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Distributed Hydrological Model for an Ungauged Subcatchment Msa5 in Andhra Pradesh, India

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ABSTRACT

Rainfall and runoff producing mechanisms are not only stochastic but are also spatially variable. But unfortunately, many hydrological models do not account for this spatial variability of watersheds and instead use lumped or spatially averaged parameters. Recent advances in Geographic Information Systems have made it possible to account for this spatial variability of hydrological parameters, thus enabling the invention and application of distributed models which are superior to the conventional approaches. The major problem in the assessment of relationships between rainfall and runoff occurs when a study is carried out in ungauged subcatchments in the absence of observed stream flow data. This study aims to evaluate the applicability of Natural Resources Conservation Service-Curve Number (NRCS-CN) method together with GIS in estimating the runoff in an ungauged subcatchments. The study was carried out in the semi-arid Msa5 subcatchments of Musi river which lies within the geographical coordinates of 15°33' and 15°46' North latitudes and 79° 17' and 79°33' East longitudes in the state of Andhra Pradesh, India. The land use/land cover, soils, hydrologic soil groups and curve number maps were prepared using standard GIS techniques. Runoff was computed for a selected rainfall event using NRCS-CN equations and was mapped using GIS. The study ultimately leads to the development of a distributed hydrological model referred to as NRCS-CN-GIS model. Depending up on the accuracy of the results obtained, it can be suggested to apply the model to other subcatchments in the region.

Keywords: *Rainfall-runoff modeling, Ungauged subcatchments, Distributed hydrological models, Geographic Information Systems and NRCS-CN-GIS Model.*

1. INTRODUCTION

Water is vital for the survival of human as well as plant and animal life. While the world population is growing at an alarming rate, the rainfall on the land is more or less constant. To meet the increasing water needs, man has therefore to find out ways and means of utilizing the water which runs off from the land to the fullest extent. It is a curious and surprising fact that the exploding population has its future delicately poised on the mere 44,700 Cubic km of water which returns to the Oceans as runoff. Obviously, methods of assessing hydrological conditions and planning of water control and utilization projects that were satisfactory hitherto in good old days will no more be adequate to meet the present situation leaving alone the future requirements. Thus in a world of decreasing choices, decisions must be more sharply taken as cheap water is no longer abundant everywhere, consequently, projects for the control and use of water are now problems of national or even international concern.

For the design of various water resources structures, information must be known about the hydrology of the catchment areas such as peak discharge, runoff volume, and the time to peak of large storm events. Many design applications including dams and reservoirs, weirs and barrages, spillways, aqueducts and siphon aqueducts, super passages and canal syphons, level crossings, inlets, outlets and urban stormwater systems depend on this information. Hydrological processes which control the rainfall-runoff phenomenon must be investigated to accurately predict the peak discharge, runoff volume, and time to peak of design storms.

1.1 Review of Literature

Rainfall-runoff modeling began in the latter half of the 19th century. These first generation models were based on empirical equations developed under unique conditions and used in applications with similar conditions. These models predict peak discharge and time to peak. Mulvaney in 1851 used the "rational method" to predict runoff peaks. Early in the 20th century, hydrologists tried to improve the applicability of the rational method to large catchments with heterogeneity in rainfall and catchment characteristics. Sherman [6] introduced the "unitgraph" or unit hydrograph technique using the principle of superposition in 1932. This concept dominated hydrology for more than twenty-five years and is still in widespread use today. It was one of the first attempts to predict an entire hydrograph instead of just the peak flow and time to peak. Many researchers followed with increasingly complex models to improve the unit hydrograph shape. Although these techniques produced mathematically correct hydrographs, Todini [8] states that their connections with the "real world" were lost.

The 1960s brought the introduction of computers into hydrological modeling. The first comprehensive hydrological computer model, the Stanford Watershed Model, was developed at Stanford University. In the late 1960s, HEC-1, a conceptual predictive model, was developed by the Hydrological Engineering Center, U. S. Army Corps of Engineers. Real-time forecasting rainfall-runoff models were developed in the late 1970s and 1980s in response to the need of warnings in flood prone areas.

Due to limitations in the amount of available data and computing power, these physically based parameters were aggregated or lumped together, thus greatly decreasing the amount of data to be processed. These models with aggregated parameters are termed as *lumped parameter models*.

The development of Geographic Information Systems and increase in computing power of the 1980's and 1990's has enabled development of more precise models that can handle complexities in the systems analysis. Parameters no longer need to be lumped together because of computing limitations. *Distributed parameter models* are capable of incorporating information about the spatial variability of soils, land use, topography, or any other parameter in the modelling scenario. The availability of geographic information systems aids in managing the large amounts of data required for distributed parameter models. The development of Geographic Information Systems (GIS) has vastly increased the quality and availability of data required for hydrological modeling in the form of digitized topographic maps. GIS software can be combined with digital data such as land use and land cover, soil type and digital elevation models (DEMs) to create distributed hydrological models. Distributed models commonly have a grid matrix with each grid cell containing a set of parameter values.

