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Surface Water Modeling Using SCS-CN Model -Hydroinformatic Approach

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Abstract:

Tandava River Basin experiencing undeterministic flood, overflow in the reservoir and soil erosion due to surface runoff. This study aiming to blend the application of Remote Sensing (RS) and Geographic Information System (GIS) techniques to estimate surface runoff based on the land use/land cover, hydrological soil group, rainfall data (P), Potential Maximum Retention (S), Antecedent Moisture Condition (AMC), and Weighted Curve Number (CN). Soil Conservation Service (SCS) model is used for surface runoff estimation. The data for the above mention parameters are acquires from different governmental offices and all SCS model parameters are derived by using remote sensing and GIS techniques. From middle of June to October, the river basin as a whole and the remaining sub-basins generated considerable amount of runoff because of monsoon season rainfall in these regions. During June to October, in most of the sub-basins, around 90% of annual runoff occurred except in the sub-basin 1, 7 and 17.therefore such model helps to estimate surface runoff and support to take flood prevention measures, soil conservation action and Check dam recommendation.

Key words: Soil, Land treatment, Land use/cover, Hydrological soil group, CN, Rainfall

Introduction

The information access and accuracy has lion portion to get good result on runoff estimation in which in India this is scarce. However, to see and highlight basin management programme for conservation and development of natural resource and its management, the runoff information assumes great relevance. Runoff model is best expressed by spatially variable parameters such as rainfall, soil types and land use / land cover etc. (Kumar, 1997).

The development of geographic information system (GIS) and remote sensing techniques, the hydrological catchments models have been more physically based and distributed to enumerate various interactive hydrological processes considering spatial heterogeneity (Mohan and Shrestha 2000).

To make feasible the Hydrological models, distributed models in particular, land use and soil type with their location within the basin is a compulsory. The conventional methods of detecting land use changes are costly and low in accuracy where as remote sensing technique, because of its capability of synoptic viewing and repetitive coverage provides useful information on land use dynamics. For efficient management of large and complex databases a GIS which a computer-based tool that displays, stores, analyzes, retrives and generates spatial and non-spatial (attribute) data provides suitable alternatives(Arwa, 2001). It is an input in the hydrological modeling to facilitate the processing, managing and interpretation of hydrological data. The Soil Conservation Service- Curve Number (SCS-CN) method has been widely used to compute direct surface runoff (McCuen 1982).

Study area

The study area, Tandava River Basin, is bounded in between North latitudes $17^0$20’ to $17^0$50`N and East longitudes $82^0$20` to $82^0$40’ E. It forms part of Survey of India Toposheets 65 K/5, K/6, K/7, K/10 and K/11 and covers an area of 1283 Km^2. Major part of the area is in Visakhapatnam district but adjacent drainage carries under the jurisdriction part of East Godavari district is also included to see the total Morphometric of the drainage basin (figure 1.1).

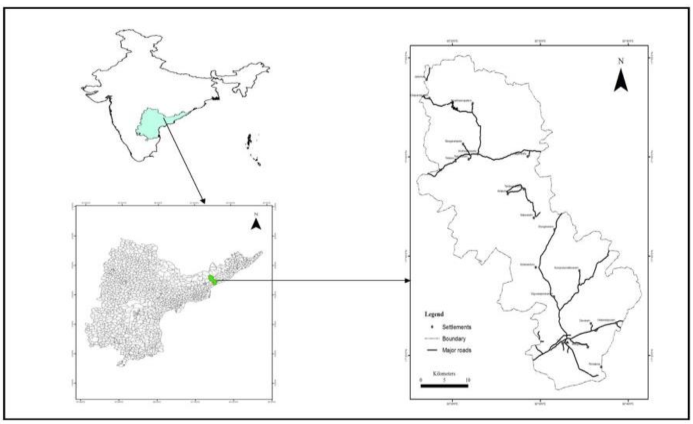

Figure 1.1: Location map of the study area

Methodology

Rainfall

For this study the rainfall data collected from Visakhapatnam and East Godavari distric collector office for the year 2006 - 2011 mandalswise so based on the nearest mandals the rainfall is distributed to the sub-basin to get clear and accurate result of rainfall – runoff estimation.

