Analysis of Rainfall-Runoff, Evapotranspiration and Infiltration of Kandukuru Vagu Watershed Nalgonda District A.P. India Using Remote Sensing and GIS Technique

Ayad Ali Faris [*], Y.Sudhakar Reddy
Dept. of Geology , University College of Science , Osmania University

Abstract

Numerous methods and techniques are used in the hydrological modeling and the estimation of runoff , evapotranspiration and infiltration . Each model uses specific parameters as inputs for the analysis . Due to the great spatial and temporal variability of watershed characteristics , precipitation patterns and the number of variables involved in the physical process , the relation of rainfall-runoff , evapotranspiration and infiltration is one of the most complex hydrologic phenomena . The main objective of the present study is to study the relation of rainfall – runoff , evapotranspiration and infiltration using remote sensing and GIS techniques based on land use/land cover , soil types and basin parameters computed from the digital elevation model of Shuttle Radar Topographic Mission (SRTM) data . Runoff is estimated using Soil Conservation Service (SCS) - Curve Number (CN) losses method with Hydrologic Engineering Center (HEC-1) model in WMS package . This technique was employed to simulate the characteristics of surface runoff i.e. runoff volume , peak flow , time of peak flow for different sub watersheds and outlets for three storm events of rainfall belong to three different antecedent moisture conditions (AMC),. The evapotranspiration , calculated by Surface Energy Balance Algorithm for Land (SEBAL) method using Landsat-7 ETM+ imagery . Depending upon the rainfall , runoff and evaptranspiration the rainfall- infiltration coefficients calculated for each sub basins . The results shows the effect of soil types , land use/land cover , vegetation densities and basin morphometric parameters on the spatial distribution of the surface runoff , evapotranspiration and the recharge of the ground water in the sub basins of Kandukuru Vagu basin .

* Dept.of Geography , Education College , al-Mustansiriyah University ,Baghdad ,Iraq (presently working for Ph.D programme in the department of Geology OU , under ICCR exchange programme)

Key words : Kandukuru Vagu basin , SEBAL , GIS , Remote Sensing , watershed , runoff , evapotranspiration , infiltration . groundwater , SCS , Curve Number , HEC-1 .

1 Introduction .

Basin watershed is a geohydrological unit of land and water area which drain to a common outlet , and bounded by a divide separating one drainage basin from another .

Due to the great spatial and temporal variability of watershed characteristics , precipitation pattern and the number of variables involved in the physical process , rainfall-runoff evaptranspiration and infiltration relationship is one of the more complex hydrologic phenomena (Weizhe, 2007) . The surface runoff in the catchment is mainly controlled by intensity , duration of rainfall , soil conditions , land cover and terrain slope (Anbazhagan et al., 2005 ; Ligang et al., 2007) . All the sub watersheds of Kandukuru Vagu basin not only varying in their geology , soil types but also showing variation in vegetation, landform , water bodies , land use- land cover , morphometric parameters and varying water table depths. Ground water occurs mainly in shallow weathered and deep fracture zones under unconfined and semiconfined conditions .

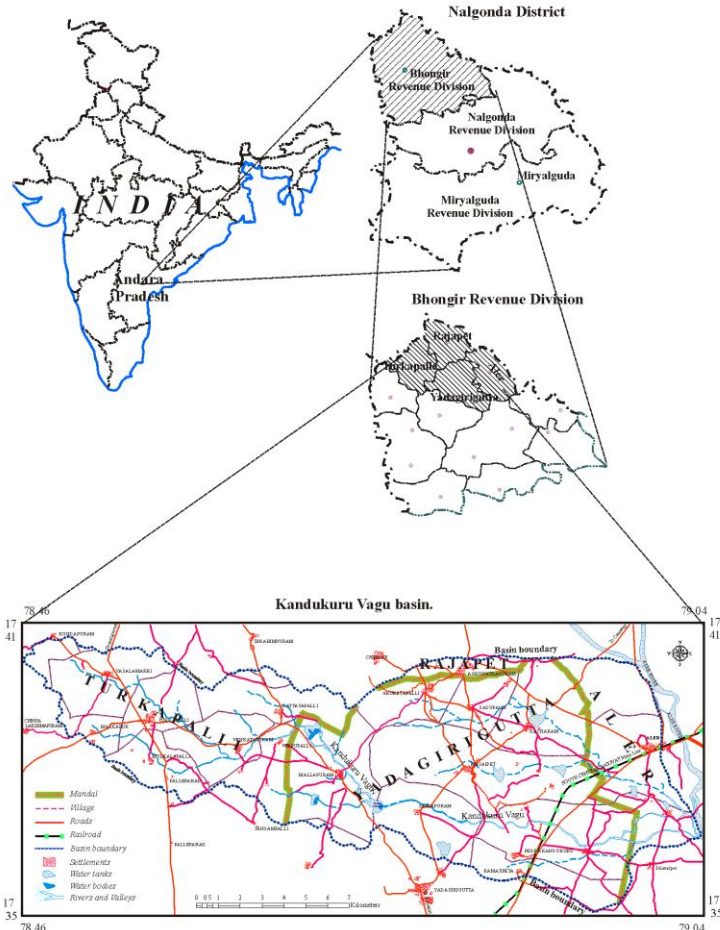
The watershed of Kandukuru Vagu basin – a sub basin of Aler river Nalgonda (dist.), A.P. India , covering an area of 212 sq.kms (Fig. 1) , is bounded by longitudes 78° 46′ and 79° 04′ and latitudes 17° 35′ and 17° 41′ . The area , mainly occupied by granites and gneisses of Archean age , intruded by quartz veins and dolerite dykes of varying thicknesses and lengths .

The objective of the present study is to analyze the relation of runoff , evapotranspiration and infiltration using remote sensing and GIS techniques by employing the Soil conservation Service (SCS) Curve number and Hydrologic Engineering Center(HEC-1) model using WMS software approach , Surface Energy Balance Algorithm for land (SEBAL) and Water balance equation , based on rainfall storms , soil types , land use and basin morphometric parameters .

Numerous methods and techniques are used in the hydrologic modeling for the estimation of the runoff . Each model uses specific parameters as inputs for the analysis of runoff. The Soil Conservation Service (SCS) method developed by U.S. Department of Agriculture (SCS, 1972) , is used to compute the direct runoff depending on the rainfall data and the watershed coefficient i.e. Curve Number (CN) as an input parameters (Sharma and Singh , 1992 ; Nayak and Jaiswal , 2003) .