Due to serious soil erosion and water deficiency in some areas of Andhra Pradesh, natural resources conservation has become a vital issue. Conventional methods of runoff measurement are costly, time consuming, error-prone and difficult because of inaccessible terrain in many of the watersheds. Thus the use of new tools like GIS to generate supporting land based data for conserving soil and water resources in watershed planning is very much needed. In addition, some basins in Andhra Pradesh do not have sufficient number of rain gauges to record rainfall. Scarcity of reliable recorded data has become a serious problem which planners and researchers face for the analysis of the hydrology of catchments.

There are several approaches to estimate runoff in ungauged catchments like the University of British Columbia Watershed Model (UBCWM), Artificial Neural Network (ANN), NRCS Curve Number (NRCS-CN) method and Geomorphological Instantaneous Unit Hydrograph (GIUH) method. Among these methods, the NRCS-CN method (previously called as Soil Conservation Service - Curve Number method (SCS-CN)) is widely used because of its flexibility and simplicity. The method combines the catchment parameters and climatic factors in one entity called the Curve Number (CN).

1.2 Objective of the Study

The objective of the present study is to develop and apply distributed hydrological model viz. “NRCS-CN-GIS MODEL” for the computation of direct runoff for a given precipitation for a selected subcatchmen

1.3 Scope and Limitations of the Study

The scope and limitations of the present study are given below.

1. To prepare Land use / Land cover mapping of the study area
2. To take up soil mapping and hydrological soil grouping of the study area
3. To prepare rainfall map for selected storms and AMC map of the study area
4. To generate curve number maps for the study area
5. To develop and apply NRCS-CN-GIS methodology for the computation of surface runoff for the selected storms in the study area
6. To obtain unit hydrograph (NRCS dimensionless parametric UH) for the study area

1.4 Significance of the Present Study

The study emphasizes the use of GIS technique to develop a database containing all the information of the study subcatchment for the estimation of direct runoff using the NRCS-CN-GIS model. Based on the accuracy of results obtained, the NRCS-CN-GIS method can be recommended for estimating runoff in other ungauged subcatchments of the region.

1.5 Study Area

Msa5 subcatchment on Musi river in Prakasam district of Andhra Pradesh state in India is taken as the study area for the development of NRCS-CN-GIS model. It lies within the geographical coordinates of $15^{o}33'$ and $15^{o}46'$ North latitudes and 79^{o} 17’ and $79^{o}33'$ East longitudes. The total area of the subcatchment is 466.25 sq km. The location map of the study area is shown in the following figure 1.1.

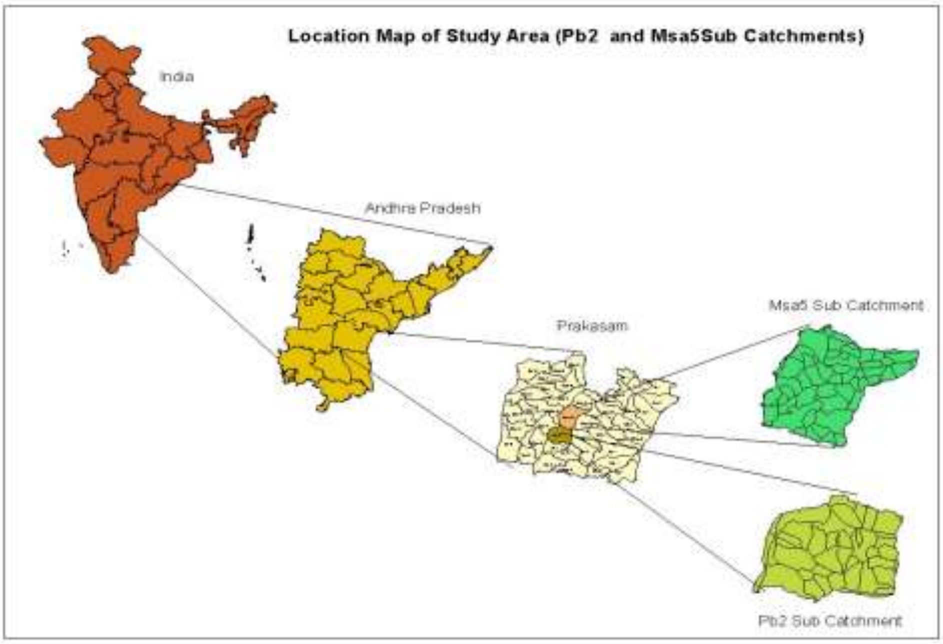


Figure 1.1. Location map of the study area

2. METHODOLOGY

The NRCS-CN methodology is generally applied for the computation of runoff for a given precipitation by considering lumped parameters required for the computation of runoff. In the present study, an attempt was made to integrate the NRCS-CN methodology with GIS to capture the spatial variation of catchment characteristics in terms of curve numbers to account for in the computation of runoff.

The main objective of the present study is to develop a suitable model for the evaluation of runoff over selected subcatchments. This work has been taken up in three phases.

Phase 1 consists of derivation of Digital Elevation Models for the study area from the base maps in order to exactly delineate the subcatchments of interest.

Phase 2 consists of studies relating to RS and GIS based thematic mapping carried out in connection with the development of land use / land cover maps and soil maps which are the required inputs for arriving at the hydrologic soil group map and curve number map of the study area.

Phase 3 is the linking of the above maps to the knowledge data base of curve number values available in literature and evaluating the runoff using NRCS-CN method for a selected storm.