Table1. 1: Rain gauge station in the study area

Mandals	District	Sub-basins
Gudem KothaVeedhi	Visakhapatnam	10, 11
Chintapalle	Visakhapatnam	8
Koyyuru	Visakhapatnam	12, 13, 14
Golugonda	Visakhapatnam	2, 21
Rajavommangi	East Godavar	15, 14
Nathavaram	Visakhapatnam	1, 7, 17, 18
Kotananduru	East Godavar	19
Nakkapalli	Visakhapatnam	3, 4
Payakaraopeta	Visakhapatnam	20

Normals of Rainfall Data

The length or period of record needed to achieve stability varies between seasons and regions. Based on World Meteorological Organization (WMO) rainfall data of 30 years is adequate under Indian conditions. For this study, the current normal period is 2006-2011.

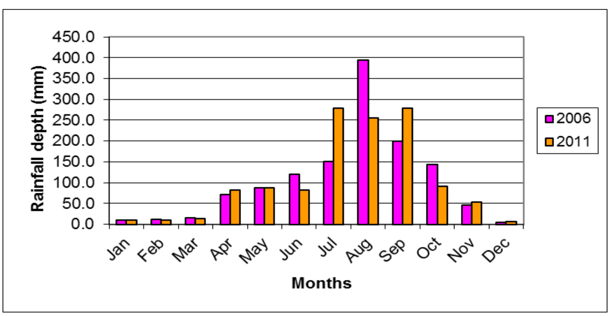

Figure 1.2: Monthly normal rainfall distribution

Determination of Average Rainfall

According to litratures (MWRI, 2007), in this study we apply arithmetic mean method in order to determine average depth of rainfall of the drainage basin.

$$P = (P1 + P2 + P3 + \ldots\ldots\ldots\ldots\ldots\ldots + Pn)/ n \qquad 1.1$$

Where, P is the average rainfall, n, the number of years of data and P1, P2, P3 ……… Pn , precipitations measured at stations 1, 2,3 ……… n.

The total depth of the rainfall for the study period is (2006 total + 2011total) / 2 = 774mm.

Rainfall Frequency curve

In this graph the peak rainfall for the time span of 5 years is 774mm. It occurs with a time interval of 56 months. For 65 months, the probable rainfall estimated is 660mm.

$$Pro = \frac{m * 100}{N+1} \qquad 1.2$$

Where Pro- Probability percent of peak rainfall

m - Ranking of the storm

N – No. of months

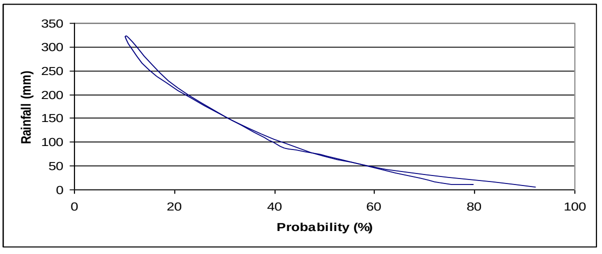

Figure 1.3: Rainfall frequency Curve

$$T = 100/Pro \qquad 1.3$$

Where T – recurrence time interval

With this we can estimate the runoff for a given point of time in the future.

