considered for the estimation of runoff from watershed. (Table 7.5).

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