This entire methodology of obtaining runoff for given rainfall event will be referred to as NRCS-CN-GIS model. Figure 2.1 shows the flow diagram of the NRCS-CN-GIS model.

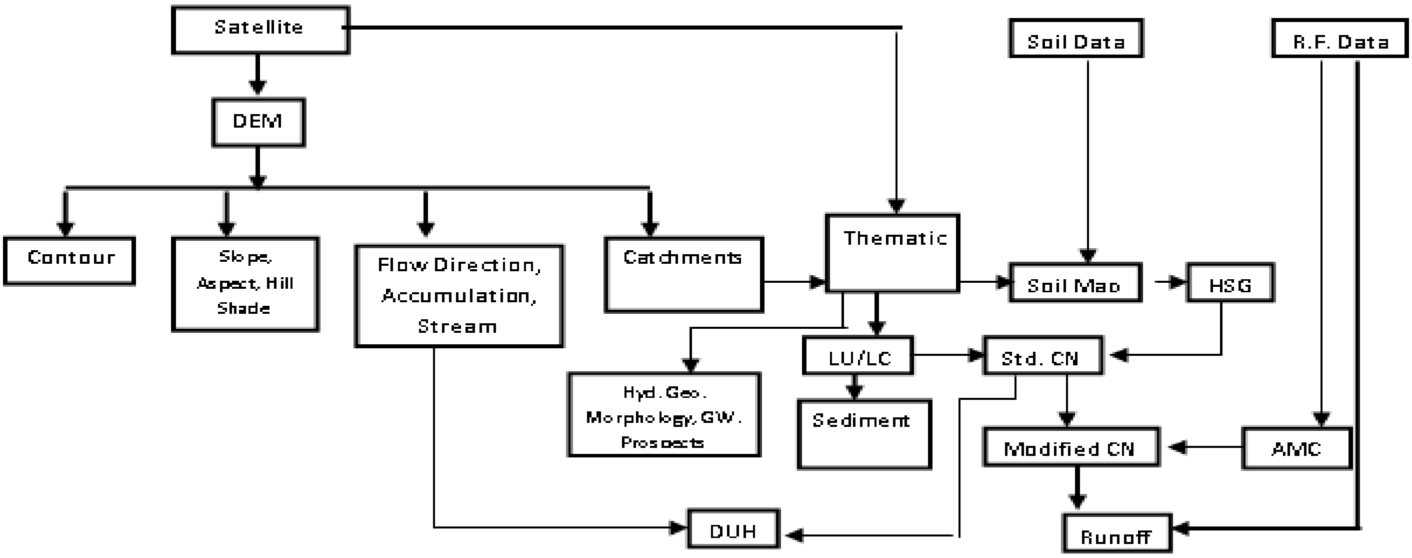


Figure 2.1. Flow diagram of the NRCS-CN-GIS model

3. NRCS-CN METHOD FOR RUNOFF COMPUTATION

The runoff is computed using the formula

$$Q = (P-I_a)^2 / [(P- I_a)+S] \qquad \ldots \qquad (1)$$

Where Q = The runoff depth in mm
P = Storm rainfall in mm
I_a = Initial Abstraction
S = Potential Maximum Retention

The potential maximum retention S can be computed using the following equation,

$$S = (25400/CN) - 254 \qquad \ldots \qquad (2)$$

To simplify equation (1) empirical relationship between the variables S and Ia was developed from data collected from various watersheds in USA. This empirical evidence resulted in the following equations.

$$I_a = 0.3\,S \quad \text{for AMC I} \qquad \ldots \qquad (3)$$
$$I_a = 0.2\,S \quad \text{for AMC II} \qquad \ldots \qquad (4)$$
$$I_a = 0.1S \quad \text{for AMC III} \qquad \ldots \qquad (5)$$

The runoff curve numbers for various hydrological cover complexes of NRCS-CN method are given in the following table 3.1.

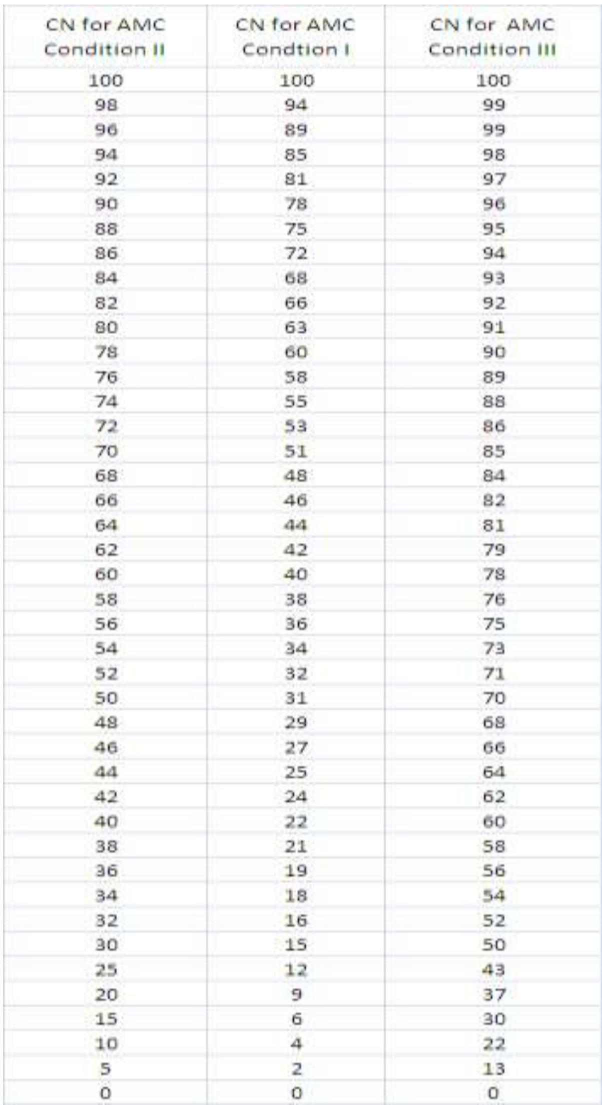
Runoff curve numbers for AMC group II and the corresponding curve numbers for AMC group I and III of NRCS-CN method are shown in Table 3.2. Grouping of Antecedent Moisture condition is given in Table 3.3. The curve numbers of Group I and Group II are related to each other by a curve linear relationship as shown in Figure 3.1. The curve numbers of Group III and Group II are related to each other by a curve linear relationship as shown in Figure 3.2.