GeoTuris

Fig. 1 : Location map of Kandukuru Vagu basin



2 Methodology .

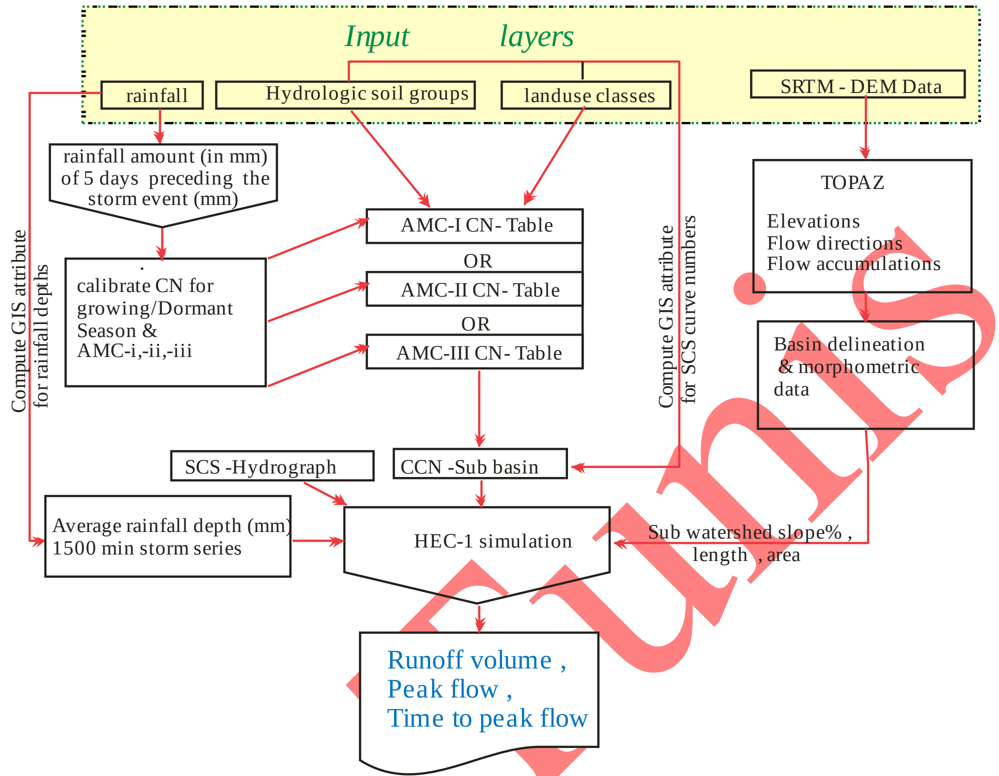
In the present study ,several steps are implemented to carry out the hydrogeological analysis of the Kandukuru Vagu basin , i.e. Estimation of the surface runoff by SCS (1972) – Curve number method , Evapotranspiration computed for the same studied area by Faris and Sudhakar Reddy (2008) and infiltration values are computed from the water balance equation .

2.1 Estimation of Runoff by SCS Curve Number Method .

The watershed modeling system(WMS)developed by Environmental Modeling Research Laboratory (EMRL) of Brighan Young University , is a flexible software which can be used with most GIS input data sources ,or even building a model from the scratch . It also support many hydrologic models like HEC-1 , NFF , TR20 , TR55 , Rational , MODRAT and HSPF (WMS , 2008) . In the present study HEC-1 model was employed , because the HEC-1 is suitable model to represent all the aspect of a watershed and to compute all the components of stream flow hydrographs at desired location in the river basin (Araya and Mohtar , 2006) .

Figure 2 is a flowchart for the estimation of Runoff parameters using HEC-1 Simulations model of WMS software by WMS software .

Fig. 2 : Flowchart of Runoff estimation by WMS software approach



- Digital Elevation Model (DEM) .

The DEM data for Kandukuru Vagu basin was prepared from Shuttle Radar Topographic Mission SRTM image (Fig. 3a) .The elevations , flow directions and flow accumulations are computed by TOPAZ tool (WMS -Tutorial , 2008). From the DEM data the sub basin parameters such as area , perimeter , basin slope , basin length are computed as given in table no. 6.

- Hydrologic Soil Groups and Land use Classes

In the present study the Landsat-7 ETM+ imagery is used to prepare soil types , land use/land cover , The data were analyzed and prepared by ERDAS V.9.1 image processing , and ArcGIS v.9.2 software

Soil types and land use layers (Fig 3b,c) , are used to calculate the Curve Number(CN) of the sub watershed in Kandukuru Vagu Basin .

Based on the hydrologic soil groups suggested by SCS (1972) and mentioned in National Engineering Handbook (USDA , 2007 , chapter 7) , (USDA , 2004, chapter 9) and Soil Survey Manual (USDA, 1993) , four types i.e. A,B,C and D hydrologic soil groups (Table 1) are identified . Using ArcGIS software , a polygon schematic the soil data layer prepared and imported as a shapefile to WMS software and converted to feature object (Fig. 3b).

Using ArcGIS V.9.2 , land use layer of Kandukuru Vagu basin prepared and classified in to ten classes following the classification mentioned in National Engineering Handbook (USDA , 2002 , chapter 8 ; USDA , 2004 , chapter 9) . Figure 3c and table no 2 , shows the spatial distribution and attribute of the hydrologic land use classes .

Table 1 : Attributes of Hydrologic soil groups.

Soil_type	Area	Perimetro	Muid	Hydgrp
red gravelly clay soils	81675725.629	900179.083	1	B
rock lands	49262095.294	765959.727	2	D
red gravelly loam soils	77770053.002	1053200.868	3	B
alluvio-colluvial clay soils	15362921.226	135221.585	4	C
alluvial clayey soils	1320203.828	36361.575	5	A

Table 2 : Attribute of hydrologic Land use classes .

	CLASS_NAME	LUCODE	COUNT	SUM_AREA	ID
1	Mixed Barren land	77	1887	12208080.1800	10
2	Bare Exposed Rock	74	2345	72783124.2910	9
3	Reservoirs	53	189	1731676.6800	8
4	Streams and Valleys	51	2797	19538320.2540	7
5	Evergreen Forest Land	42	1855	25919499.9430	6
6	Mixed Range Land	33	2206	8162350.9850	5
7	Other Agricultural Land	24	3298	15044538.6110	4
8	Cropland and Pasture	21	2571	36989848.6820	3
9	Mixed Urban or Built-Up Land	16	1412	7007451.7010	2
10	Transportation	14	2614	13570811.0020	1

- Rainfall Data .