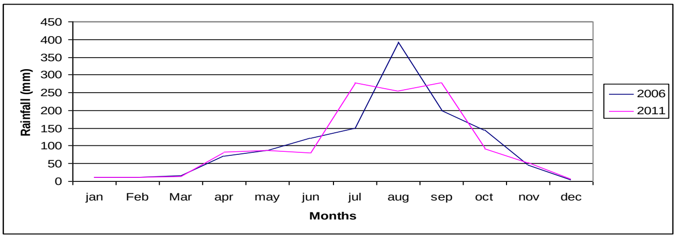

Figure 1.4: Average mean monthly rainfall correlation between 2006 Vs 2011

Soils

The soil maps were collected from National Bureau of Soil Survey and Land Use, Hyderabad which were prepared on a scale of 1:5, 00,000. The collected soil maps were scanned and registered with tic points and rectified. Further, the rectified maps were projected. All individual projected maps were finally merged as a single layer. Later, the delineated study area map was overlaid on projected soil map and finally, soil map pertaining to the study area was thus extracted in GIS environment. Boundaries of different soil textures were digitized in ArcGIS and the polygons representing soil classes were assigned different colors for reorganization of hydrologic soil groups. The soils of the study area are classified into Four types of soil texture are found in the Tandava river basin area, namely loamy, clay, sandy clay and silty clay (fig 1.5) and four Hydrologic Soil Groups based on their minimum infiltration rate (SCS, 1972) covers 0.48 %, 24.38 %, 42.73 % and 32.41 % for the groups A, B, C and D, respectively Figure 1.6.

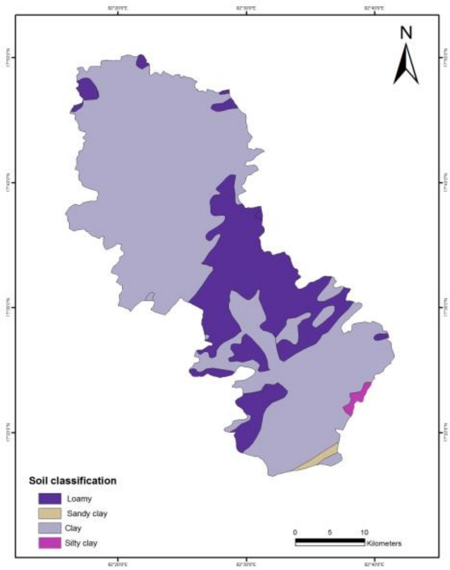

Figure 1.5: Soil map of the study area, based on Visakhapatnam and East Godavari soil sheets

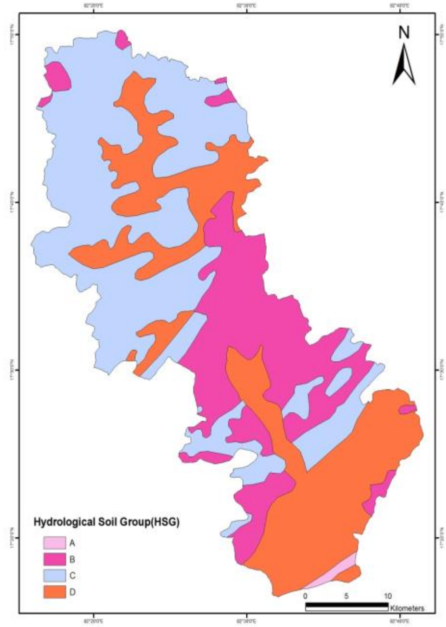

Figure 1.6: Hydrologic soil group map of the study area, based on Visakhapatnam and East Godavari soil sheets

Land use

Land use/land cover is one of the very important variables for runoff estimation. Visual interpretation cross checked and verified by ground truth data is used to classify both LANDSAT-7 and IRS-P6 LISS III satellite data using ArcGIS software. After field verification, initial classification is modified by recoding techniques and final land use/land cover map is produced (Fig. 1.6-1.7). The detail statistics of land use/land cover of the study area is shown in table 1.2.