Table 3.1. Runoff curve numbers for hydrologic soil cover complexes for AMC group II of NRCS-CN Method

Land use or cover	**Hydrologic Condition**	**Hydrologic Soil Grouping**			
		A	B	C	D
Fallow	Poor	77	86	91	94
Row Crops	Poor	72	81	88	91
	Good	67	78	85	89
	Poor	70	79	84	88
	Good	65	75	82	86
	Poor	66	74	80	82
	Good	62	71	78	81
Small Grain	Poor	65	76	84	88
	Good	63	75	83	87
	Poor	63	74	82	85
	Good	61	73	81	84
	Poor	61	72	79	82
	Good	59	70	78	81
Close seeded Legumes of rotation meadow	Poor	66	77	85	89
	Good	58	72	81	85
	Poor	64	75	83	85
	Good	55	69	78	83
	Poor	63	73	80	83
	Good	51	67	76	80
Pasture or range	Poor	68	79	86	89
	Fair	49	69	79	84
	Good	39	61	74	80
	Poor	47	67	81	88
	Fair	25	59	75	83
	Good	6	35	70	79

Meadow (Permanent)	Good	30	58	71	78
Wood Lands	Poor	45	66	77	83
	Fair	36	60	73	79
	Good	25	55	70	77
Farmsteads		59	74	82	86
Roads, dirt		72	82	87	89
Roads, hard-surface		74	84	90	92

Table 3.2. Runoff curve numbers for AMC group II and the corresponding curve numbers for AMC group I and III of NRCS-CN method.



CN for AMC Condition II	CN for AMC Condtion I	CN for AMC Condition III
100	100	100
98	94	99
96	89	99
94	85	98
92	81	97
90	78	96
88	75	95
86	72	94
84	68	93
82	66	92
80	63	91
78	60	90
76	58	89
74	55	88
72	53	86
70	51	85
68	48	84
66	46	82
64	44	81
62	42	79
60	40	78
58	38	76
56	36	75
54	34	73
52	32	71
50	31	70
48	29	68
46	27	66
44	25	64
42	24	62
40	22	60
38	21	58
36	19	56
34	18	54
32	16	52
30	15	50
25	12	43
20	9	37
15	6	30
10	4	22
5	2	13
0	0	0

Table 3.3. Grouping of Antecedent Moisture condition

AMC Group	Total 5 days antecedent rainfall			
	Dormant Season		Growing Season	
	inches	mm	inches	mm
I	<0.5	<12.7	<1.4	<35.56
II	0.5 to 1.1	12.7 to 27.94	1.4 to 2.1	35.56 to 53.34
III	>1.1	>27.94	>2.1	>53.34

