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Estimation of surface runoff from agricultural watershed using remote sensing and GIS technique

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ABSTRACT

Soil Conservation Service-Curve Number (SCS-CN), is an empirical model was applied for estimating direct runoff from a small watershed (Arang) in Chhattisgarh (India). Various maps including Digital Elevation Model (DEM), watershed and sub-watershed boundaries, drainage network and soil texture were generated using topographic and soil resource data in the environment of a Geographical Information System (GIS). Supervised classification method was used for land use/ cover classification of a satellite image of IRS 1D using daily rainfall data of selected events. Performance of model was evaluated by using several test criterions including graphical, statistical and mathematical. Results revealed that the observed runoff values were having good agreement with the runoff values predicted by the SCS-CN model. Student's t-test resulted that the means of observed and predicted runoff were found to be similar at 95 per cent confidence level. Value of coefficient of determination (r^2) was found to be 0.73 and it was indicated that the estimated runoff values for each selected rainfall events were having good agreement with the observed values. Overall deviation indicated that the model over predicted the daily runoff by 26.6 per cent. On the basis of the study it can be concluded that the SCS-CN model can estimate surface runoff from the Arang watershed marginally well for various daily storm events.

Key words : Remote Sensing, GIS, SCS–CN Model, Runoff, Land use map, Watershed

Most of the watersheds in India are still ungauged due to economic and social constraints. Several hydrological models including empirical models and physically based models are available to study the rainfall-runoff transformation process. The tediousness and time-consuming nature of extraction of watershed parameters can be eliminated by means of Remote Sensing Technology (RST) and Geographical Information System (GIS) in addition to obtaining high accuracy. Input data for the model can be extracted with the use of GIS mainly from the map layers including land use/cover, DEM, soil, slope, drainage and watershed and sub-watershed boundaries.

Several studies (Bingner *et al.*, 1996; Sharma *et al.*, 1996; Tiwari *et al.*, 1997; Wang and Hjelmfelt, 1998, Tripathi *et al.*, 2002) found that the remote sensing technique is most suitable to study the most recent pattern of land use/land cover. Among the various empirical models the Soil Conservation Service-Curve Number (SCS-CN) models have been widely used for establishing the rainfall-runoff relationship of different watersheds. Many studies applied SCS-CN model for estimating the surface runoff by deriving curve numbers using satellite data and GIS technique (Singh, 1994). Looking to the importance of empirical models, remote sensing data and GIS technique the current study was under taken with the use of a widely used empirical model (SCS-CN), remote sensing data and a GIS technique to estimate the surface runoff from a small watershed (*Arang)* in Chhattisgarh (India).

METHODOLOGY

Study area and data collection:

The selected watershed is a part of eastern plateau Mahanadi basin of Chhattisgarh state in India. It is located between $81^0 90^|$ to $82^0 0^|$ E longitude and $21^0 20^|$ to $21^0 26^|$ N latitude and covers an area of 54.50 km^2. The Arang is 3rd order watershed according to Strahler's stream ordering scheme (Strahler, 1957). The elevation of the watershed ranges from 270 to 290 m above Mean Sea Level (MSL). The average slope of the watershed was 1.5 per cent. Location map of the study area watershed is shown in Fig.1. Predominant soil of the watershed is clay loam. Sandy loam, loam, sandy clay are also found in the watershed. The watershed receives an average annual rainfall of 1420 mm, out of which the monsoon season (June to October) contributes more than 80 per cent rainfall.

The topographic map of the watershed was collected for use from the Department of Soil and Water Engineering, Faculty of Agricultural Engineering, I.G.A.U., Raipur. Soil texture map and soil resources data of the study area were collected from the Department of Soil and Water Engineering, I.G.A.U., Raipur. The cloud free digital data of 5th October 2002 of IRS-1D (LISS-III), which covers the study area, was collected from National Remote Sensing Agency (NRSA), Hyderabad, India.

Soil texture map:

Soil texture map was generated using soil resource data of the study watershed, which was collected by personal visits as shown in Fig. 2. Sub-watershed wise area covered by each soil texture were also extracted and used for assigning the soil hydrological groups for calculation of CN values. Soil texture were found to be about 174.6, 520.20, 711.8 and 4043.4 ha for sandy loam (*Bhata*), sandy clay loam *(Matasi*), loam (*Dorsa*), and clay (*Kanhar*), respectively.