Table 1.2: Statistical data of land use land cover

Land use / land cover categories	2006		2011	
	Area (km^2)	%	Area (km^2)	%
Barren rocky land	0.0365	0.003	0.479484	0.037
Beach	0.1808	0.014	2.12806	0.166
Dry land and other	18.5513	1.445	30.30302	2.360
Evergreen forest	483.0720	31.941	469.2376	36.545
Gullied / Ravenous land	23.0996	1.799	12.21762	0.952
Industry	0.0926	0.007	0.0903537	0.007
Irrigated land	474.7194	31.134	343.79	26.775
Lakes	1.5510	0.121	0.812265	0.063
Marshy land	1.5085	0.118	2.75448	0.215
Plantation	32.1579	2.505	153.3569	11.944
Reservoir	14.4203	1.123	17.3122	1.348
Rural	6.2841	0.489	17.81161	1.387
Salt affected land	2.0166	0.157	4.1691	0.325
Scrub / Degraded forest	60.1282	4.683	65.28756	5.085
Tank	5.3602	0.418	5.737488	0.447
Unirrigated land	297.1697	23.147	142.4214	11.092
Upland with / without scrub	5.1289	0.399	12.70054	0.989
Urban	6.3793	0.497	3.373688	0.263

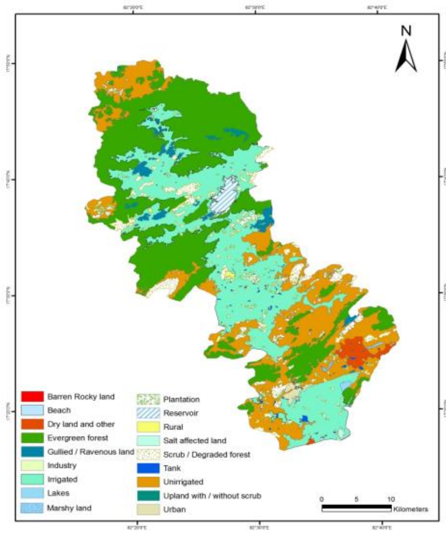

Figure 1.6: Land use/ land cover map generated from Landsat TM scene, 2006 of the study area

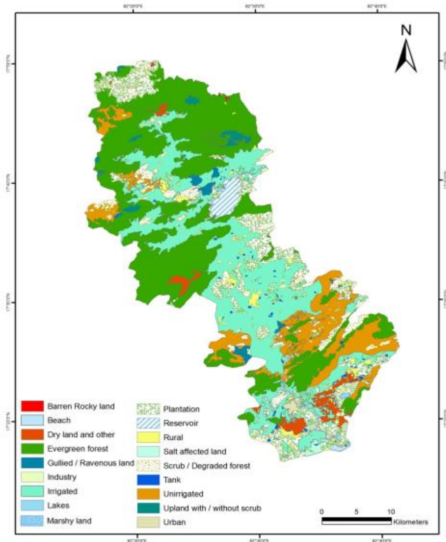

Figure 1.7: Land use/land cover map generated from IRS-P6 LISS-III, 2011 of the study area

Antecedent Moisture Condition (AMC)

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 and are governed by AMC. For purposes of practical application three level of AMC are recognized by SCS as follows:

- AMC-I: Soils 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 five days. Saturated soil conditions prevail.

Table 1.3: Antecedent moisture conditions (AMC) for determining the values 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

Curve number estimation

First, 21 sub-basins are demarked according to the Drainage pattern of the Tandava river basin. The overlay operation is performed using the land use map and hydrologic soil group map to identify land use and soil group for each sub-basin and determine area of each land use under same soil group. Curve numbers of each unique land use-soil groups are assigned within the boundaries based on standard SCS curve number which is derived from the standard categories typically used for hydrologic analysis using the SCS methodology (SCS, 1972). With all of the ambiguity surrounding the origin and development of CN values, it is crucial to use the CN value that best mimics the Ground Cover Type and Hydrologic Condition by considering antecedent moisture conditions from the soil and land use information by using logical expression. The weighted curve number for each sub basin is calculated by using the Equation 1.4.

