Investigation of Rainfall – Runoff modeling of the Ashti catchment by SCS Curve Number using Remote Sensing and GIS

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Abstract:

The runoff volumes of the Ashti sub-basin on River Godavari are calculated by SCS Curve Number and GIS. While determining the results the data sets such as IRS AWiFS satellite image, 1:50000 standard topographic map, drainage map of Ashti and soil map on. 1:500000 are used. AWiFS image is classified by using digital image techniques for extracting Land Use and Land Cover and integrated into GIS with hydrological soil map. Soil Conservation Curve Number method is used to determine Curve Numbers and runoff volume distribution of the basin area. The Remote Sensing and GIS technologies are suitable for analysis of the runoff volume distribution of the basin area. The statistical analysis indicates that the SCS Curve Number method can be applied to predict runoff volumes or depths of ungaged watersheds and other water resource applications.

Keywords: Remote Sensing, GIS, SCS Curve Number, ArcCN tool,

1. Introduction:

The rainfall-runoff process is a complex, dynamic and nonlinear process, which is affected by many and often interrelated, physical factors. The influence of these factors and many of their combinations in generating runoff is an extremely complex physical process, and is not clearly understood. During this process, the input i.e., rainfall to the system i.e., watershed goes through 'translation' in time due to variable source areas of the watershed contributing runoff at the outlet at different times.

The modeling and forecasting of floods and their consequences requires extensive spatial information of catchments and flood risk areas. Geographical Information Systems (GIS) and Remote Sensing offer valuable tools to contribute to the required data. The use of GIS also facilitates visualisation of the modeling results for enhanced decision making.

Due to lack of the rainfall and runoff gauge stations, it has not been able to understand hydrologic condition of a River basin. Thus, it has become inevitable to determine rainfall-runoff model by using remote sensing and GIS technologies. So, to achieve the obtaining runoff depth or volume of the basin area, Soil Conservation Model is used. Curve number is a model coefficient, which is determined based on the factors based on land use and land cover from classified RS images and hydrologic soil groups.

Remote sensing can provide measurements of many of the hydrological variables used in hydrologic / environmental model applications, either as direct measurements comparable to traditional forms, as surrogates of traditional forms, or as entirely new data set (Assefa and Shih., 2002). One of the major inputs for rainfall–runoff modeling is land-cover. Satellite remote sensing is the best source of mapping this information (Parihar, 1995).

Harbor, 1994 had developed a simple rainfall-runoff model based on the U.S. Department of Agriculture's Curve Number (CN) method, to help land-use planners and watershed managers obtain initial insight into the hydrologic impacts of different land-use scenarios, including historic, current, and future alternatives.

In this study, Soil conservation Curve Number method is used to determine runoff volume with the aid of remote sensing and GIS technologies.

2. Description of study area:

The Godavari basin receives its maximum rainfall during the Southwest monsoon. The monsoon currents follow the Eastward slope of the country from the crest of the Ghats, The Godavari receives the drainage from a length of about 129 km. of the high rainfall zone in the Western Ghats. The annual rainfall varies from 1,000 to 3,000 mm in this reach. The Godavari basin as a whole receives 84% of the annual rainfall on an average, during the Southwest monsoon, which sets in mid June and ends by mid October. The largest tributary of the Godavari is the Pranhita with about 34% coverage of drainage area.

The River Pranahita, conveying the combined waters of the Penganga, the Wardha and the Wainganga. The Wainganga, which originates in the southern slopes of the Satpura Range, and flows south through Madhya Pradesh and Maharashtra stretches a course length of 576 kms approximately. The chief tributaries of the Wainganga are Garhavi, Khobragadi, Kathani and Potphondi on the left bank and Andhari on the Right Bank. The extent of Wainganga is 50,990 sq. km. Ashti is the sub-basin of Wainganga (fig. 1) with an extent of 9,930 sq. km, its gauge – discharge station is located at

Ashti with an altitude of 141.42 m, its coordinates are: latitude 19º 41' 05" and longitude 79º 47' 19".