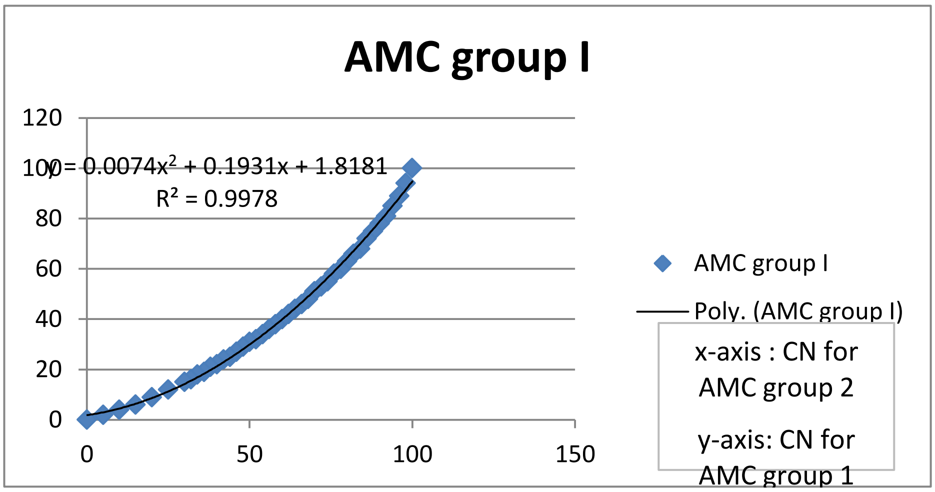


Figure 3.1. Curve Number for AMC group I

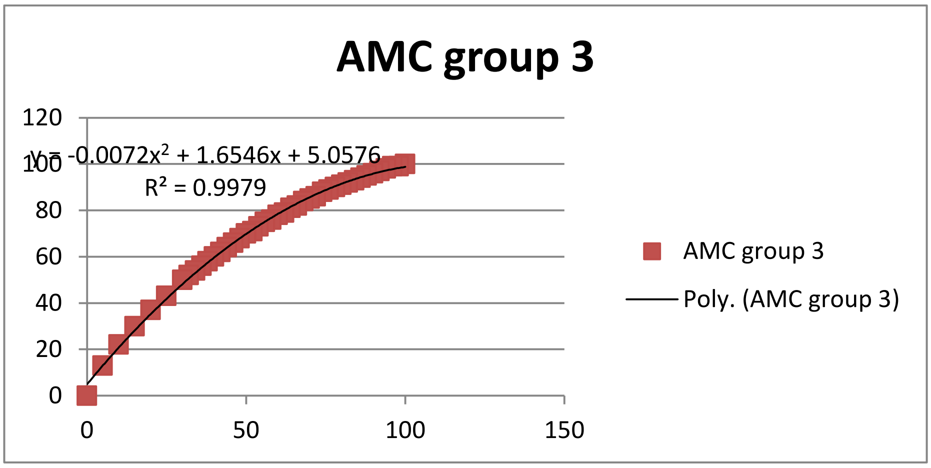


Figure 3.2. Curve Number for AMC group III

4. EXECUTION OF METHODOLOGY

SOI toposheets and Satellite imageries were used for demarcation of study area boundary, identification of types and areas of land use/land cover and extracting soil information etc. Rainfall data was obtained from CPO office of the district. Arc View 3.1 Spatial analyst extension, Basin 1 extension and ERDAS Imagine softwares were used for carrying out the GIS operations.

In order to develop NRCS-CN-GIS model, it is required to undertake thematic mapping of the study area. The themes required are land use/land cover and soil maps which form the basic inputs for the model.

4.1 Land use / Land cover Mapping

The land use/land cover map is prepared for the study area using satellite imagery and SOI toposheets followed by ground truth verification. Land use describes how a parcel of land is used such as for agriculture, industry, forestry, residential etc whereas land cover describes the materials such as vegetation, rocks, buildings etc that are present on the surface. The land use/ land cover map of the study area is given in the following figure 4.1.

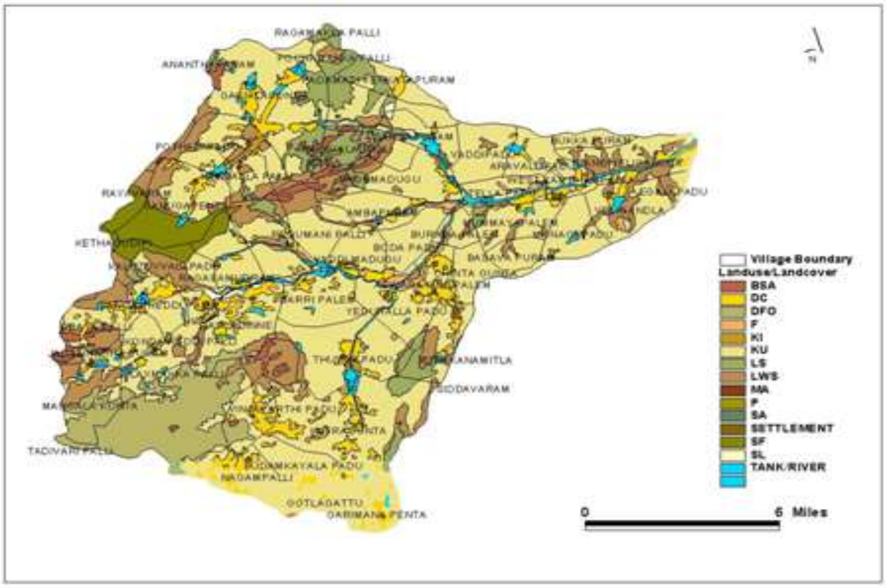


Figure 4.1. Land use/Land cover map of the sub-catchment Msa5

4.2 Soil Mapping

Soil mapping is an important phase in the hydrological analysis since it enables the hydrologists to arrive at the hydrological soil grouping of the study area which in turn helps in evaluation of curve numbers in the runoff computations. It involves interpretation of imagery by using image elements such as color, tone, texture, shape, size, pattern, location, association and correlating them with land features such as lithology, land form, vegetation cover and drainage which reflect variations in soils. The soil map of the subcatchment is shown in the following figure 4.2.