Using Thiessen polygons method the spatial distribution of average daily rainfall for three storm events in the basin , prepared with ArcGIS V.9.2 software (Fig. 3 d)

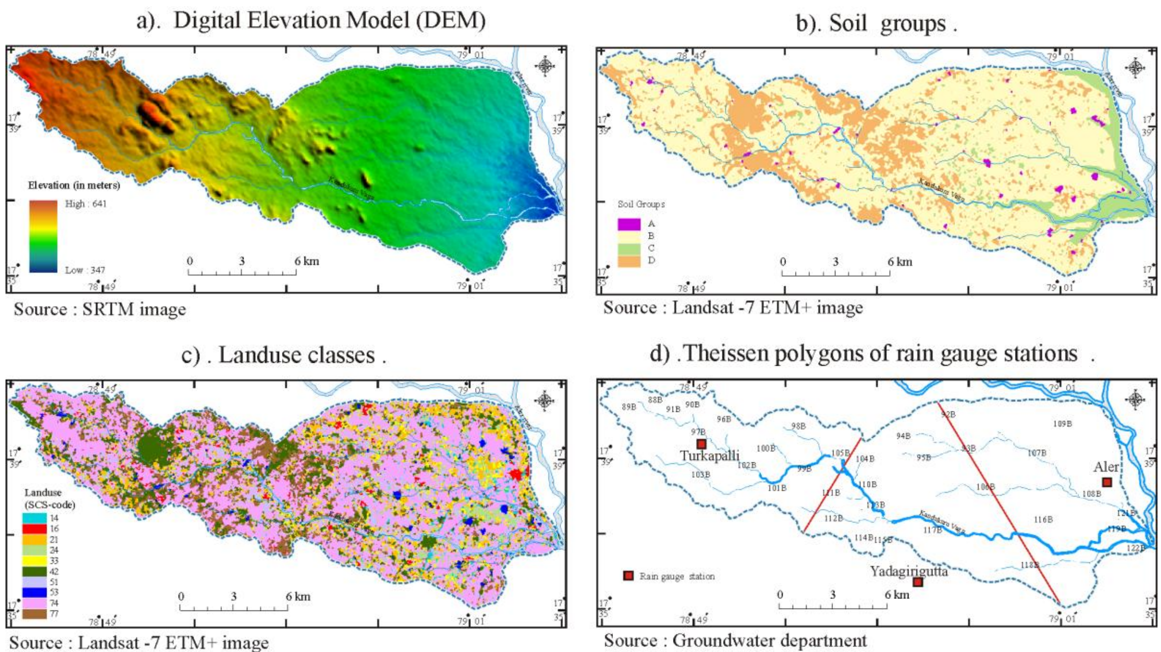
The rainfall data for three daily storm events with different Antecedent Moisture Conditions dated 23rd September 2003 , 29th July 2004 and 10th July 2005 collected from three rain gauge stations at Turkapalli , Yadagirigutta and Aler rain gauge stations is used (Table 3).

Table 3 : 24-hours rainfall storm events and preceding 5 days rainfall amount (mm/5 day)

Rain gauge station	23-9-2003		29-7-2004		10-7-2005	
	Rainfall (mm)	AMC (mm)	Rainfall (mm)	AMC (mm)	Rainfall (mm)	AMC (mm)
Turkapalli	22.50	14.80	35.00	38.50	80.20	57.1
Aler	30.40	16.50	38.50	35.70	79.00	56.8
Yadagirigutta	18.40	16.70	32.20	36.80	82.30	60.1
Average	**23.77**	**16.00**	**35.23**	**37.00**	**80.50**	**58**

GeoGis

Fig. 3 : Input themes for runoff estimation -WMS approach - Kundakuru Vagu Basin.



- Composite Curve Number (CCN) .

The composite curve numbers(CCN) describe the surface potential for estimation runoff as a function of the soil type and land use .

The value of curve number (CN) ranged between zero and 100 ; where zero as a theoretic lower limit for the surface which absorbs all precipitation , and 100 is the upper limit representing an impervious surface such as asphalt or water bodies (Weizhe , 2007). When the area covered by a variety of land use and soil groups the weighted CN is used as a composite curve number (CCN) . It is calculated from the following equation (Sharma and Singh , 1992 ; Anbazhagan et al. , 2005) .

$$CCN = \frac{1}{A}\sum_{i=1}^{n} CN_i \times A_i$$

where CN_i is the curve number for i^{th} area . , A_i is the area of i^{th} CN and A is the total area of the watershed .

The values of CN for different land use and soil groups need to be corrected based on Antecedent Moisture Conditions (AMC) (Weizhe , 2007). Based on the amount of rainfall in a period of five days preceding a particular storm cases of Antecedent Moisture Conditions (AMC) are given in table no.4 .

Table 4 : Amount of rainfall for AMC cases (after SCS , 1972) .

AMC	Amount of rainfall along preceding 5 days (in mm)	
	Dormant season	Growing season
I	< 12.7	< 35.6
II	12.7 - 28	35.6 – 53.3
III	> 28	> 53.3

The following equations are used to calibrate the curve number for three conditions of dry , wet and normal conditions

$$CN_I = \frac{4.2 \times CN_{II}}{10 - 0.058 \times CN_{II}}$$ .... for dry conditions

$$CN_{III} = \frac{23 \times CN_{II}}{10 + 0.13 \times CN_{II}}$$ ....for wet conditions

$$CN_{II} = CN$$ ....for normal conditions

Based on four types of soil groups , the curve numbers selected for each land use classes, as per CN values given in National Engineering Handbook (USDA , 2004 , Chapter 9) , and corrected to Antecedent Moisture Conditions (AMC) (Table 5) .

The Values of CCN are computed in WMS software by overlying the land use , soil types and sub watersheds coverages as per the procedure given by WMS software - tutorial (2008) .

Table 5: CN –Values for three Antecedent Moisture Conditions (AMC) .

Land use		CN of soil types at three AMC											
		A			**B**			**C**			**D**		
Code	Description	Dry	Norm.	Wet	Dry	Norm.	Wet	Dry	Norm.	Wet	Dry	Norm.	Wet
77	Mixed Barren Land	57.1	76	87.9	70.4	85	92.8	77.3	89	94.9	80.9	91	95.8
74	Bare Exposed Rock	98	98	98	98	98	98	98	98	98	98	98	98
21	Cropland and Pasture	51.9	72	85.5	64.1	81	90.7	75.5	88	94.4	80.9	91	95.8
42	Evergreen Forest Land	15.2	30	49.6	33.9	55	73.7	49.5	70	84.3	58.4	77	88.5
33	Mixed Range Land	21.2	39	59.5	39.6	61	78.2	54.4	74	86.7	62.6	80	90.1
16	Mixed Urban or Built-Up Land	58.4	77	88.5	70.4	85	92.8	79.0	90	95.3	82.8	92	96.3
24	Other Agricultural Land	54.4	74	86.7	67.2	83	91.8	75.4	88	94.4	79.1	90	95.3
53	Reservoirs	44.9	66	81.7	54.4	74	86.7	62.6	80	90.2	65.7	82	91.3
51	Streams and Valleys	51.9	72	85.5	65.7	82	91.3	73.7	87	93.8	77.3	89	94.9
14	Transportation	67.2	83	91.8	62.6	80	90.2	82.8	92	96.4	84.8	93	96.8

- SCS Dimensionless unit hydrograph .

The input data for the Soil Conservation Service (SCS) dimensionless unit hydrograph method (1972) , consists of a single parameter i.e lag time (T_{lag}) , which is equal to the lag (hours) between the center of mass of rainfall excess and the peak of the unit hydrograph . Lag time is computed

GeoTunis

using SCS method based on length , slope of the stream , curve number and watershed area , by the following equation (WMS , 2008) .

$$T_{lag} = L^{0.8}(\frac{1000}{CN}) - 10)^{0.7} / 1900 \times \sqrt{Y}$$

where T_{lag} is equal to the lag time (in hours) between the center of mass of rainfall excess and the peak of the unit hydrograph , *L* is the watershed length in ft , CN is the curve number (dimensionless) and *Y* is the watershed slope in percent (HEC, 1998) .

