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Run-off and flood estimation in Krishna River Delta using Remote Sensing & GIS

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ABSTRACT

Run-off and flood estimation is attempted for cyclone induced rainfall in this study using real time data. A cyclone has potentially destructive characteristics such as strong winds, heavy rains and waves induced from storm surges as exemplified by the severe storm that crossed the Bay of Bengal coast in the Krishna delta region, 40 km south of Machilipatnam on 9th May 1990 is the subject of present investigation. Flood mapping and hazard zonation are indispensable for a real time study of floods and is only possible through remote sensing and GIS. An attempt is made to estimate run-off and flood with real time information derived from remote sensing as conventional approach does not give accurate estimates nor is fast. Soil Conservation Society (SCS) model is adopted to estimate storm run-off. Weighted Curve Number (CN) of the Krishna river basin (India) is determined as 72.4 based upon combinations of land use, soil type and hydrologic features. Flood estimation in the Krishna river basin using SCS Run-off model is estimated at 989.74 MCM during rainfall of 11 days from 5th may to 15th May 1990. The method of weighted curve number is easier, less time consuming and accurate with real time data, hence is applicable for the assessment of flood due to cyclone elsewhere.

INTRODUCTION

A cyclone is characterized by potentially destructive meteorological features as storm surges, wave effects, strong winds and heavy rains (Philip Stenchion 1997). Every hydrologic design is different as the factors affecting the design, vary with space and time. It is essential to make measurements of factors such as size, slope, soil type and land use, vegetation and flow capacity of the channel. The drainage area, length of the water courses and mainstream are the most significant variables for prediction of run-off. An accurate run-off modeling computing these factors is important, as the transport of sediment and pollutants from watershed depends on the run-off processes. Zollweg, Gburek & Steen huis (1996) has developed SMORMOD; a GIS integrated rainfall-runoff model. White (1998) has used a raster GIS to model rainfall run-off for a 421 Sq.km. watershed in Pennsylvania. Remote Sensing integrated with GIS has been efficiently used in generating input parameters of hydrological models. A few researchers in India applied this technology to calculate runoff curve numbers using Landsat, IRS-1A and IRS-1B data. Regan & Jackson (1980), Chakravorty (1993), Tiwari et al. (1997), Bhanumurty et al., (2002), Chatterjee et al., (2001),Tripathi et al., (2002), Nayak & Jaiswal (2003), Ashish et al., (2003), Mohan Zade et al., (2005) and Gupta & Panigrahy (2008) have estimated the run-off using curve number of a basin and RS data in GIS environment. Geographic information systems and remote sensing (thereafter abbreviated to GIS and RS) provide a broad range of tools for determining areas by floods or for forecasting areas likely to be flooded due to high river or sea water levels. For an effective management of flood water in low lying flood-prone areas, GIS and RS technology is proving to be a useful and efficient instrument (Wagner 1989 and Rahman 1992).

Most of the models developed are empirical in nature for a particular location under specific physiographic and climatological conditions, which cannot be applied elsewhere. Since the time series data of rainfall is available, the Krishna River basin is selected for the present study (Fig.1). The Krishna River basin is located between the $73^0.41'$ to $81^0.25'$ E longitude and $13^0.00'$ to $19^0.30'$ N Latitude. It occupies an area of 261,375 sq.km. An attempt is made in the present investigation to estimate the run-off and flood calculations using rainfall data during the storm period of 11 days, 5th to 15th of May 1990 to demarcate the inundated area in the delta of Krishna basin. Only the affected area due to storm rainfall in the basin is considered during the run-off calculations. Remote sensing and GIS approach is adopted in preparing themes and integration of data.

When a storm occurs, a portion of rainfall infiltrates into the ground and some portion may evaporate. The rest flows as a sheet of water over the land surface, which is termed as overland flow. The rainfall data are collected from Indian Meteorological Department (IMD). The data of heavy rainfall from 5th to 15th of May 1990 is taken to estimate the run-off and flood calculations for the river basin. Very heavy rainfall is recorded on 10th - 12th May. Polampalle and Kankipadu villages of Krishna district recorded 579.6 and 492.4 mm respectively. It is 50% to 60% of the total annual rainfall.

METHODOLOGY

The Krishna river basin is extracted from National Atlas & Thematic Mapping Organization (NATMO) maps in the scale of 1:6 million. Soil map also prepared using NATMO maps in the same scale. Rainfall contours are prepared for entire basin. IRS 1C/1D satellite WiFS sensor data is obtained and prepared a mosaic. Krishna river basin boundary (AOI) is taken and basin satellite image is extracted from the mosaic.

A land use / land cover map is prepared from the basin satellite data. An intersection map is created from the soil map and land use map of the above. Using the characteristics of soil and land use land cover, a curve number is extracted from various combinations of soil and land use. The curve number is used to estimate the run-off and flood during the cyclone period.