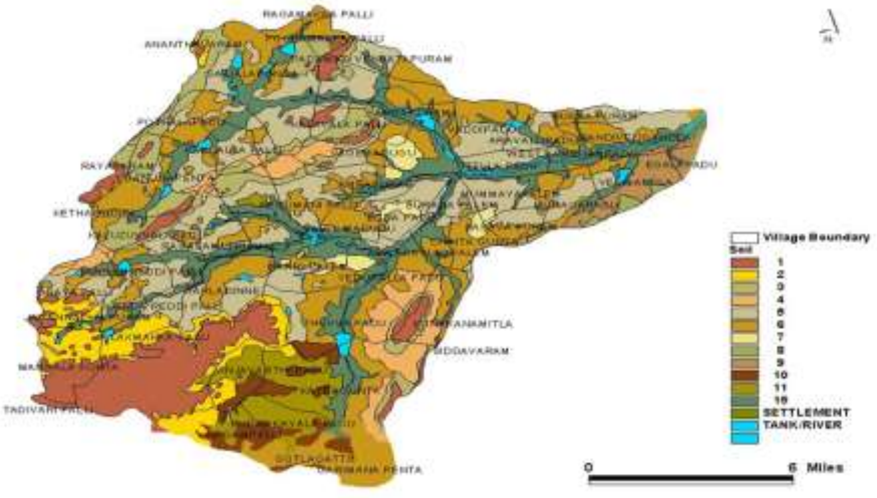


Figure 4.2. Soil map of the sub-catchment Msa5

4.3 Hydrological Soil Grouping

The hydrological soil grouping of the study area is carried out with the help of the data bank on soil series, their taxonomy, soil permeability and the hydrological soil grouping provided by NRCS. The generated map contains individual polygons of the characterized hydrologic soil groups. The hydrological soil grouping of the study area is shown in the following figure 4.3.

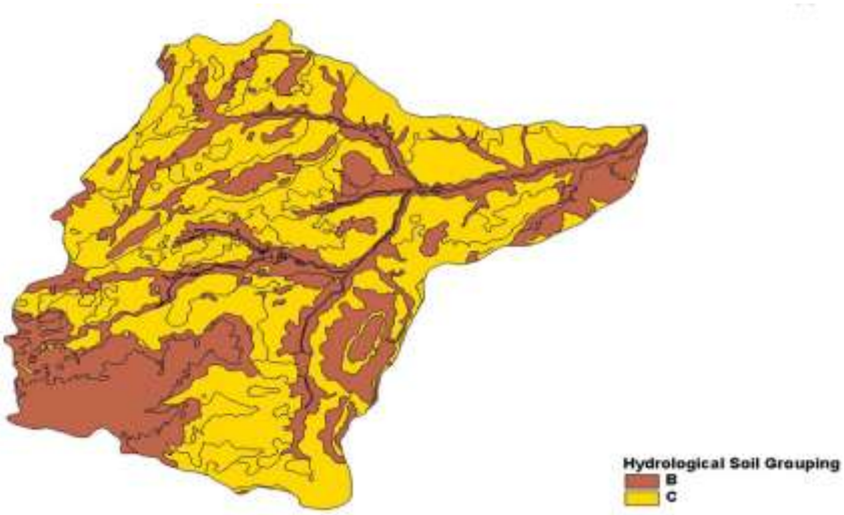


Figure 4.3. Hydrological soil grouping of the sub-catchment Msa5

4.4 Rainfall Mapping

The rainfall map of the study area is arrived by calculating the rainfall over the area considering the location of raingauge stations in the catchment area and the area influenced by these stations which is found by constructing thiessen polygon network. Three raingauge stations are identified in the subcatchment a viz. Hanumanthuni padu, Mohammada puram and Panduva Nagula Varam. The rainfall data collected from the CPO office of the district for the storms on 21st, 22nd and 23rd August, 2000 are used in the present analysis. The rainfall mapping of the subcatchment Msa5 is shown in the following figures 4.4 to 4.6.

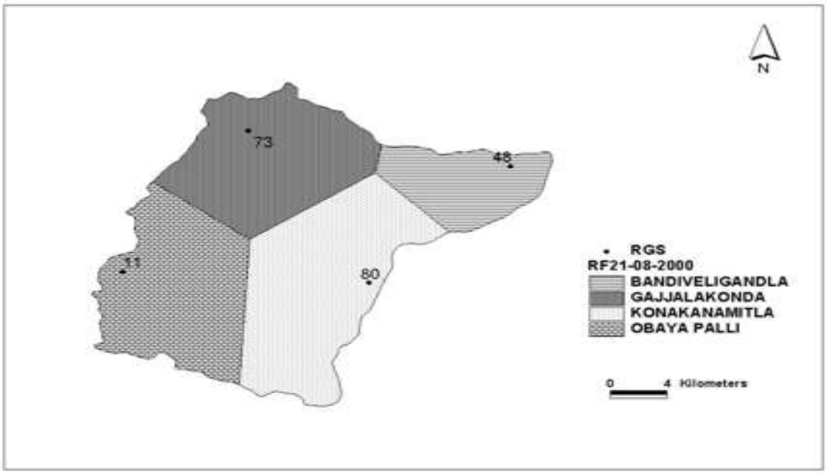


Figure 4.4. Rainfall thiessen polygon map of the sub-catchment Msa5 for the storm of 21st August, 2000