-Simulation of HEC-1 model .

The SCS curve number method and the Hydrologic Engineering Center "HEC-1" model , used to compute surface runoff components i.e. volume of peak flow (m^3) , time to peak flow (minutes) and peak flow (m^3/s) , based on rainfall , hydrologic soil groups, land use classes and lag time .

The HEC-1 Model and SCS curve number method simulates the behavior of a watershed by carrying out water balances for each element of matrix of land covers and sub areas of a watershed and then routing the resulting runoff between sub areas . The Peak flow and time to peak values are computed as:

$$T_{peak} = 0.5 \times \Delta t + T_{lag} \quad \text{.................................(1)}$$

$$Q_{peak} = \frac{484 \times Area}{T_{peak}} \quad \text{...(2)}$$

$$\Delta t = 0.2 \times T_{peak} \quad \text{...(3)}$$

where T_{peak} is the time to peak of unit hydrograph in hours , Δt is the duration of excess in hours , Q_{peak} is the peak flow of unit hydrograph in m^3/s , and *Area* is the sub-basin area in square kilometer . The unit hydrograph is interpolated for the specified computation interval and computed peak flow from the dimensionless unit hydrograph shown in figure no. 4 (SCS , 1972 , Chapters 15, 16 ; HEC, 1998 ; USDA , 2007 , Chapter 16) .

To estimate the surface runoff components i.e. volume of peak flow , time to peak flow and peak flow , for all the 34 sub basins , for three average daily storms for dry, normal and wet conditions of antecedent moisture conditions (AMC) are presented in table no.5 .To execute the HEC-1 simulation, all the important computed parameters for basin characteristics i.e. basin data , SCS – CN losses method , unit hydrograph and the routing data of Muskingum – Cunge (RD) method are assigned for each of the sub basin of Kandukuru Vagu basin and the computed values of volume of peak flow (volume of surface runoff) , time to peak flow and rate of peak flow for all the 34 sub basins for the three average daily rainfall storms i.e. dry , normal , wet conditions (AMC) are presented in tables nos. 6,7 and 8 . Figure no. 5 show the graphical presentation of the sub basins , routing and outlets SCS dimensionless unit hydrographs in Kandukuru Vagu basin .

GeoTuts

Fig. 4 : SCS –Dimensionless unit hydrograph .

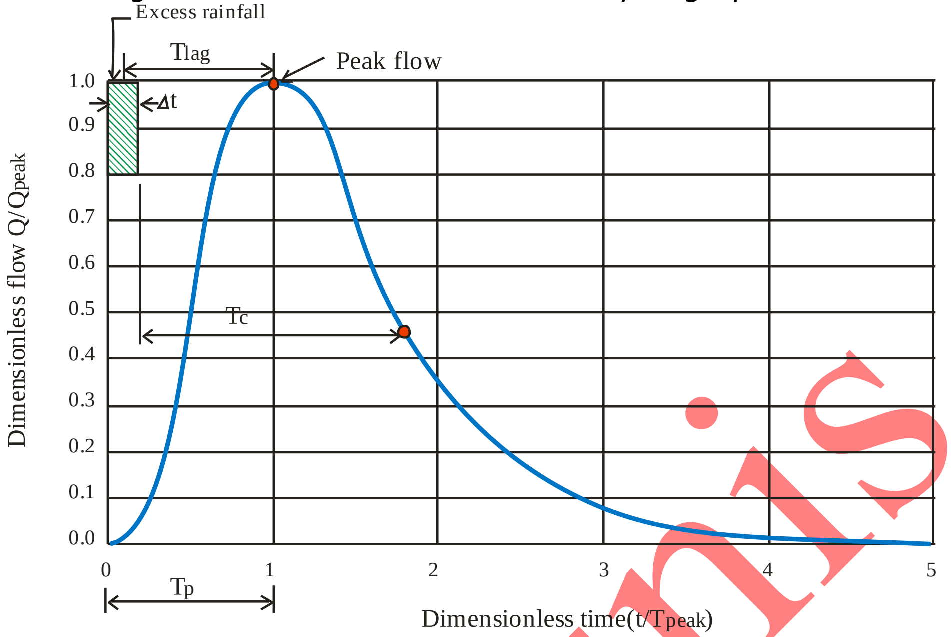
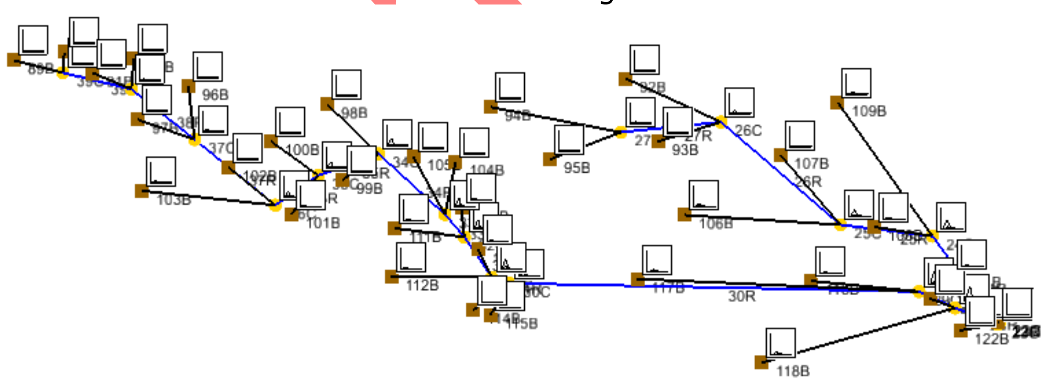


Fig. 5 : Flow chart of basins , routings , outlets and hydrographs in Kandukuru Vagu basin.



2.2 Evapotranspiration .

The Evapotranspiration computed using Landsat ETM+ image by Surface Energy Balance Algorithm for Land (SEBAL) method as mentioned in Faris and Sudhakar Reddy (2008) , and presented in table no.9.

2.3 Infiltration .

The infiltration amounts are calculated from the following water balance equation and presented in table no. 10.

$I = P - Qs - ET - ds$

Where I is the infiltration , Qs is surface runoff , P is precipitation , ET is evapotranspiration and ds is depression storage .

3 Results and Discussion .

The results of application HEC-1 model of WMS packages , shows the spatial and temporal domain variations in the volume of runoff (m^3), peak runoff time(min) , value of peak runoff (m^3/s) and runoff coefficients .

The surface runoff in Kandukuru Vagu basin was analyzed for all the 34 sub basins , for three average daily rainfall storms at different dates and antecedent moisture conditions (Tables 6,7,8) .