Land use/cover classification:

IRS-1D (LISS-III) image of 5th October 2002 was collected from the National Remote Sensing Agency (NRSA), Hyderabad and used to prepare the land use/ cover map of the Arang watershed. Most commonly used method *i.e.* "Supervised classification" was used to classify the image considering various land use classes. Maximum Likelihood Classifier (MLC) module was used for classifying the land uses. Areas occupied by each land use for each sub-watershed were determined in Arc/ INFO as shown in Fig. 3. The land use/cover classes were found to be upland paddy, lowland paddy, fallow land, grasses and shrubs, barren land, water body and settlements as shown in Fig. 4. Sub-watershed wise land use information was also extracted for calculating the weighted average CN values of the watershed.

Estimation of surface runoff using SCS-CN model:

Surface runoff volume was estimated by using Soil Conservation Service (SCS) Curve Number (CN) technique (USDA-SCS, 1972). The SCS-CN equation given as follows:

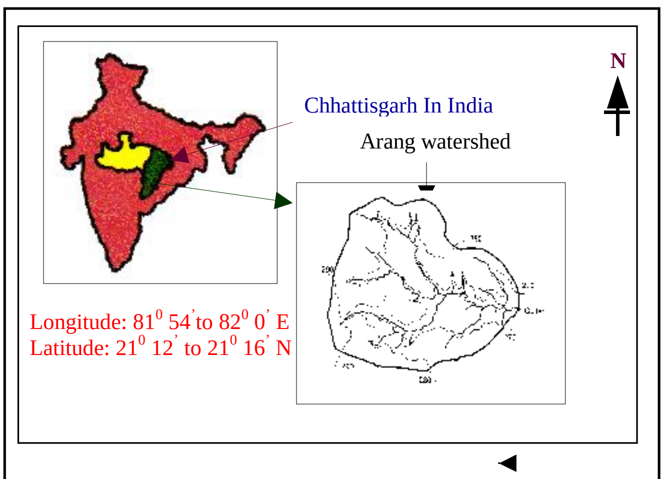

Fig. 1: Location map of the Arang watershed

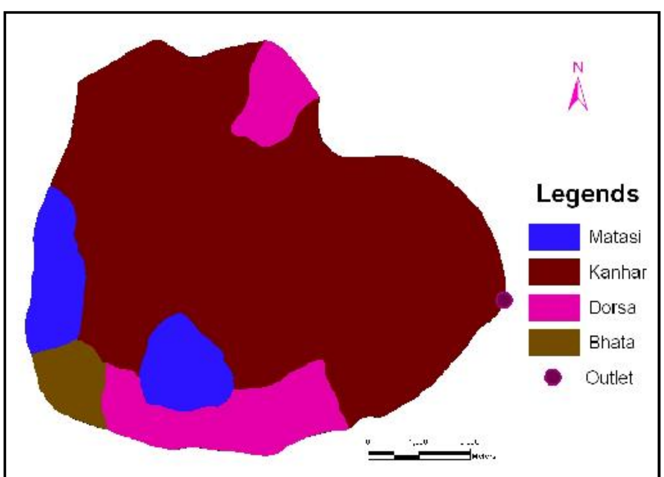

Fig. 2 : Soil texture map of the Arang watershed

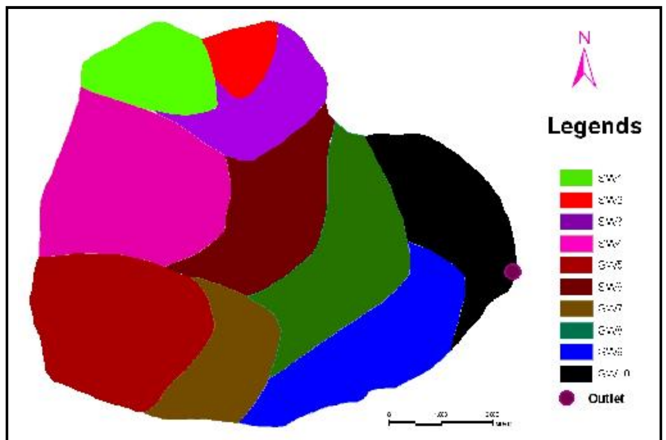

Fig. 3 : Sub-watershed map of the Arang watershed

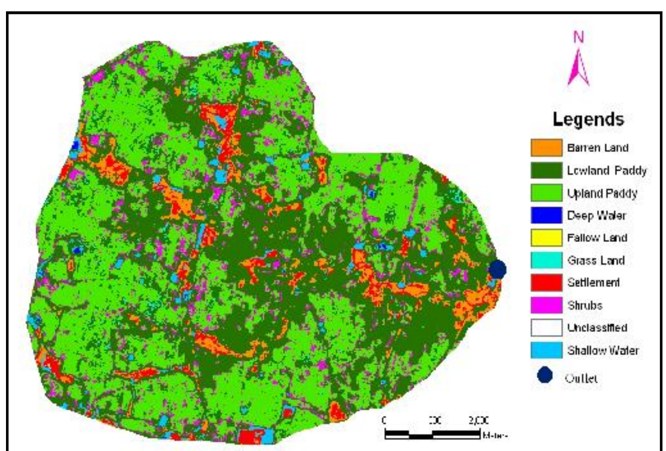

Fig. 4 : Land use/cover map of the Arang watershed

$$Q = \frac{(R - 0.2s)^2}{R + 0.8s}, R > 0.2s \quad (1)$$

$$Q = 0.0, \qquad R \leq 0.2\ s$$

where, Q is the daily runoff, R is the daily rainfall, and s is a retention parameter. The retention parameter, s, varies (a) among sub-basins because of the variation in soils, land use, management, and slope all vary and (b) with time because of changes in soil water content. The parameter s is related to CN as (USDA-SCS, 1972):

$$s = 254\left(\frac{100}{CN} - 1\right) \quad (2)$$

The constant, 254, in equation (16) gives s in mm. Thus, R and Q are also expressed in mm. CN is the curve number for antecedent moisture condition (AMC) II.

RESULTS AND DISCUSSION

The results obtained from the present investigation are presented below :

Land use classification:

Land use/cover map was generated through ERDAS IMAGINE image processing software using satellite imagery of 5th October 2002. Land use classes include deep water, shallow water, upland paddy, lowland paddy, barren land, fallow land, shrubs and settlements. Fig. 4 shows the land use/cover map of the study watershed for the monsoon season of the year 2002. The sub-watershed wise areas occupied by different land use classes obtained after classification are given in Table 1 and it is indicated that maximum area (4366.74 ha) was under paddy, therefore, watershed was considered as agricultural watershed.