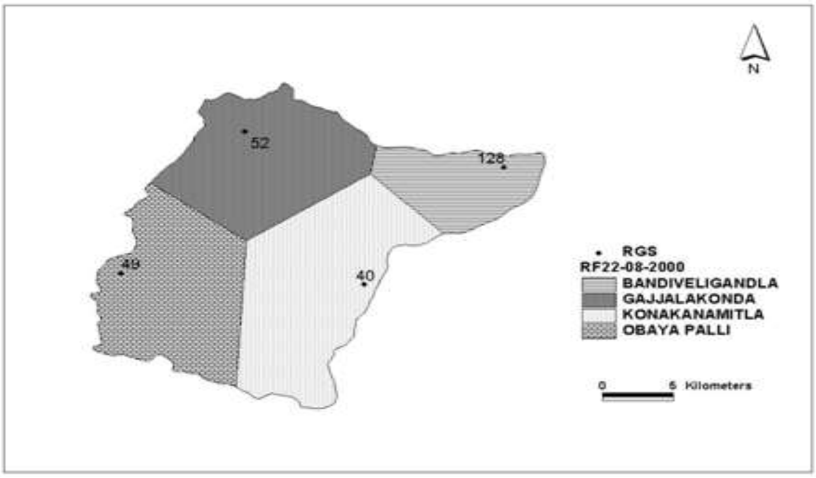


Figure 4.5. Rainfall thiessen polygon map of the sub-catchment Msa5 for the storm of 22nd August, 2000

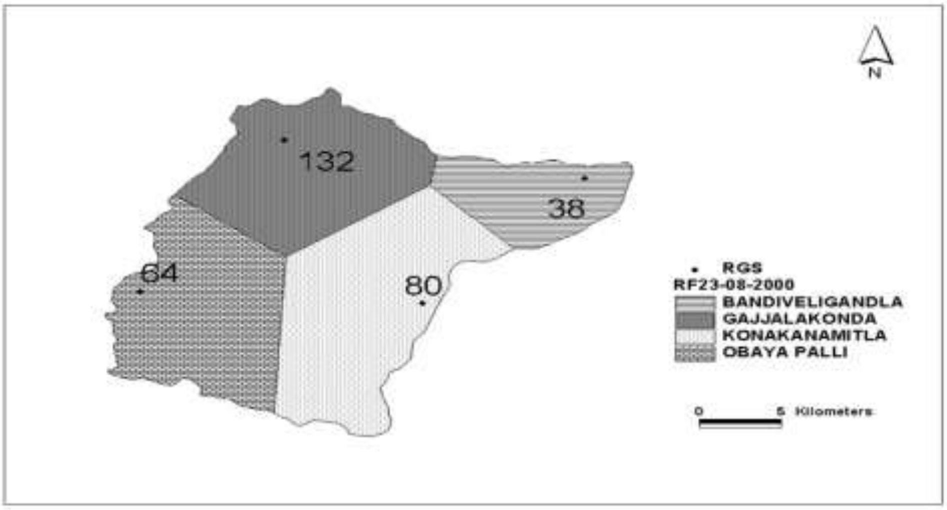


Figure 4.6. Rainfall thiessen polygon map of the sub-catchment Msa5 for the storm of 23rd August, 2000

4.5 Antecedent moisture condition (AMC) map

The index of the watershed wetness on the day of storm is described as Antecedent Moisture Condition (AMC) which is determined by the total rainfall in the 5 days period preceding a storm as given in table 3. The AMC maps of the study area are shown in the following figures 4.7 to 4.9.