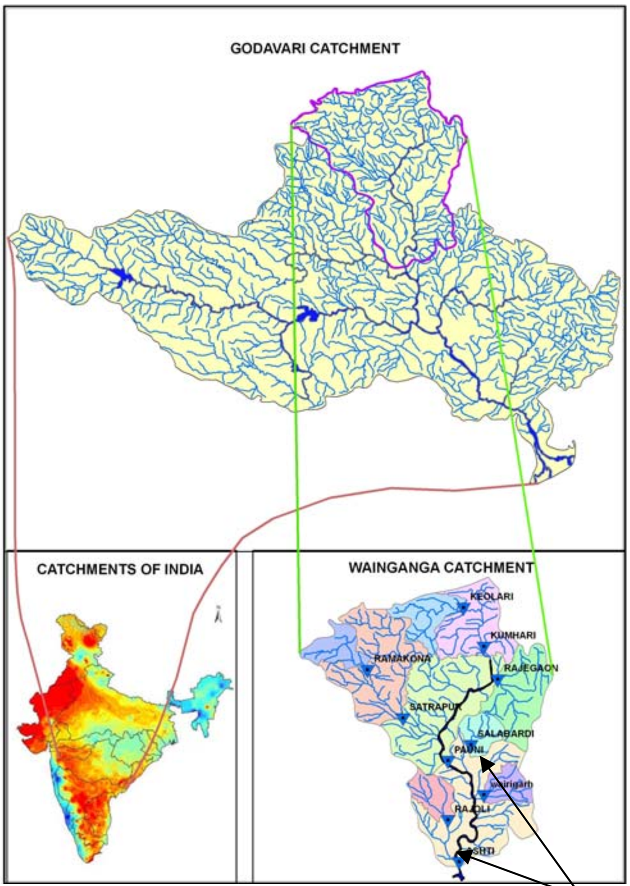

fig.1 Location map of Wainganga Catchment. (Ashti sub-basin is located at the bottom)

The study region is then subdivided into different hydrologic sub-systems for analyze characterizing of hydrology. In this study, Ashti river sub-basin is selected to determine runoff volume with the help of the Remote Sensing and GIS integration included Soil Conservation method.

3. Data and Methodology:

The datasets of imagery covering the study area captured by IRS – AWiFS sensors are considered for the present study. The study area is available on two paths, after observing the quality of imagery Febraury 13th, 2005 and May 25th, 2005 are chosen.

Remote sensing data are distorted by the earth curvature, relief displacement and the acquisition geometry of the satellites (i.e. variations in altitude, aspect, velocity, panoramic distortion). The intent of geometric correction is to compensate for the distortions introduced by these factors so that the corrected image will have the geometric integrity of a map. Rectification is the process of projecting the data onto a plane, and making it conform to a map projection system. Satellite images are rectified using 1:50000 topographic map and are geometrically corrected to the coordinate system using geographic with spheroid Everest and datum undefined projection system.

The digital image is then registered using the resampled output of the image to its corresponding geographic coordination. Polyconic projections are adapted for area calculation. Attribute data are added corresponding polygon coverage from the available data.

3.1 Classification:

Image classification is the process of establishing a link between a category of interest and a related spectral class. Unsupervised classification is based on the fact that most remotely sensed image composed of spectral classes that are reasonably uniform with respect to reflectance across one or more spectral channels, and can therefore be defined .and mapped. Tou and Gonzalez (1974).reported the use of Iterative Self Organizing Data Analysis Technique (ISODATA) unsupervised classification algorithm for classifying images.

The purpose of classification is to link the spectral characteristics of the image to a meaningful information class value, which can be displayed as a map so that resource managers or scientist can evaluate the landscape in an accurate and cost effective manner (Weber and Dunno, 2001) Firstly, AWiFS data applied pre-processing techniques such as image enhancement to increase visual distinctions. Then image is classified by using ISODATA unsupervised algorithm techniques. The Land use / Land cover classification of Ashti is shown in fig. 2.

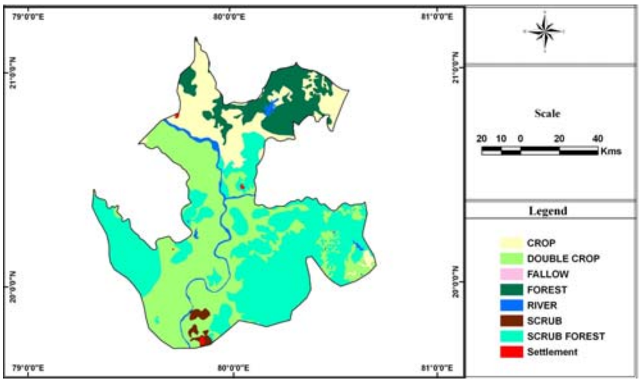

fig.2 Land use. Land cover map of Ashti sub-basin

3.2 Hydrologic soil mapping:

The soil map of Maharashtra (challa *et. al.*,1996) was downloaded, digitized and overlaid by boundary of Ashti. The soil map is then classified into the hydrologic soil groups, that refer to the infiltration potential of the soil after prolonged wetting. The hydrologic classification of soil characteristic is assigned to each polygon unit as per the following groups (shown in fig. 3):

Group A Soils: High infiltration (low runoff) for Sand, loamy sand, or sandy loam. Infiltration rate ranges from 7.62 – 11.43 mm/hr. when wet.