Accuracy of image classification was judged after performing the land use/cover classification. A high value of overall accuracy (89.6%) and Kappa coefficient (KHAT) of 0.95 indicated that the land use/cover classification was appropriate for the study watershed. Land use/cover classification was matched well with the land use/cover actually prevailing in the ground. In many previous studies (Yifang *et al*., 1995; Pratt *et al.*, 1997; Tiwari *et al.*, 1997; Tripathi *et al.*, 2002) observed and accepted the similar range of classification accuracy and Kappa coefficient for further use.

Calculation of curve numbers:

The map layers like land use, soil and sub-watersheds were overlaid and statistical information (number of pixels corresponding to various land use and soil texture) were extracted. Hydrologic condition of the watershed based on the drainage network, hydrological soil groups based on the soil properties, and antecedent moisture condition (AMC-II) as described by Singh (1994) and Dhruva Narayana (1993) were considered. Then, weighted average curve numbers for each sub-watershed were determined by referring standard table of curve numbers for the Indian conditions. Weighted average value of CN for the Arang watershed was found to be 89. Weighted average values of CN for each sub-watershed are given in Table 2.

Verification of SCS-CN model:

The observed and simulated daily runoff values of the study watershed for selected events were compared graphically as shown in Fig. 5. The simulated runoff

Table 1: Sub-watershed wise area (ha) occupied by different land use classes

Sub-watershed	Land use classes							
	Deep water	Shallow water	Upland paddy	Lowland paddy	Barren land	Fallow land	Grasses & Shrubs	Settlem-ents
SW1	0.0	0.65	114.03	176.07	2.33	0.0	32.47	3.08
SW2	0.10	6.02	57.72	64.80	5.60	0.0	14.41	9.72
SW3	0.01	17.45	119.89	149.76	21.90	0.04	38.13	22.41
SW4	2.91	22.48	335.53	352.37	65.19	0.0	77.13	35.42
SW5	0.58	18.09	260.78	432.04	20.61	0.24	64.56	26.93
SW6	0.24	11.76	320.77	151.62	26.50	0.0	50.31	18.26
SW7	0.23	10.56	155.03	158.59	22.46	0.0	31.95	13.05
SW8	1.15	11.10	317.79	256.32	39.69	0.0	50.04	23.26
SW9	0.09	16.08	279.09	219.76	26.99	0.0	48.74	28.47
SW10	0.30	6.88	234.52	191.53	47.68	0.0	38.55	21.01
SW*	5.616	121.08	2199.48	2167.26	278.94	0.288	446.30	200.81