RESULTS AND DISCUSSION

Rainfall Contour Map

Rainfall contour map is prepared under GIS environment by plotting the rainfall according to lat/long positions in the river basin layer and it is stored as point data (Fig.2). Data from 57 rain gauge stations

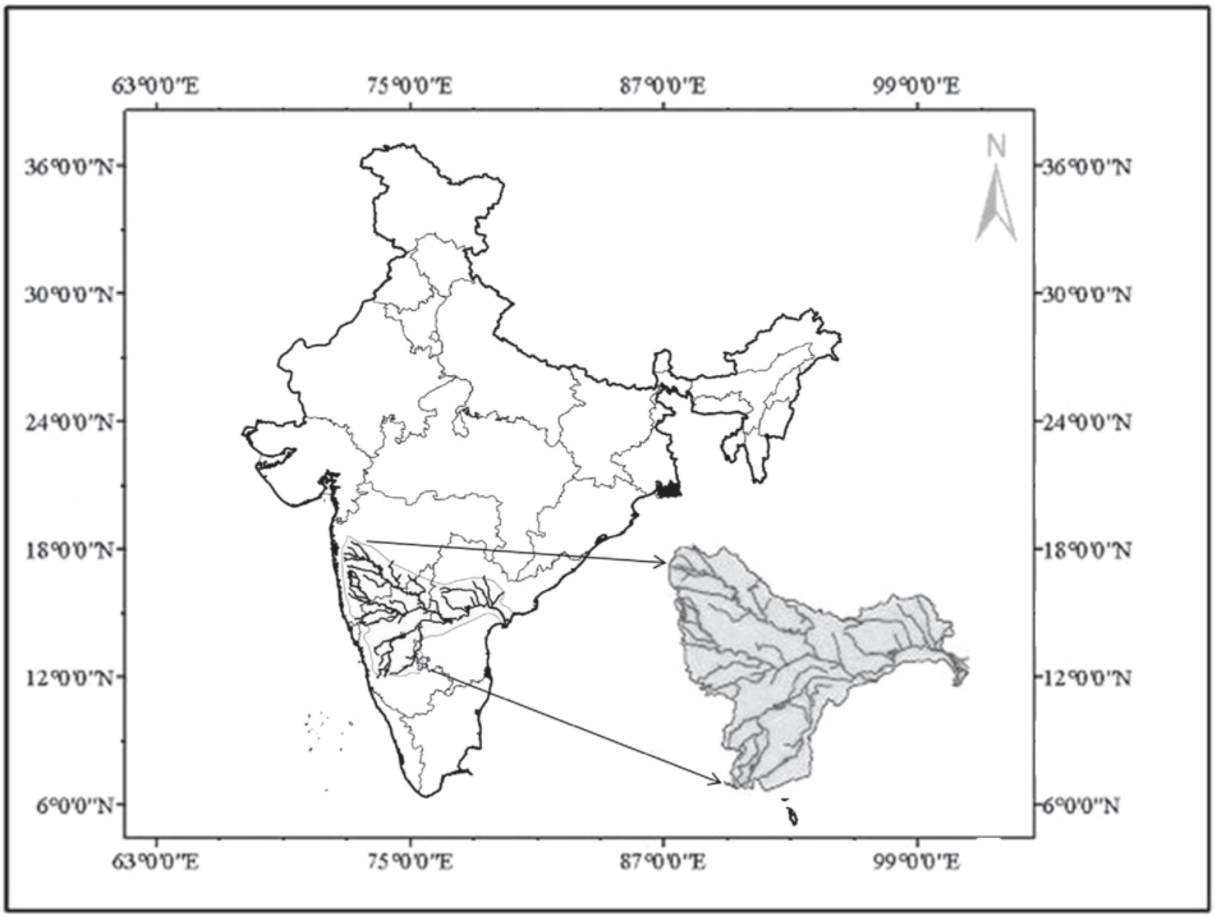

Figure 1. Location map of Krishna river basin.