The rainfall storm event dated 23rd September 2003 belong to dry conditions (AMC-I) . The results of hydrological modeling (Table 6) , shows that , the values of curve number ranged between 65 to 89 , and the values of runoff coefficient varied from zero where no surface runoff to 0.37 in the area of relatively high surface runoff . The rainfall storm between 18 -30 mm and recorder at different rain gauge stations , are not adequate to occur surface runoff in some area of kundukuru Vagu basin because the rainfall depth is not sufficient to overcome the initial abstraction . The spatial distribution of runoff coefficient (Fig. 6a) shows most of the sub basins having runoff coefficients between zero to 0.1 except some sub basins located at upstream and downstream areas associated with steep slopes or covered by rock out crops .

The results of runoff estimation from normal conditions(AMC-II) of rainfall storm dated 29th July 2004 (Table 7) , gives more details about the nature of runoff in Kundukuru Vagu basin. Shows a correlation between CN and runoff coefficient . The high values of CN ranged from 80.5 to 93 , shows high values of runoff coefficients ranging from 0.18 to 0.62 , that means the rainfall depth of about 35 millimeters per day is sufficient to overcome the initial abstraction values over all the area of the Kundukuru Vagu basin . The Spatial distribution of runoff coefficients (Fig. 6b) , shows relatively low runoff coefficients for the sub basins located along the main valleys in Kundukuru Vagu basin , due to dense vegetation cover and the presence of high permeable soils.

To Understand the situation of runoff in the case of wet conditions (AMC-III) . The runoff parameters were analyzed (Table 8) , shows that , the general increase in the CN values from 89.4 to 96.17 , lead to increase in the runoff coefficients ranged from 0.66 to 0.86 . The rise in runoff coefficients insure the effect of wet conditions in the preceding period of the analyzed storm which is reached about 58 mm on the runoff , because the saturated soil reduce the infiltration and storage capacity of the soil and lead to increase in the runoff , beside that the high values of rainfall depth about 81 millimeters per day also increased the runoff volumes .The spatial distribution of runoff coefficients(Fig. 6c) , shows some sub basins still having relatively low runoff coefficients , at the area of dense vegetation cover , because the dense roots and the presence of organic matter in the soil increase the porosity and permeability of the soil and so lead to increasing the infiltration among the runoff volumes .

GeoTurns

Table 6 : Rainfall- Runoff data for the storm event at 23rd September 2003

Sub-basin id	B. Area .(km2)	B. slope.	B .Length (m)	Lag Time (hr)	CCN (Curve Number)	Rainfall depth (mm)	Runoff (m^3)	Peak time (min)	Runoff peak(m3/s)	Rainfall (m^3)	Runoff Coefficient
109B	21.7	0.02	8790.8	3.08	73.6	30.4	30810.9	445	1.98	658527.8	0.047
118B	23.8	0.02	12217.2	3.95	75.4	24.0	14523.6	500	0.75	571160.0	0.025
106B	22.9	0.03	9287.7	2.19	75.4	24.0	13832.1	400	1.24	549226.9	0.025
122B	1.2	0.01	2082.8	0.74	89.7	30.4	13626.6	310	1.35	36881.3	0.369
107B	6.2	0.02	5244.9	1.84	75.3	30.4	11959.5	375	1.17	188619.8	0.063
97B	5.6	0.04	4183.4	0.94	81.8	22.5	10289.4	325	1.45	125246.2	0.082
112B	9.4	0.04	6046.7	1.17	81.9	19.6	10077.9	340	1.37	184842.4	0.055
116B	4.8	0.02	5559.8	1.86	75.3	30.0	8929.8	375	0.87	144665.4	0.062
89B	5.5	0.05	3136.4	0.80	79.9	22.5	6981.6	320	1.14	122634.0	0.057
108B	6.8	0.02	4022.5	1.52	70.7	30.4	5175.6	365	0.63	205364.2	0.025
121B	3.9	0.01	3378.3	1.54	72.2	30.4	4290.9	360	0.51	119262.2	0.036
101B	2.4	0.05	2619.6	0.55	80.2	22.5	3339.9	310	0.62	54857.3	0.061
98B	6.1	0.05	4191.4	0.83	76.3	22.5	3248.4	325	0.62	138064.5	0.024
103B	16.9	0.04	8335.7	1.75	73.6	22.5	3171.3	385	0.36	380902.5	0.008
119B	0.8	0.02	1471.2	0.74	79.9	30.4	3132.0	315	0.43	24870.2	0.126
91B	3.5	0.04	2359.3	0.62	77.9	22.5	2913.9	315	0.59	79319.3	0.037
92B	10.8	0.02	6249.6	2.23	70.9	25.5	2133.9	410	0.19	276183.3	0.008
96B	3.0	0.07	3296.9	0.58	76.7	22.5	1776.6	315	0.40	68364.0	0.026
117B	19.7	0.03	13623.6	3.12	73.6	20.8	1389.6	465	0.09	408796.1	0.003
88B	0.5	0.05	1106.3	0.29	84.8	22.5	1386.9	300	0.22	10327.5	0.134
111B	3.3	0.03	4104.7	1.12	77.7	20.1	1314.3	345	0.21	66959.3	0.020
105B	6.2	0.04	3717.2	0.99	75.0	21.3	1298.7	340	0.24	131581.8	0.010
90B	1.1	0.05	1740.3	0.52	79.2	22.5	1237.8	310	0.25	25312.5	0.049
110B	1.5	0.05	2117.3	0.51	81.2	18.4	1029.3	310	0.23	28118.9	0.037
93B	3.1	0.02	3364.8	1.15	72.1	24.8	797.4	350	0.13	77224.5	0.010
99B	3.5	0.03	2912.5	0.88	73.8	22.5	750.3	335	0.15	79218.0	0.009
114B	1.0	0.04	2255.0	0.70	79.4	18.4	367.5	320	0.08	17917.9	0.021
113B	1.2	0.03	1689.6	0.59	74.4	18.4	9.3	320	0.00	21594.2	0.000
102B	2.9	0.12	3229.4	0.53	65.0	22.5	0.0	0	0.00	65529.0	0.000
100B	4.8	0.09	3332.6	0.62	67.6	22.5	0.0	0	0.00	107406.0	0.000
94B	9.2	0.05	7695.9	1.43	72.4	18.6	0.0	0	0.00	170017.0	0.000
104B	1.6	0.06	2695.3	0.55	70.5	18.4	0.0	0	0.00	30056.4	0.000
115B	1.2	0.03	2140.3	0.63	69.4	18.4	0.0	0	0.00	22852.8	0.000
95B	3.5	0.05	4413.2	1.01	73.4	18.4	0.0	0	0.00	64633.7	0.000

Table 7: Runoff rainfall of the storm at 29th July 2004.