Group B Soils: Moderate infiltration (moderate runoff) for Silt loam or loam. Infiltration rate ranges from 3.81 - 7.62 mm/hr. when wet.

***Group C Soils*:** Low infiltration (moderate to high runoff) for Sandy clay loam. Infiltration rate ranges from 1.27 - 3.81 mm/hr. when wet.

Group D Soils: Very low infiltration (high runoff) for Clay loam, silty clay loam, sandy clay, silty clay, or clay. Infiltration rate ranges from 0.00 - 1.27 mm/hr. when wet.

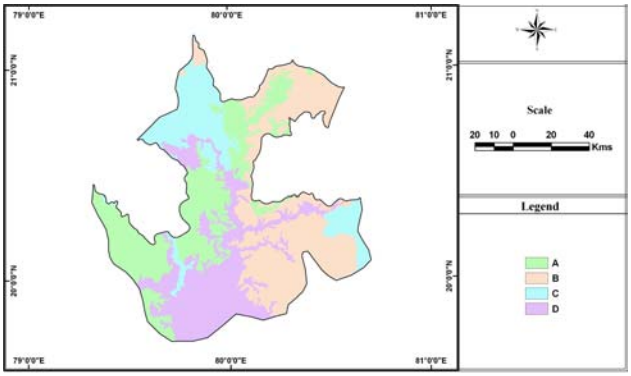

fig.3 Hydrologic soil map of Ashti sub-basin

3.3 SCS Curve Number Method:

Soil Conservation Models are distributed watershed modeling the most widely used in hydrological model. The Soil Conservation Service model developed by United States Department of Agriculture (USDA) (1972) computes direct runoff through an empirical equation that requires the rainfall and a watershed coefficient as inputs.(Nayak and Jaiswal, 2003). The general equation for the SCS curve number method is as follows;

$$Q = \frac{(P - I_a)^2}{(P - I_a) + S} \quad \ldots \quad 3.1$$

where, Q = runoff in depth, P = intesity of rainfall, I_a = initial abstraction, and S = retention parameter. In the SCS model I_a is defined as: $I_a = 0.2*S$; (based on the analysis performed by SCS for the development of the rainfall–runoff relation for average condition – Richard, 1982). Thus Q becomes a function of rainfall and S only. In practice a runoff curve number, CN, is defined as a transformation of S according to the relationship:

$$CN = 25400/(S + 254). \quad \ldots \quad 3.2$$

The parameter CN, having a range of values between 0 and 100, called the curve number. In this method, a curve number (CN) is assigned to each watershed or portion of watershed based on soil type, land use and treatment, and antecedent moisture condition.

ArcCN tool is added in ArcMap, the intersection operation is performed on land use and land cover map and hydrologic soil group map. A table is added to the coverage area which consists of curve number for land use type and soil group. A new layer of land-soil is added in the coverage with curve numbers are assigned to each feature class (fig. 4).

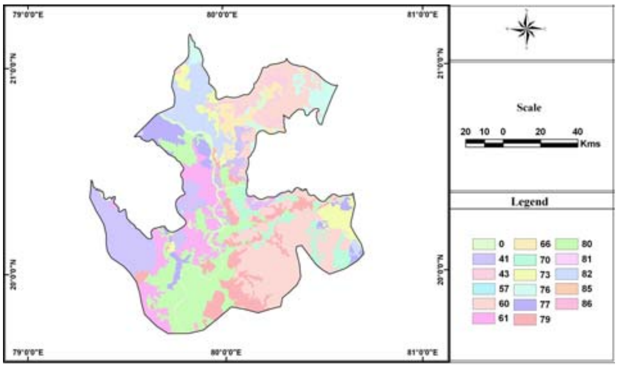

fig. 4 Runoff curve number map of Ashti sub-basin

4. Results and Discussion:

The vector coverage of soil showing the Hydrologic Soil Group, and land use / land cover classification (Anderson and James, 1976) are overlaid to estimate curve numbers and runoff depth for the entire sub-basin,. The soil layer and classified image are used to calculate curve number and runoff depth value. Curve Numbers are assigned by means of National Engineering Handbook (NEH, 1995) chapter 4 guidelines.