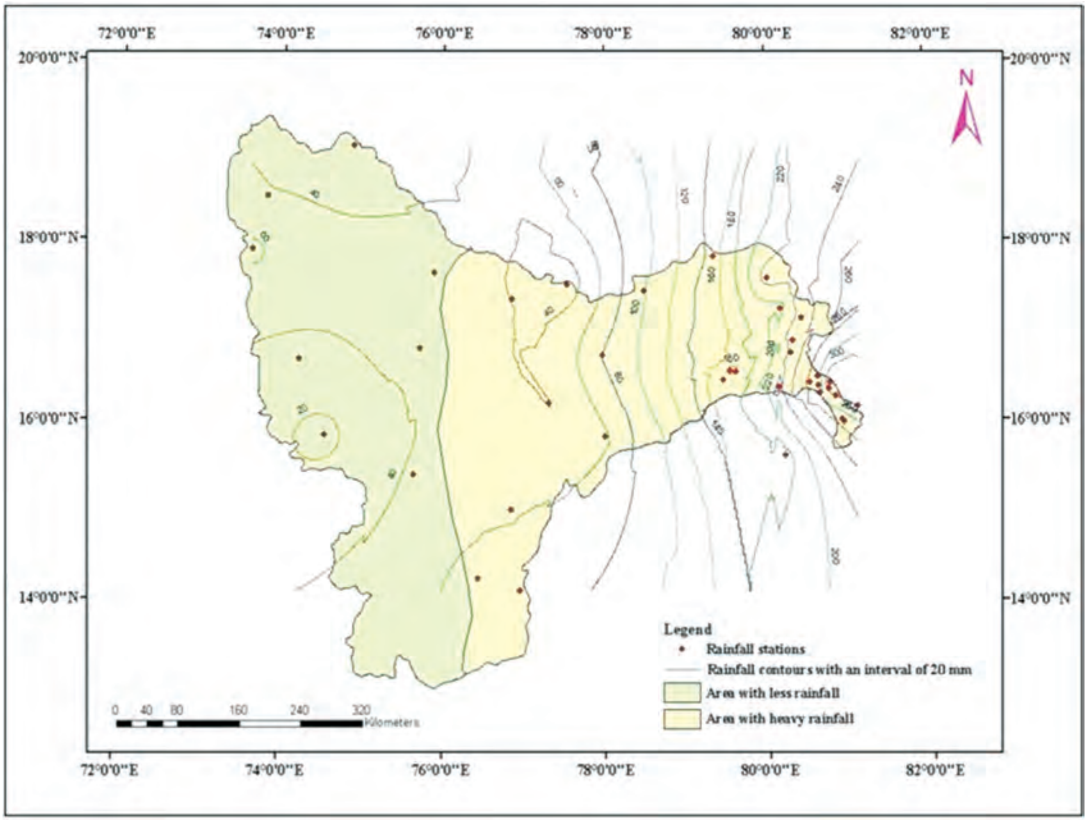

Figure 2. Rainfall contours of Krishna river basin (5th to 15th May 1990).

over the entire basin are used to prepare the rainfall contour map. The highest rainfall (579.6mm) is recorded in Polampalle village of Krishna district. The attributes such as name of the station and the total rainfall data for 11 days are built. Using spatial analyst, kriging is done for that layer based upon the total rainfall value and the contours are generated with an interval of 10 mm. The intensity of rainfall is found to be maximum in coastal areas of the basin.

Soil Map

The soil texture map is generated using India soil texture map produced by NATMO under GIS environment. It is digitized and created as Arc- Info coverage with polygon features. The soil map of the basin shows 9 different soil texture classes (Fig. 3 & Table 1). Clay loam occupies maximum area of the basin (63,457 sq.km). It is followed by loamy sand

Table 1. Soil texture and its areal extent in Krishna river basin.

ID NO	Soil texture	Area occupied in sq.km	% of Total Area
1	Clay loam	63,457	24.28
2	Loam	43,590	16.68
3	Clay	29,936	12.45
4	Loamy sand	56,720	21.70
5	Silty clay loam	17,933	6.81
6	Silty clay	1,227	0.76
7	Very fine sandy loam	9,211	3.52
8	Silt loam	29,007	11.10
9	Sand loam	4,460	2.70

with an area of 56,720 sq.km. Clay, clay loam and loam occupied 52.3% of the basin area.

Analysis of WiFS Data

IRS-1C/1D WiFS Images of multi-spectral data are used for land use classification. Survey of India topographic maps 47E, 48I, 56B, 57A, 65C and 66A of scale 1:250,000 are used as base maps. The Krishna river basin is covered in three scenes of WiFS sensor. The satellite scenes are registered for base maps. A mosaic is prepared using the three scenes and the Krishna river basin area subsets from the mosaic and shown in the Fig.4. The details of the satellite and sensor and related data are given below.

Satellite & Sensor	Path	Row	Scan lines/Pixels	Date of acquisition
IRS-1C (WiFS)	102	61	4360/4860	23-10-2000
IRS-1D (WiFS)	105	59	4349/4860	21-10-2002
IRS-1D (WiFS)	105	54	4401/4680	15-11-2002

To make the image brighter and sharper, "contrast stretching technique is used." The minimum and the maximum brightness values are determined using the image histogram. The data are classified in supervised classification model. For each of the pixels, the image is classified based upon spectral matching. After loading FCC, 8 or 9 samples for each class are bitmapped and given to the algorithm. Maximum Likelihood Classifier (MLC) algorithm is used for classifying the land use after masking agriculture lands, settlements and wetlands. Each pixel in the image data set is categorized into the land use classes in close resemble. If a pixel is insufficiently similar to any data set it is labeled "unknown" The category label assigned to each pixel in the process is then recorded in the corresponding matrix of interpreted land use types. Different colors are given to various land use classes for easy identification.