* Entire Arang Watershed

Table 2 : Sub-watershed wise area and curve number (CN) values

Sub-watersheds	Area (ha)	% Area	CN values
SW 1	345.14	6.33	91.91
SW 2	148.67	2.73	87.98
SW 3	355.17	6.52	83.40
SW 4	934.78	17.15	89.00
SW 5	838.88	15.39	89.74
SW 6	577.55	10.60	90.00
SW 7	385.30	7.08	86.91
SW 8	674.36	12.37	90.64
SW 9	634.48	11.64	89.60
SW 10	555.67	10.19	90.77
Total watershed	5450.00	100.00	89.29

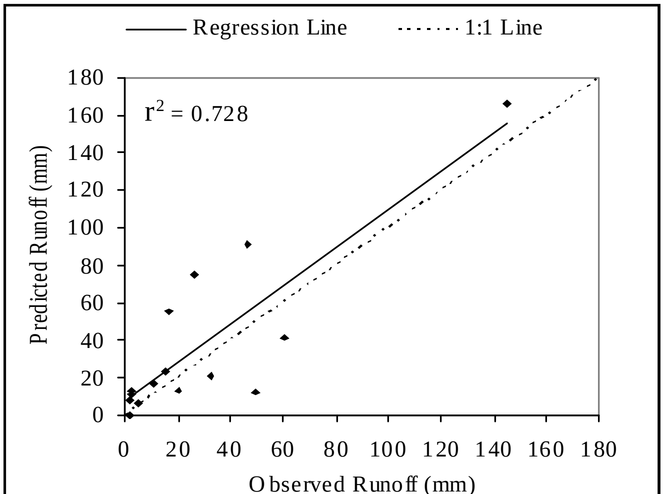

Fig. 5 : Comparison between observed and SCS-CN model predicted runoff

hydrograph matched well with the measured runoff hydrograph for most of the events. In addition, the model simulated both high and low runoff values as compared to the observed values. For the initial events model was predicting runoff close to observed runoff and there after model was some times slightly over predicted the runoff as compared to the observed runoff values.

The SCS-CN model predicted runoff was close to observed values for most of the rainfall events. It implies that the weighted average CN values determined for each sub-watershed and used for runoff prediction were reasonable. Event-wise predicted runoff values were plotted against the observed values and their distribution along the 1:1 line is shown in Fig. 5. The simulated runoff values were distributed uniformly along the 1:1 line for all the values of observed runoff except one high runoff value. A value (0.73) of the coefficient of determination (r^2) indicated a close relationship between observed and SCS-CN model simulated runoff.

The statistical results showing comparison between the observed and simulated daily runoff for SCS-CN model are given in Table 3. For the selected events, the total simulated runoff for SCS-CN model was found to be slightly more than the total of observed runoff because the model slightly over predicted for a few events. This over prediction of the runoff rates resulted in more standard deviation and mean for simulated runoff. However, Student's t-test showed that the means of observed (29.10 mm) and SCS-CN model simulated (34.85 mm) runoff were not significantly different at 95 per cent confidence level (t-cal = -1.29 and t-critical = 2.14). The overall deviation indicated that the model was over predicting runoff by about 26 per cent for the selected rainfall events.

Table 3 : Statistical analysis of the observed and SCS-CN model predicted runoff

Statistical parameters	Event based runoff (mm)	
	Observed	SCS_CN model predicted
Mean	29.098	34.854
Standard deviation	37.202	44.664
Total	436.47	552.82
Count	15	15
t-cal	-1.288	
t-critical (two tailed)	2.144	
r^2	0.728	
% Deviation (Dv)	26.65	

Conclusion:

The watershed parameters such as area, channel length, drainage density, slope and area under different soil textures can be derived accurately using various maps including DEM, drainage map, watershed and sub-watershed boundaries and soil texture map in the environment of GIS. Weighted average curve number of the Arang watershed is found to be 89 for the year 2002. Thus the study concluded that the SCS-CN model can estimate direct runoff from the Arang watershed marginally similar to observed runoff for various storm events.

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