Table 5.7: Curve number assigned for all sub-basins

		Curve Number	
Sub-Basin	Area	2006	2011
1	113	90	85
2	17	93	61
3	51	93	93
4	14	88	93
5	74	86	86
6	54	86	86
7	61	86	86
8	111	58	58
9	140	93	93
10	74	58	79
11	46	90	90
12	17	90	58
13	60	58	58
14	30	58	58
15	10	58	90
16	23	93	61
17	43	58	58
18	31	61	58
19	53	90	85
20	55	93	93
21	206	100	100

$$\text{Weighted CN} = \frac{CN_1 x\ A_1 + CN_2 x\ A_2 + CN3x\ A3\text{-------------}CN_n X_n}{A_1 + A_2\text{-----------------}An} \qquad (1.4)$$

Where,

CN_1, CN_2, ----------- CN_n are the curve numbers for different land uses and treatment, and hydrologic soil groups present in the sub-basin of the total river basin

A_1, A_2, -----------An. are its respective sub-basin areas.

The weighted CN for the whole basin is calculated by using the Equation 2.

Rainfall –Runoff calculations are done for each sub-basin. The quality of this model is improved by incorporating the spatial variation of watershed characteristics using Remote Sensing and GIS. The runoff curve numbers (AMC II) for hydrologic soil cover complexes and curve number adjustments for antecedent soil moisture conditions for Indian conditions are chosen from the information presented in the Handbook of Hydrology (1972).

The CN values arrived at based on the combination of land use and Hydrologic soil group are meant for AMC-II condition. CN values for AMC-I and AMC-III conditions have been calculated using conversion equations 1.5 and 1.6 given below.

$CN_1 = CN_2 / 2.281 – 0.01281 .2CN_2$ (1.5)

$CN_3 = CN_2 / 0.427 + 0.00573CN_2$ (1.6)

The values for the weighted CN as per AMCs were 68, 83 and 92 in 2006, 69, 84 and 92 in 2011 for the AMC I, II, and III, respectively.

Surface runoff estimation

The SCS-CN method is based on the water balance equation and two fundamental hypotheses. The first hypothesis equates the ratio of the amount of direct surface runoff Q to the total rainfall P (or maximum potential surface to the runoff) with the ratio of the amount of infiltration F_c amount of the potential maximum retention S. The second to the potential hypothesis relates the initial abstraction Ia maximum retention. Thus, the SCS-CN method consisted of the following equations (Subramanya K. (2008).

(a) Water balance equation:

$P=Ia + Fc + Q$ (1.7)

Proportional equality hypothesis

$Q (P−Ia) = FcS$ (1.8)

(b) Ia - S hypothesis:

$Ia=\lambda S$ (1.9)

Where,

P is the total rainfall, Ia the initial abstraction, F_c the cumulative infiltration excluding Ia, Q the direct runoff, S the potential maximum retention or infiltration and λ the regional parameter dependent on geologic and climatic factors ($0.1<\lambda<0.3$).

Solving equation (1.8)

$Q = (P - Ia)^2 / P - Ia + S$ (1.10)

$Q = (P - \lambda S)^2 / P - (\lambda - 1) S$ (1.11)

The relation between Ia and S was developed by analyzing the rainfall and runoff data from experimental small watersheds and is expressed for Indian condition as Ia=0.3S. Combining the water balance equation and proportional equality hypothesis, the SCS-CN method is represented as

$Q = (P - 0.3S)^2 / P + 0.7S$ (1.12)

The potential maximum retention storage S of watershed is related to a CN, which is a function of land use, land treatments, soil type and antecedent moisture condition of watershed. The CN is dimensionless and its value varies from 0 to 100.The S-value in mm can be obtained from CN by using the relationship

$S = 25400 / CN - 254$ (1.13)

Results and Discussions

The result shows that considerable amount of runoff from rainfall. The sub-basin wise average CN was found to be the lowest fifty eight (58) for the sub-basin 8, 10, 12, 13, 14, 15, 17 and 18, the reason being good vegetation. But runoff potential was high in the sub-basin 8, 10, 12, 13, 14, 15, 17 and 18 because of AMC III condition during most of the months. As assigned CNs were based on average AMC II condition, CNs were later modified for AMC I (rainfall < 5 mm), and AMC III (rainfall > 71 mm) conditions. High CNs in the sub-basin 2, 3, 4, 9, 16, and 20 ninety three (93) were due to dominant HSG-C. CN for the remaining sub-basins ranges between 85 and 61.