Land Use Map

Seven classes are identified from this low resolution data (Fig.5 &Table 2). They are fallow land, agriculture land, forest land, scrubs, settlements, water and wetlands. Fallow land consists of wasteland and barren rock, is dominant in the Krishna river basin. agriculture land is shown in light green along the river coast, around Nagarjuna Sagar, Srisailam and other river project areas. Scrub and rocky wastes in magenta colour are seen in south Maharashtra and central Karnataka. It occupies larger area of basin followed by fallow land. Forest cover is confined to a few parts of the catchment area of the basin, and south of Srisailam dam.

SCS Curve Method

In hydrological modeling run-off estimation is the most important parameter. A number of empirical

Table 2. Land use classification and their areas, Krishna river basin.

ID NO	Classification	Area occupied in sq.km	% Of Total Area
1	Agriculture land	22,732.3	8.69
2	Fallow land	144,470.9	55.28
3	Forest	20,775.8	7.95
4	Shrubs	62,418.5	23.88
5	Built up land	1,646.7	0.63
6	Wetland	660.9	0.25
7	Water bodies	5,825.1	2.22
8	Others	2,846.1	1.1

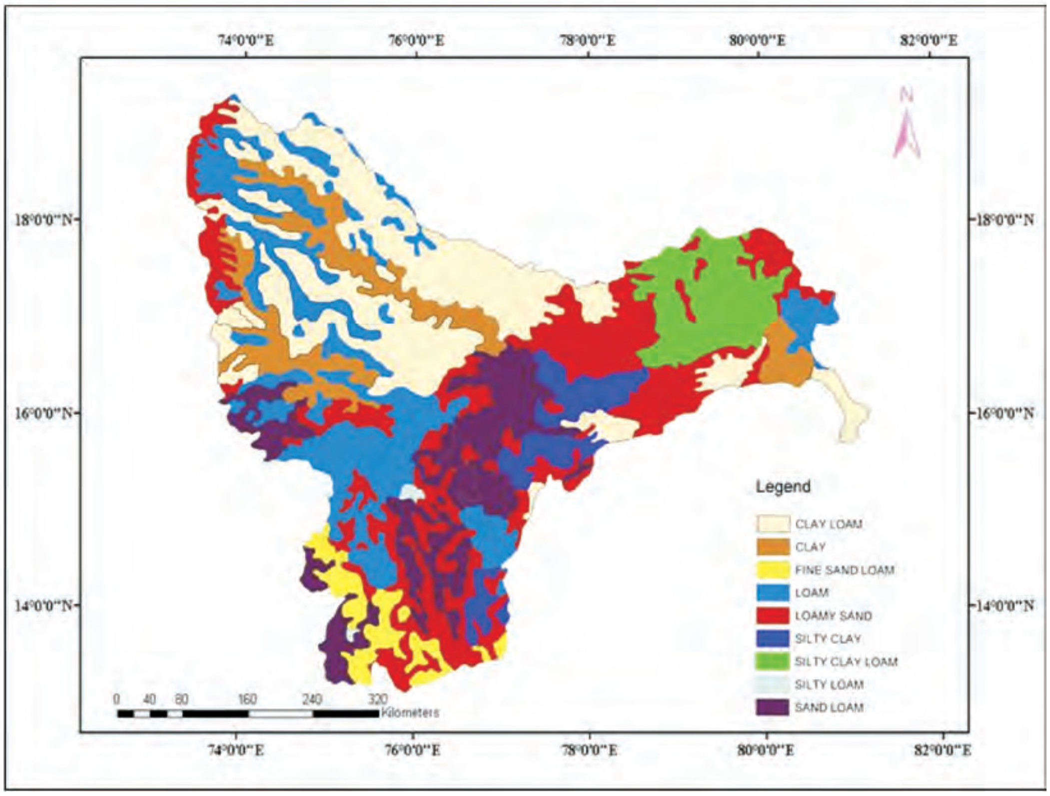

Figure 3. Krishna river basin soil map.