Sub-basin id	Lag Time (hr)	CCN (Curve Number)	Rainfall depth (mm)	Runoff (m^3)	Peak time (min)	Runoff peak(m3/s)	Rainfall (m^3)	Runoff Coefficient
109B	3.08	85.3	38.5	260704.2	415	15.0	833990.8	0.31
118B	3.95	86.2	35.2	257343.9	465	12.3	835470.4	0.31
106B	2.19	86.1	35.1	245442.3	370	17.7	805190.8	0.31
117B	3.12	85.3	33.4	175775.4	420	10.2	658414.9	0.27
103B	1.75	84.9	35.0	160432.2	350	13.3	592515.0	0.27
112B	1.17	89.5	33.0	121275.6	325	10.7	311705.9	0.39
92B	2.23	83.7	35.9	97589.7	375	7.2	388955.7	0.25
107B	1.84	86.0	38.5	78948.6	355	6.1	238877.1	0.33
97B	0.94	89.3	35.0	78750.3	315	7.3	194827.5	0.40
108B	1.52	83.9	38.5	72188.7	340	6.3	260082.9	0.28
94B	1.43	84.9	32.3	72124.5	340	6.7	295997.3	0.24
98B	0.83	86.9	35.0	70084.8	315	7.1	214767.0	0.33
89B	0.80	88.0	35.0	68679.3	310	6.8	190764.0	0.36
105B	0.99	86.0	34.2	61557.0	320	6.2	211364.7	0.29
116B	1.86	85.9	38.3	60160.8	355	4.7	184479.5	0.33
121B	1.54	85.0	38.5	45865.5	340	3.9	151039.3	0.30
91B	0.62	87.2	35.0	41291.1	305	4.3	123385.5	0.34
111B	1.12	87.6	33.4	36644.7	325	3.4	111004.0	0.33
100B	0.62	82.2	35.0	34802.1	310	4.3	167076.0	0.21
96B	0.58	86.9	35.0	34639.8	305	3.7	106344.0	0.33
99B	0.88	85.2	35.0	34219.5	315	3.6	123228.0	0.28
101B	0.55	88.7	35.0	32532.9	305	3.3	85333.5	0.38
95B	1.01	85.6	32.2	29697.6	320	3.1	113108.9	0.26
93B	1.15	84.6	35.6	29634.9	325	2.9	110752.7	0.27
122B	0.74	93.9	38.5	29142.6	305	2.3	46708.2	0.62
110B	0.51	89.4	32.2	18567.0	305	1.9	49208.0	0.38
102B	0.53	80.5	35.0	17790.0	305	2.4	101934.0	0.18
90B	0.52	88.3	35.0	14504.4	305	1.5	39375.0	0.37
119B	0.74	88.8	38.5	13190.4	310	1.2	31496.9	0.42
104B	0.55	84.1	32.2	11797.8	305	1.5	52598.7	0.22
114B	0.70	88.9	32.2	11254.2	310	1.1	31356.4	0.36
113B	0.59	85.9	32.2	10153.2	305	1.2	37789.9	0.27
115B	0.63	83.1	32.2	8112.9	310	1.0	39992.4	0.20
88B	0.29	90.9	35.0	7420.8	300	0.7	16065.0	0.46

GeoJuris

Table 8: Runoff rainfall of the storm at 10th July 2005 .

Sub-basin id	Lag Time (hr)	CCN (Curve Number)	Rainfall depth (mm)	Runoff (m^3)	Peak time (min)	Runoff peak(m3/s)	Rainfall (m^3)	Runoff Coefficient
118B	3.09	92.32	80.75	1424912.1	395	72.98	1918840.4	0.74
106B	2.19	92.25	80.77	1371678.6	350	82.45	1852144.9	0.74
109B	3.08	91.86	79.00	1239349.2	395	63.97	1711305.9	0.72
117B	3.12	91.83	81.65	1174506.9	395	60.08	1607638.2	0.73
103B	1.75	91.46	80.20	971916.9	335	63.58	1357705.8	0.72
92B	2.23	91.05	80.34	612536.7	355	37.12	869581.8	0.70
112B	1.17	93.77	81.70	608751.0	310	41.26	771789.9	0.79
94B	1.43	91.68	82.22	548232.3	320	37.40	753297.0	0.73
108B	1.52	91.29	79.00	377547.3	325	25.72	533676.6	0.71
98B	0.83	92.68	80.20	370060.2	305	26.62	492123.2	0.75
105B	0.99	92.08	80.83	368039.4	310	26.38	500231.6	0.74
107B	1.84	92.15	79.00	359220.9	335	22.95	490163.4	0.73
97B	0.94	93.69	80.20	349514.7	305	24.31	446433.3	0.78
89B	0.66	92.91	80.20	331743.3	300	24.03	437122.1	0.76
116B	1.86	92.02	79.10	277740.0	335	17.72	380855.4	0.73
100B	0.62	90.41	80.20	262561.5	300	20.26	382842.7	0.69
121B	1.54	91.84	79.00	224269.2	325	15.11	309924.9	0.72
95B	1.01	92.14	82.30	214315.2	310	15.27	289095.2	0.74
91B	0.62	92.60	80.20	211920.6	300	15.51	282729.1	0.75
111B	1.12	93.01	81.41	207023.1	310	14.34	270650.7	0.77
99B	0.88	91.60	80.20	203284.5	305	14.91	282368.2	0.72
96B	0.58	92.61	80.20	182725.8	300	13.42	243679.7	0.75
93B	1.15	91.52	80.54	180270.9	315	12.84	250880.9	0.72
102B	0.53	89.41	80.20	153713.4	300	12.25	233574.5	0.66
101B	0.55	93.32	80.20	150848.1	300	10.90	195535.6	0.77
110B	0.51	93.84	82.30	99636.3	300	7.09	125770.9	0.79
104B	0.55	91.37	82.30	96674.4	300	7.30	134437.0	0.72
122B	0.74	96.17	79.00	82542.0	300	5.46	95842.8	0.86
113B	0.59	92.17	82.30	71687.4	300	5.29	96587.3	0.74
115B	0.63	90.68	82.30	71512.5	300	5.45	102216.6	0.70
90B	0.52	93.34	80.20	69660.0	300	5.04	90225.0	0.77
114B	0.70	93.63	82.30	62974.5	300	4.45	80143.7	0.79
119B	0.74	93.69	79.00	50418.9	305	3.57	64629.9	0.78
88B	0.29	94.45	80.20	29701.2	295	2.11	36811.8	0.81

The daily evapotraspiration for the 34 sub basins of kandukuru Vagu basin estimated using Landsat ETM+ image by Service Energy Balance Algorithm of Land (SEBAL) method (Table 9) .These values are more accurate spatially representative for the sub basins and help in calculation of volume of Evapotranspiration at each sub basin . from the figure no. 7 , it is noticed that the values of average Evapotranspiration increased in sub basins where the vegetation cover and water bodies area increased (Faris and Sudhakar Reddy , 2008) .

Table 9 : Daily evapotranspiration values in Kundukuru Vagu basin .