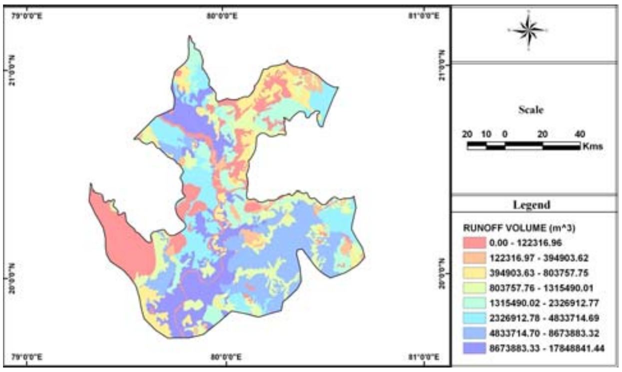

fig. 5 Runoff in volume map of Ashti sub-basin

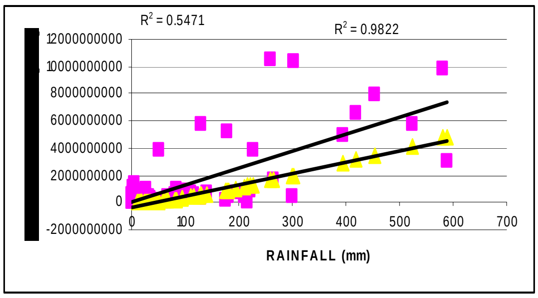

fig 6 Rainfall – Runoff Graph
Observed Vs. Computed – ASHTI

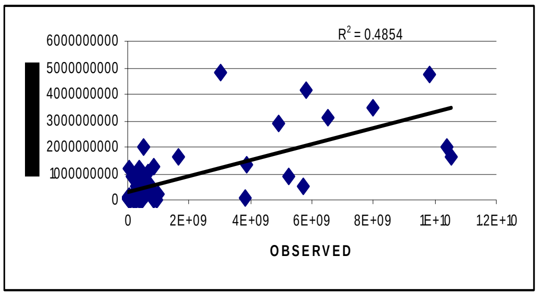

fig 7 Observed Vs. Computed
Runoff Volume Graph – ASHTI

ArcCN tool is executed to generate runoff volumes. A form in VB is prompted, soil classification field, land use / land cover description, Curve Number, intensity of rainfall and Area fields are chosen, then the form is submitted to execute, the results of runoff in depths and runoff volumes are added to the attribute table (using equations 3.1 and 3.2). Any number of runoff volume maps can be generated for the input of rainfall events. One of the runoff volume maps for a given precipitation event is shown in fig. 5.

The computation of runoff volumes generated for different inputs of precipitation event for Ashti are evaluated. In addition to the computation of daily rainfall-runoff, peak rainfall events and monthly rainfall intensities for the monsoon months June to Sept. of 2001 to 2005 are computed. The maximum rainfall observed during July and Aug. '06 is 195.2 mm, total rainy days are 21 and 23 respectively; monthly rainfall intensities are 389.6 mm and 453.8 mm respectively.

Table – 1: Correlation Matrices between rainfall and runoff (Computed and Observed)

S. No	r	r^2	t	p	R^2
1	0.9911*	0.9822*	53.597*	0.0000	0.9822*
2	0.7008*	0.4912*	7.0847*	0.0000	0.5471
3	0.69669*	0.48538*	7.0003*	0.0000	0.4854

Note: * Marked correlations are significant at 95% confidence level (case wise deletion of missing data).

(Where, r and r^2 are Correlation statistics, t is test of significance, p is probability and R^2 is coefficient of efficiency and S. No. 1 represents rainfall vs. runoff Computed, S. No. 2 represents rainfall vs. runoff Observed and S. No. 3 represents Observed vs. Computed runoff)

The runoff volumes are computed for each rainfall event, runoff volume map for one such event is shown in fig. 4. Though there are 44 input values of rainfall events, only 14 runoff volumes are computed, For other rainfall events, the runoff volume is computed as 0 due to intensity of rainfall less than 0.2*S, where S is retention parameter (Xiaoyong Zhan, *et.al*., 2004). The scattered plot of rainfall vs observed and computed runoffs and observed vs computed runoff volumes are shown in fig. 6 and 7 respectively. The coefficients of efficiencies (R^2) for the scattered plot are 0.5471, 0.9822 and 0.4854 also shown in Table – 1 The correlation statistics and test of significance for all the relationships i.e., rainfall vs. runoff (observed and computed) showed that the model is efficient in flood prediction

5. Conclusions:

In this work, it is shown that the remote sensing satellite images are very useful to determine runoff distribution of the basin area with 58 m spatial resolution. There are several parameters effecting water level fluctuations such as climatic condition like rainfall and runoff. Water level of the Ashti has been changed abruptly in recent years because of these parameters. Due to lack of the rainfall and runoff gauge station, it has not been able to understand hydrologic condition of Ashti catchment. Thus, it has become inevitable to determine rainfall / runoff model by using Remote Sensing and GIS technologies i.e., to predict runoff depth or volume of the basin area for a given intensity of rainfall of an ungauged location of river, Soil Conservation Model is efficient. Curve number as a model coefficient, which is determined on the factors, based on land use / cover from classified IRS images and hydrological soil groups.

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