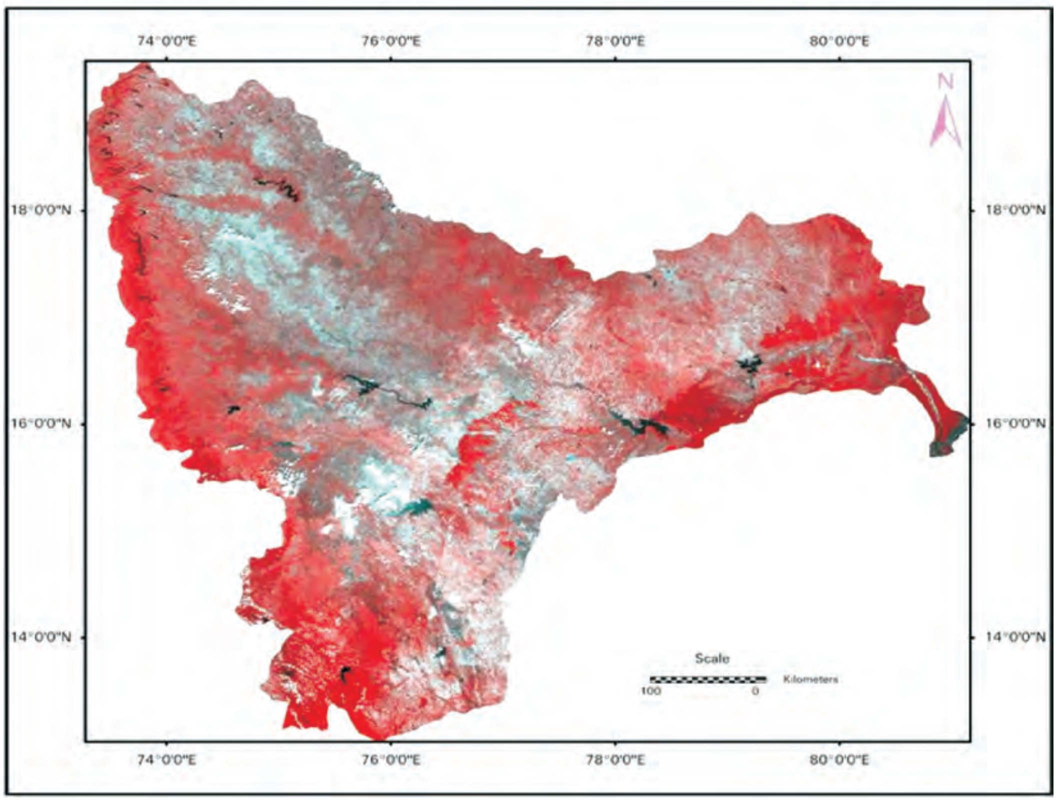

Figure 4. Krishna river basin from WiFS data.

methods are available but commonly and widely used empirical method is Soil Conservation Services Curve Numbers (SCS-CN 1993) method. The model developed by United States Department of Agriculture (USDA) Soil Conservation known as curve number (CN) is popular among all rainfall- runoff models because of simple mathematical relationships and low data requirement, Nayak & Jaiswal (2003).

The SCS model compute direct run-off through an empirical equation which requires rain fall, hydrological soil group and land use land cover. CN is a computed variable which is based on the Antecedent Moisture Condition (AMC), land use /land cover class and hydrological soil group. The SCS approach involves the use of simple empirical formulae and readily available tables and curves. The empirical equation requires the rainfall and watershed coefficients as inputs. The watershed coefficient is called the CN, which is an index that represents the combination of hydrologic soil group and land use and land treatment classes, Richard (1982), Rao, Bhattacharya & Mishra (1996), Kumar, Tiwari & Pal (1997), Tiwari et al. (1997) and Pandey, Panda & sudhakar (2002).

One of the major inputs for rainfall-runoff modelling is land cover where Satellite remote sensing is the best source of mapping this information Parihar (1995). Basic data requirements fulfilled for this model are amount of rainfall that runs off the Krishna river basin after the combined effects of soil type in the basin, land use treatment, AMC and hydrologic condition.

Data are collected on type of land use/cover such as bare soil, vegetation, impervious surface, agricultural lands etc. and hydrologic condition of each land use. The AMC is important parameter, being the index of the soil condition with respect to run-off potential before the storm.

Antecedent Moisture Condition

AMC is defined as the summation of 5-day precipitation before the runoff-producing storm. The first step in the model was to derive hydrological soil group which is qualitative term given by SCS. The hydrologic soil group classification is based on texture of distributed soil, soil group, texture and infiltration rate. Ideally, a hydrological soil grouping was to be derived on the basis of soil type, infiltration, soil depth and permeability (Stuebe & Johnston 1990, Sharma et al., 2001, Mohan Zade et al.. 2005). AMC is used as an index of wetness in a particular area in three levels as shown below (Table3).

Soil texture prepared from NATMO maps is used to prepare hydrological soil group based on the soil infiltration and drainage characteristics of different soil features. Soils of the basin are divided into four groups based in infiltration rate and soil texture as shown below (Table 4). Sand, sandy loam, and loamy sand termed as Hydrological Soil GroupA (HSG-A). Silt Loam and loam as HSG-B, sandy clay loam as HSG-C and clay and silty clay, clay loam has HSG-D. Area under different hydrological soil group (A-D, high to low infiltration) is calculated and validated with the study area land cover. The areas of different soil groups were 26.9 to 27.78, 6.81 and 36.25% (considering total area of the basin as – 261,375 sq km).