Sub-basin id	Sub-Basin Area (km^2)	Evapotranspieration (mm/day)	Evapotranspiration -Volume (m^3)
88B	0.5	3.59	1647.81
89B	5.5	4.05	22074.12
90B	1.1	4.32	4860.00
91B	3.5	4.18	14735.75
92B	10.8	4.48	48488.83
93B	3.1	4.29	13362.92
94B	9.2	4.53	41503.86
95B	3.5	4.50	15807.15
96B	3.0	4.38	13308.19
97B	5.6	4.02	22377.33
98B	6.1	4.22	25894.76
99B	3.5	4.48	15773.18
100B	4.8	4.76	22722.34
101B	2.4	4.15	10118.12
102B	2.9	5.33	15523.09
103B	16.9	4.68	79227.72
104B	1.6	5.02	8200.17
105B	6.2	4.35	26919.54
106B	22.9	3.79	86905.46
107B	6.2	3.69	22894.97
108B	6.8	3.70	24994.98
109B	21.7	4.49	97262.83
110B	1.5	3.98	6082.24
111B	3.3	4.10	13630.86
112B	9.4	4.13	39013.63
113B	1.2	4.15	4870.44
114B	1.0	4.29	4177.60
115B	1.2	5.15	6396.30
116B	4.8	3.78	18200.70
117B	19.7	4.19	82498.17
118B	23.8	4.01	95288.43
119B	0.8	4.35	3558.74
121B	3.9	4.24	16633.94
122B	1.2	3.43	4161.28

The results of infiltration calculated from water balance equation (Table 10) , shows the infiltration coefficients are correlated to runoff coefficients and effected by the moisture conditions of the soil .

The infiltration ratios for the rainfall event dated 23rd September , 2003 , shows high infiltration coefficients ranged between 0.52 to 0.85 , that is due to the dry conditions of the soil and the rainfall depth not overcome the infiltration capacity of the soil in most of the sub basins (Fig. 8a).

For the normal conditions the infiltration coefficients resulted from the storm dated 29th July 2004 are relatively less than the dry conditions ranged between 0.287 to 0.673 (Fig. 8b) .

GeoTuris

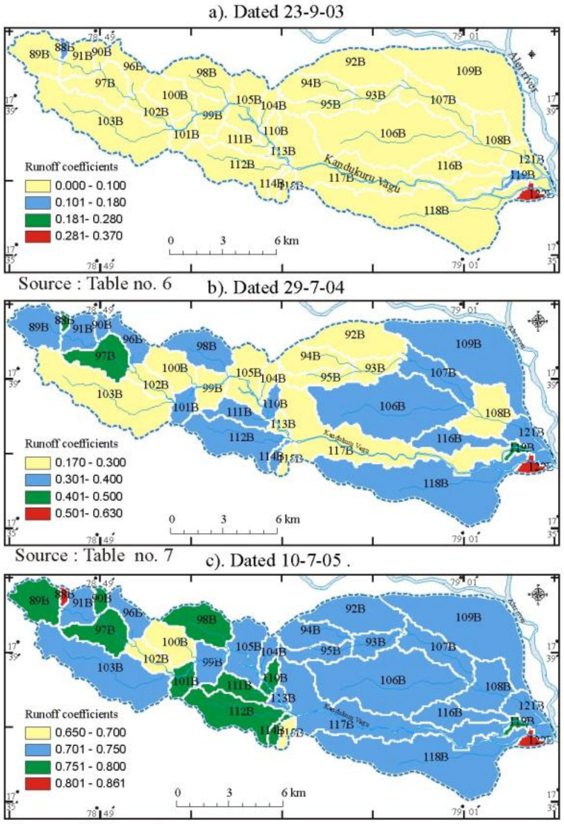
In the wet conditions all the sub basins shows low values of infiltration coefficients , because the wet conditions of soil , reduces the infiltration capacity of the soil .(Fig. 8c)

Table 10 : Infiltration data for three storms .

Sub-basin id	Sub-Basin Area .(km^2)	Date 23-9-03		Date 29-7-04		Date 10-7-05	
		Infiltration volume (m^3)	Infiltration Coefficient	Infiltration volume (m^3)	Infiltration Coefficient	Infiltration volume (m^3)	Infiltration Coefficient
89B	5.5	93578.3	0.76	100023.1	0.524	83304.7	0.19
103B	16.9	298503.5	0.78	352777.2	0.595	306561.2	0.23
91B	3.5	61669.6	0.78	67373.8	0.546	56072.7	0.20
97B	5.6	92579.5	0.74	93707.1	0.481	74541.3	0.17
88B	0.5	7292.8	0.71	6995.3	0.435	5462.8	0.15
90B	1.1	19214.7	0.76	20005.4	0.508	15705.0	0.17
96B	3.0	53279.2	0.78	58407.6	0.549	47645.7	0.20
102B	2.9	50005.9	0.76	68624.4	0.673	64338.0	0.28
100B	4.8	84683.7	0.79	109564.5	0.656	97558.9	0.26
98B	6.1	108921.3	0.79	118791.7	0.553	96168.2	0.20
101B	2.4	41399.3	0.76	42691.5	0.500	34569.4	0.18
112B	9.4	135750.9	0.73	151389.3	0.486	124025.3	0.16
99B	3.5	62694.5	0.79	73245.2	0.594	63310.5	0.22
111B	3.3	52014.1	0.78	60721.1	0.547	49996.7	0.19
94B	9.2	128513.1	0.76	182348.8	0.616	163560.8	0.22
105B	6.2	103363.6	0.79	122898.7	0.581	105272.7	0.21
104B	1.6	21856.2	0.73	32600.4	0.620	29562.4	0.22
110B	1.5	21007.4	0.75	24552.8	0.499	20052.4	0.16
113B	1.2	16714.5	0.77	22765.6	0.602	20029.5	0.21
114B	1.0	13372.8	0.75	15927.1	0.508	12991.6	0.16
115B	1.2	16456.5	0.72	25487.8	0.637	24307.8	0.24
117B	19.7	324908.3	0.80	400094.1	0.608	350633.1	0.22
95B	3.5	48826.5	0.76	67608.4	0.598	58972.9	0.20
92B	10.8	225560.6	0.82	242891.2	0.624	208556.3	0.24
106B	22.9	448489.3	0.82	472907.2	0.587	393560.8	0.21
118B	23.8	461348.0	0.81	482738.3	0.578	398639.9	0.21
93B	3.1	63064.2	0.82	67770.1	0.612	57247.1	0.23
109B	21.7	530454.1	0.81	475958.8	0.571	374693.9	0.22
107B	6.2	153765.3	0.82	137020.5	0.574	108047.5	0.22
116B	4.8	117534.9	0.81	106139.2	0.575	84914.7	0.22
108B	6.8	175193.6	0.85	162926.9	0.626	131134.3	0.25
121B	3.9	98337.4	0.83	88541.4	0.586	69021.8	0.22
119B	0.8	18179.5	0.73	14745.4	0.468	10652.3	0.17
122B	1.2	19093.4	0.52	13402.6	0.287	9139.5	0.10