It was observed that only the sub-basins 10 and 11 generated considerable amount of runoff throughout the study period, because the sub-basins received rainfall between 1587.4 and 1317.67 millimeter during 2006 and 2011. From middle of June to October, the river basin as a whole and the remaining sub-basins generated considerable amount of runoff because of monsoon season rainfall in these regions. During June to October, in most of the sub-basins, around 90% of annual runoff occurred except in the sub-basin 1, 7 and 17. The runoff pattern from June to September typically matched with the advancement of the monsoon system.

However, the gap between rainfall and runoff was significant during different time periods and also widely different for different basins. This gap was wide for the sub-basin 10 and 11. The temporal variation in the gap between rainfall and runoff was due to the fact that, the ratio between rainfall and runoff was low during low rainfall months. This is because during low rainfall period, water is generally retained by the soil and runoff occurs only when retention capacity is filled.

Though the highest runoff depth occurs in August, i.e. above 200 millimeter, in majority of the sub-basins, uniform runoff was observed between January and February, though peak runoff was almost reduced by two-thirds. Sub-basin 1, 2, 3, 4, 5, 6 and 21 had low runoff throughout the year. Thus the spatial variability of runoff was high during five months, i.e. June to September. During other months, there was low spatial variability of runoff, because most of the sub-basins had low rainfall.

The spatial variation of annual runoff showed high runoff (1587.44–1317.67 millimeter) in the sub-basins 10, 11 and 12 due to high annual rainfall in these regions (2056.8–1717.6 millimeter). Low to very low runoff depth of the order 368.83– 682.58 millimeter was observed in sub-basins 1, 2, 3, 4, 5, 6, 7, 8, 17, 18, 19, 20 and 21, caused by low to very low rainfall (754–1026.1 millimeter). Medium to high runoff 1033–1051 millimeter was found in the sub-basins 9, 13, 14, 15 and 16. The average annual runoff depth over Tandava River Basin was found to be 819.27 millimeter, which was around 66.8% of the total rainfall in Tandava River Basin, i.e. 1225.75 millimeter. Though the runoff pattern mostly followed the rainfall pattern, there were deviations, that could be attributed to variation in textural classes and hydrological land cover classification generated using remote sensing

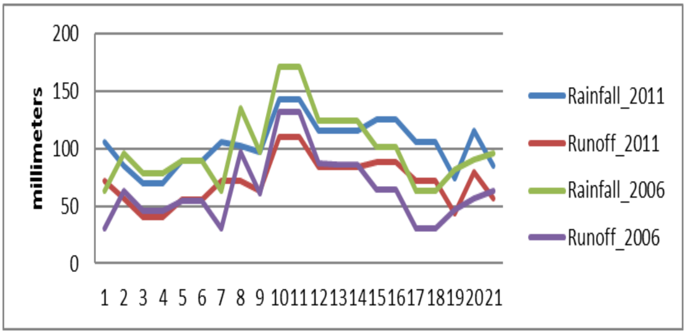

Figure 1:8: Rainfall- Runoff distribution over sub-basins in 2006 and 2011

Conclusions and recommendations

The SCS-CN model provides a very sufficient solution for this study interms of estimating surface runoff from two rainfall year that is 2006 and 2011 and hence the researcher recommend this valuable document for the safeguard of the Tandava River Basin community for further prevention, mitigation and conservations activity that cause due to excess rainfall occurrence. These results also recommend further extension work of the current reservoir in order to prevent abrupt flood and built of check dams in the upper catchment of the river basin.

Acknowledgments

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