Table 3. AMC class and condition.

AMC - CLASS	AMC (mm)	CONDITION
1	<35	Dry soil but not the wilting point
2	35 – 52.5	Average conditions
3	>52.5	Saturated soils; heavy rainfall or light rain

Table 4. Soil group, texture and infiltration rate of soils.

Group	Infiltration rate (mm/hr)		Soil Texture
A	HIGH	>25	Sand, Loamy Sand, or Sandy Loam
B	MODERATE	12.5 - 25	Silt Loam or Loam
C	LOW	2.5 – 12.5	Sandy Clay Loam
D	VERY LOW	< 2.5	Clay Loam, Silty Clay Loam, Sandy Clay, Silty Clay or Clay

Two input values, precipitation and curve number are necessary for the application of the SCS equation. The run-off curve number value, which represents the amount of rainfall runs- off in a catchment with AMC as one of the important factors, is estimated from a semi-objective field survey referenced to appropriate USDA-SCS tables (1972). These tables relate the curve numbers for average AMC to specific combinations of hydrologic soil group, land use treatment and hydrologic condition. On the basis of the SCS, the soils are classified generally into four groups: A.B.C and D (Table 4). This classification is based on their minimum constant infiltration rates.

The influence of the surface conditions of catchments on run-off is evaluated by means of land use and treatment classes. The different land use patterns present in the basin are (1) dry crop and wet crop are included in agriculture land, (2) fallow land, which also includes rock outcrop and waste lands, (3) forest land, which is further classified as deciduous, mixed and shrubs, (4) shrubs and (5) built-up area.

Curve Number

The layers like land use/land cover map and soil map are intersected (Fig.6) using GIS utility of Arc- Info 8.1 software to establish curve numbers under average AMC-II. Gumbo et al., (2001) found that the CN method worked out well in GIS environment because of its relatively simple equations. The curve numbers for various land use classes are computed using standard tables available for the Indian conditions (Rao, Bhattacharya & Mishra 1996). The weighted curve number for the basin is calculated based upon the areas occupied by each land use class. The land use classes and the soil textures and their corresponding curve numbers are given in Table 5

Estimation of runoff and flood

For the estimation of direct run-off produced by a given precipitation in a basin, various models are available. The SCS approach involves the use of simple empirical formulae and various available tables and curves. The weighted curve number for the basin is calculated based upon the areas occupied by each land use class as shown above. The following relationships between initial abstraction and potential maximum retention have been developed for Indian condition for run-off is

$$Q = \frac{(R - 0.3s)^2}{R + 0.8s}$$

Where, Q is the daily run-off, R is the daily rainfall, and S is the retention parameter.

The retention parameter varies in space because of varying soil, land use, management, and slope; and in time because of changes in soil water content. The parameter S is related to CN as follows

$$S = 25400/CN - 254$$

Flood discharge from daily run-off was calculated by multiplying the depth of run-off, which is arrived from SCS method with area of the river basin. Only the part of the river basin (131,385 sq km) with high intensity of rainfall is considered on the basis of rainfall contour map.

From Rational method, the flood is estimateed from observed rainfall in a river basin and compared. The equation is

$$Q = \frac{AIR}{360}$$

Where

A = Area of river basin in Sq.km

I = Impermeability factor based upon geological properties of river basin

Impermeability factor for southern and central India is given as a range 13.5 - 19.0. Impermeability factor is taken as 16.0 for the basin.

Q = Flood discharge

R = Rainfall mm/hr (rainfall is estimated as mm/day in this present investigation)

The results of the flood estimation from above method and rational formulae are given below. The flood in Krishna river basin is 989.74 MCM.

Table 5. Curve numbers for different land use and soils (Dhruva Narayana, 1993).

Sl.No	Land Use	Soil Type	Soil Group	Area in sq.km	CN
1	Agriculture land	Clay loam	D	2305.11	95
		Loam	B	1356.19	95
		Clay	D	4204.35	90
		Loamy sand	A	1099.19	85
		Silt clay loam	D	207.21	90
		Silty clay	D	966.62	90
		Fine sand loam	A	285.55	85
		Silt loam	B	6012.85	80
		Sand loam	A	222.91	80
2	Fallow land	Clay loam	D	50496.35	85
		Loam	B	32716.99	85
		Clay	D	16522.32	85
		Loamy sand	A	29639.56	71
		Silt clay loam	D	16319.00	88
		Silty clay	D	10731.00	85
		Fine sand loam	A	6860.00	80
		Silt loam	B	19028.00	85
		Sand loam	A	1267.55	80
3	Forest	Clay loam	D	2596.88	58
		Loam	B	1814.96	58
		Clay	D	396.03	58
		Loamy sand	A	17241.40	26
		Silt clay loam	D	526.74	61
		Silty clay	D	141.82	61
		Fine sand loam	A	635.41	58
		Silt loam	B	1662.62	58
		Sand loam	A	2956.00	40
4	Shrubs	Clay loam	D	7765.56	64
		Loam	B	7681.10	64
		Clay	D	2709.52	64
		Loamy sand	A	8488.32	33
		Silt clay loam	D	861.98	67
		Silty clay	D	406.40	64
		Fine sand loam	A	1428.00	47
		Silt loam	B	2303.00	64
		Sand loam	A	12.78	47
5	Built up area	Clay loam	D	289.09	91
		Loam	B	20.821	91
		Clay	D	104.108	91
		Loamy sand	A	251.71	77
		Silt clay loam	D	17.55	93