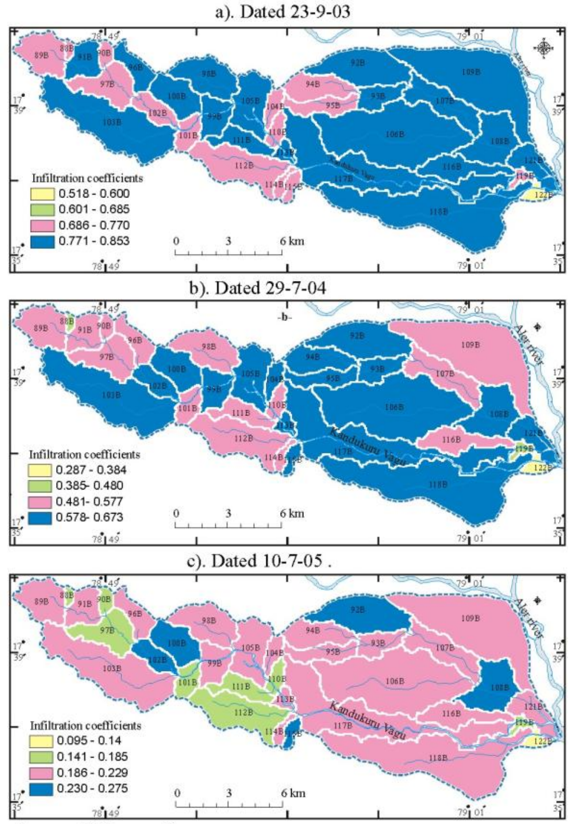
GeoLinks

Fig.6 : Runoff coefficients resulted from three rainfall storm events -Kandukuru vagu basin.



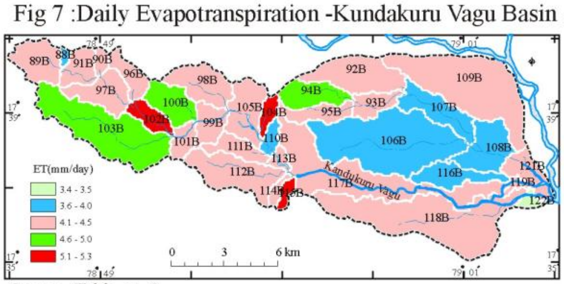
Source : Table no. 8

Fig. 8 : Infiltration coefficients resulted from three rainfall storm events -Kandukuru vagu basin.



Source : Table no. 10

Fig 7 :Daily Evapotranspiration -Kundakuru Vagu Basin .



Source :Table no. 9 .

4 Conclusions

The estimation of runoff by HEC-1 model and SCS curve number method , give more accurate and representative spatially distribution of runoff volumes for all the 34 sub basins of Kandukuru Vagu basin However the variation in runoff volumes for all the three rainfall storms events , is due to the change in the soil types , land use/land cover , slopes, area , rainfall amounts and antecedent moisture conditions (AMC) effects in the sub watersheds .

The variation in daily ET estimated spatially pixel wise by SEBAL method shows the effect of variation in the vegetation cover and water bodies across the Kandukuru Vagu basin.

The analysis of rainfall-runoff , evapotranspiration and infiltration of hydrological model of Kandukuru Vagu basin helps in the location of recharge and discharge areas and in turn locations of ground water potential zones .

Acknowledgements

The first author is thankful to ICCR , Gov. of India for providing financial assistance , dept. of Geology , UCS, Osmania University , Hyderabad for providing the laboratory facilities and staff of Groundwater department-Nalgonda district for their cooperation in supplying of the necessary maps and meteorological data .

References

1. Anbazhagan , S. , S.M. Ramasamy and S. Das Gupta , 2005 . Remote Sensing and GIS for artificial Recharge Study , Runoff estimation and Planning in Ayyar basin , Tamil Nadu , India , Environmental Geology , Int. J. of Geosciences , Springer-Verlay , online publication .
2. Araya , B. M.and Rabi H. Mohtar , 2006 . Detention Pond and Peak Runoff Analysis Using HEC-1 , ABE 527 , Computer Models in Environmental and National Resources Engineering , Purdue University .
3. Faris , Ayad Ali and Y.Sudhakar Reddy, 2008 . Estimation of Evapotranspiration from ETM+ Imagery using SEBAL Method , A Case Study : Kandukuru Vagu Basin , Nalgonda District,A.P., India , Accepted in XXXVIII INCA International Congress on Collaborative Mapping and Space Technology , Gandhinagar , Gujarat , November 4-6 .
4. HEC , 1998 . HEC-1 Flood Hydrograph Package –User's Manual , Version 4.1 , US Army Corps of Engineers , Hydrologic Engineering Center .
5. Ligang , XU , Qi. Zhang , Heng peng Li., Neil R. Viney , Jintao XU and Jia Liu , 2007 . Modeling of Surface Runoff in Xitiaoxi catchment , China , Water Resource Management , 21 , pp 1313 -1323 .
6. Nayak, T. R. and R. K. Jaiswal , 2003 . Rainfall –Runoff Modeling using Satellite Data and GIS for Bebas River in Madhya Pradesh .
7. Soil Conservation Service(SCS) , (1972) 'National Engineering Handbook', Section 4. U.S. Department of Agricultural. Washington, D.C..
8. Sharma , K.D. and Surendra Singh , 1992 . Runoff Estimation Using Landsat Thematic Mapper data and SCS Method , Hydrological Sciences – Journal –des Scoences Hydrologiques , 37 , 1 , Feb. pp 39 – 52 .
9. U.S. Department of Agriculture, Natural Resources Conservation Service. 2004. Estimation of Direct Runoff from Storm Rainfall , National Engineering Handbook, part 630, chapter 10 ,Washington, DC.
10. U.S. Department of Agriculture, Natural Resources Conservation Service. 1993. Soil Survey Manual , Agricultural Handbook No. 18, chapter 3. U.S. Government Printing Office, Washington, DC.
11. U.S. Department of Agriculture, Natural Resources Conservation Service. 2004. Soil Cover Complexes , National Engineering Handbook, Part 630 Hydrology, chapters 9 . U.S. Government Printing Office, Washington, DC.

GeoGulfs

12. U.S. Department of Agriculture, Natural Resources Conservation Service. 2007. Hydrologic Soil Groups , National Engineering Handbook, Part 630 Hydrology, chapters 7 . U.S. Government Printing Office, Washington, DC.
13. U.S. Department of Agriculture, Natural Resources Conservation Service. 2002. Land use and Treatment Classes , National Engineering Handbook, Part 630 Hydrology, chapters 8 . U.S. Government Printing Office, Washington, DC.
14. WebGIS , creating Land use Table for Curve Number Calculation within WMS software , Available on online at : http://www.emrl.byu.edu/gsda/data_tips/tip_landuse_table.html
15. Weizhe , A. , 2007 . The study of GIS –Based Hydrological Model in Highway Environmental Assessment , Ph.D. Thesis , University of Pittsburgh .
16. WMS , 2008 .Tutorials of Watershed Modeling System V 8.1, Environmental Modeling Research Laboratory of Brigham Young University, Utah. U.S.
17. WMS Watershed Modeling System V 8.1 , 2008 : Reference Manual', Environmental Modeling Research Laboratory of Brigham Young University, Utah. U.S.
18. WRCE , 1999 . Hydrological Criteria and drainage Design Manual , Section 600 , Storm Runoff , pp. 603 -639

GeoTutors