The weighted curve number is estimated from the above table as 74.2 for the watershed basin.

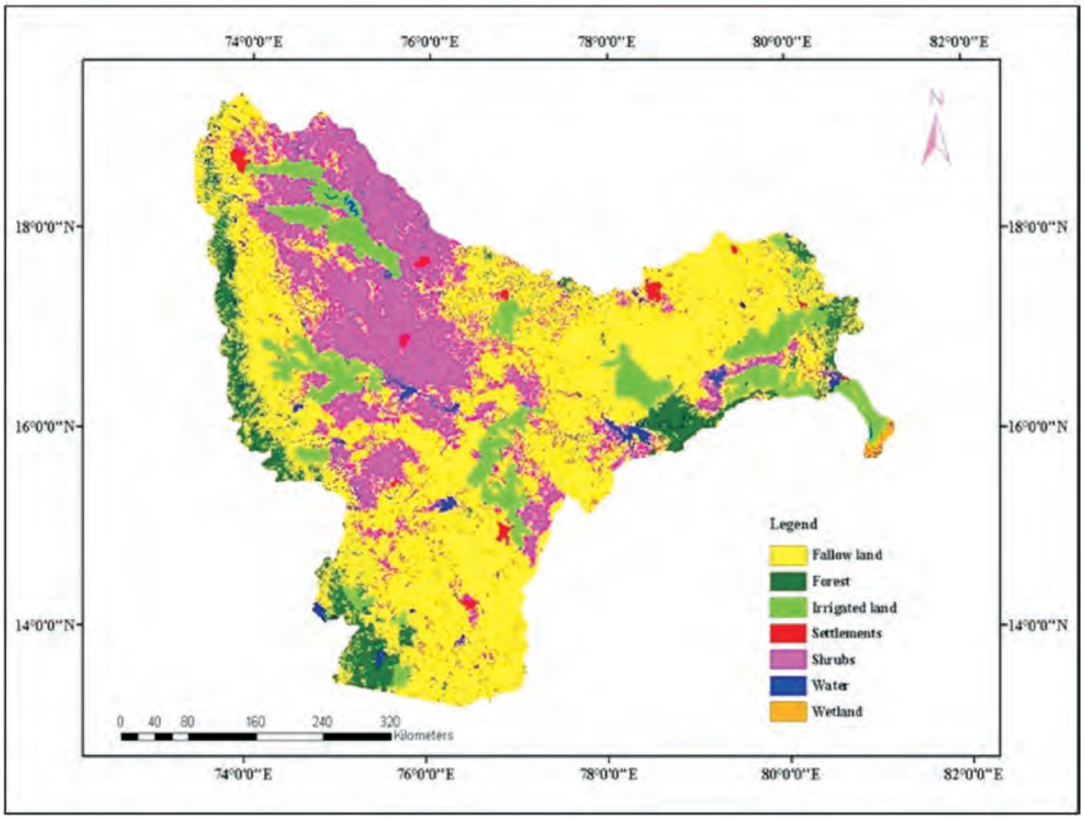

Figure 5. Classified map of Krishna river basin.

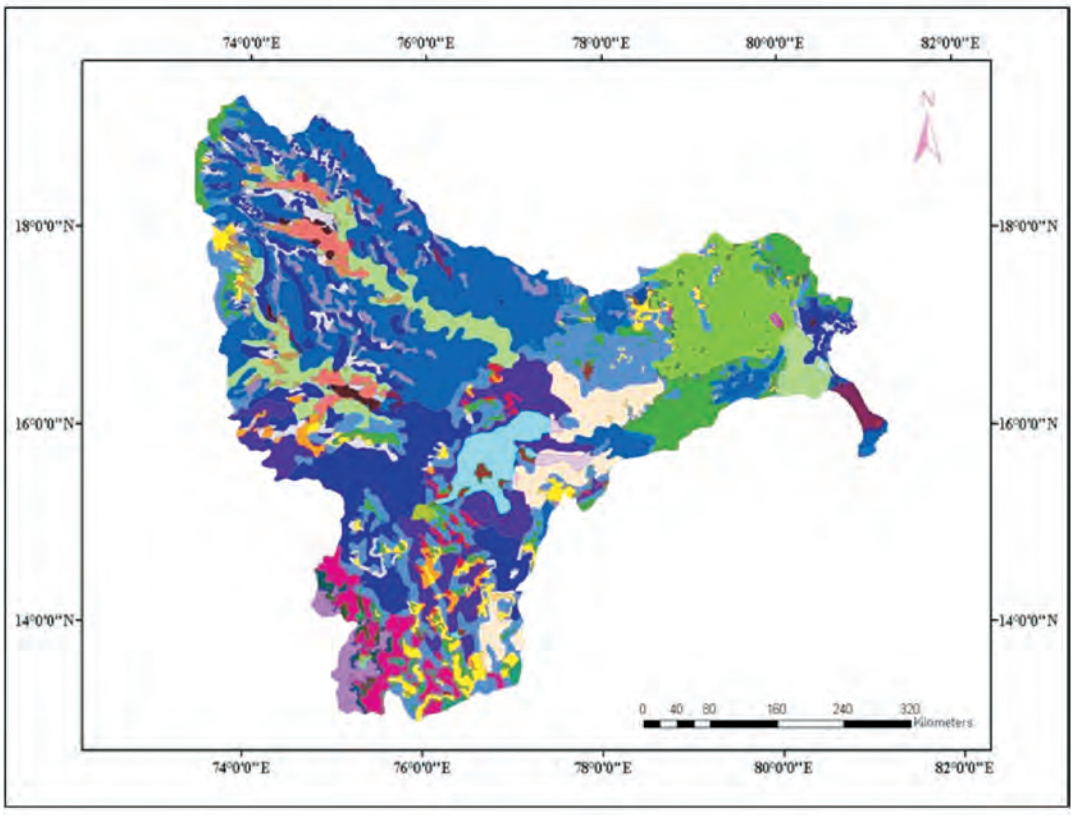

Figure 6. Soil and land use intersection map.

Table 6. Run-off and Flood estimation from observed rainfall in Krishna Basin .

Date of event	Observed Rainfall (mm)	Estimated Runoff (mm)	Flood discharge SCS method MCM	Flood discharge by Rational Method MCM	Difference MCM
05.05.90	23.0	0.36	0.89	3.22	3.081
06.05.90	92.6	23.76	3.19	12.97	7.471
07.05.90	169.6	79.99	11.25	23.96	9.805
08.05.90	158.0	70.65	10.58	22.142	9.359
09.05.90	605.8	486.90	64.53	84.89	15.26
10.05.90	2465.9	2334.87	310.59	345.58	32.29
11.05.90	1696.0	1566.90	206.15	237.68	25.43
12.05.90	1841.0	1711.42	223.18	258.00	26.73
13.05.90	870.0	746.48	98.55	121.92	17.88
14.05.90	575.0	456.88	59.58	80.828	15.218
15.05.90	56.7	5.70	1.25	7.946	5.797
Total	7978.6	7483.91	989.74	1198.936	168.121

CONCLUSIONS

Flood discharge from daily run-off in Krishna river basin is calculated by multiplying the depth of run-off, which is obtained from SCS method, with area of the river basin. The part of the river basin (131,385 sq km) with highest intensity of rainfall from 5th to 11th May 1990 is considered in the investigation. The flood occurred during the 11 days is compared with estimations obtained from empirical estimations. The comparison of estimated run-off through SCS model and relational method, the former was little lower on all days rainfall compared to the later. This could be due to accurate land use classes derived from RS data. The flood discharge form the Krishna basin is 989.74 MCM during the cyclone period. This spatial and temporal pattern of run-off estimated using remote sensing data and creating intersection maps between soils and land use of the basin in GIS helped better estimation of run-off. An ideal Flood Disaster Management System needs to support the activities related to disaster prediction, preparedness, damage assessment and rehabilitation. The space inputs could be used in taking preventive measures through vulnerability analysis, hazard zonation and prior risk assessment at regional and local levels. SAR data is more useful for flood monitoring due its capability of penetrating the cloud cover. The methodology demonstrated in this article shows the estimation of flood discharge with the latest technologies. As the satellite imageries are not available during the cyclonic period (May 1990), data for the year 2000 and 2002 were used to prepare the land use/cover. It is the authors view to estimate the flood discharge during such cyclones. The results expressed in this article are the simulation of the flood discharge if a cyclone of this intensity occurs. The only parameter that changes is the land use/cover as the soils over the area under investigation are constant. Hence with present land use/cover and rainfall data, the flood discharges can be best estimated using this methodology. Satellite technology has proven potential in monitoring, mapping and management of natural hazards including cyclone-induced floods.

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