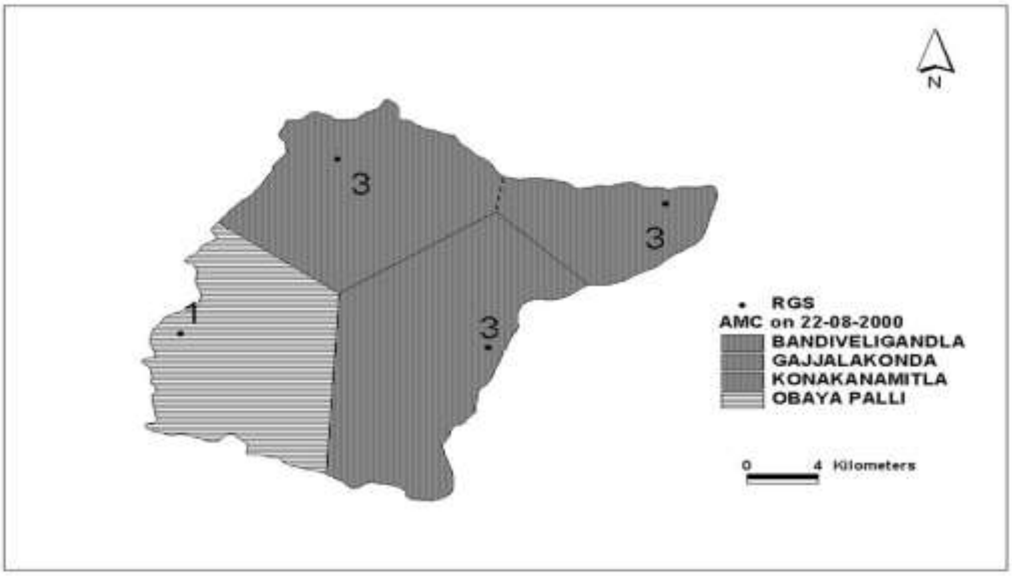


Figure 4.7. AMC map of the sub-catchment Msa5 on 21.08.2000

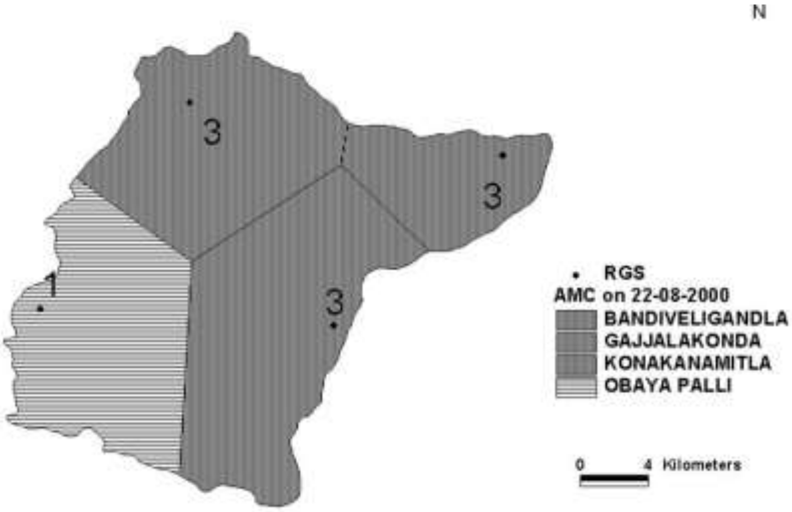


Figure 4.8. AMC map of the sub-catchment Msa5 on 22.08.2000

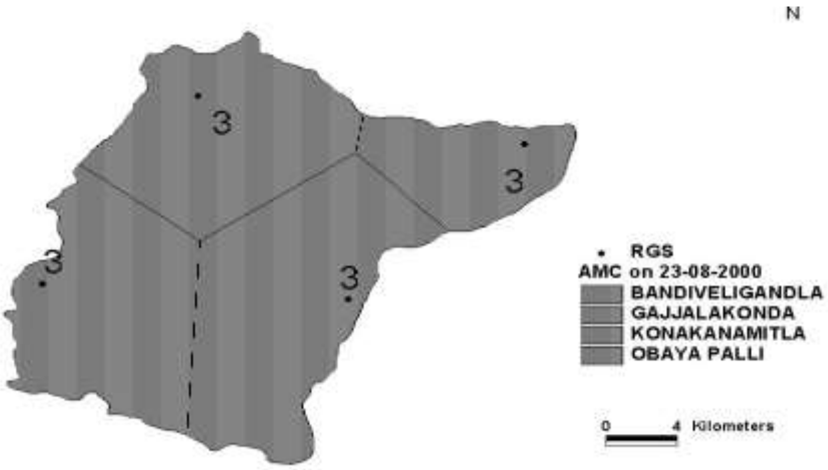


Figure 4.9. AMC map of the sub-catchment Msa5 on 23.08.2000

4.6 Curve Number Maps

The CN value for each polygon is calculated for average conditions i.e. AMC II. The standard curve number map generated for subcatchment Msa5 for AMC group II is given in the following figure 4.10.

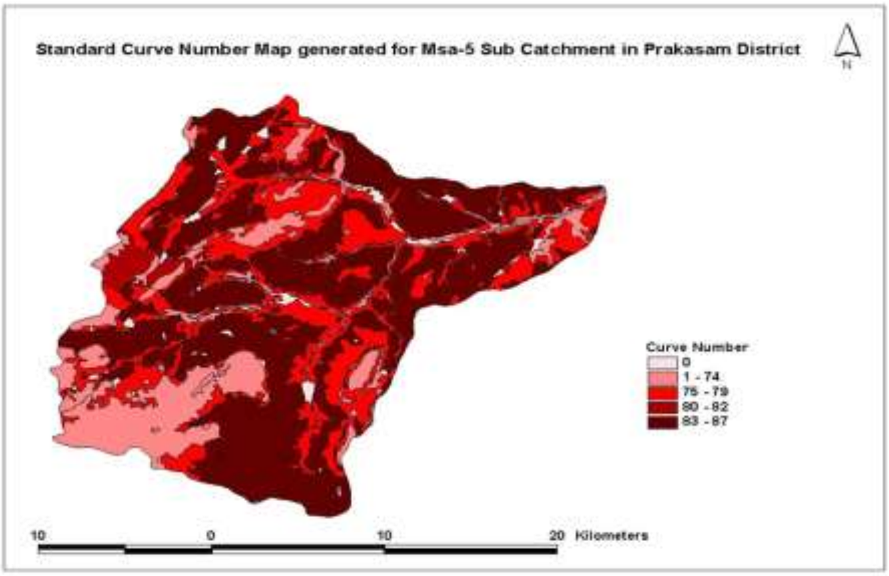


Figure 4.10. Standard curve number map generated for sub-catchment Msa5

The CN values for AMC II can be converted into modified CN values for AMC I and AMC III by using the NRCS Standard table given under table 2. To determine which AMC Class is the most appropriate in relation to the study area, the use of rainfall data is necessary. The 5-day rainfall prior to the event date was determined to know the AMC class of the subcatchment on the day of storm as per table 3. The modified curve number maps generated for the study area corresponding to AMC conditions on the days of storm are given in the following figures 4.11 to 4.13.

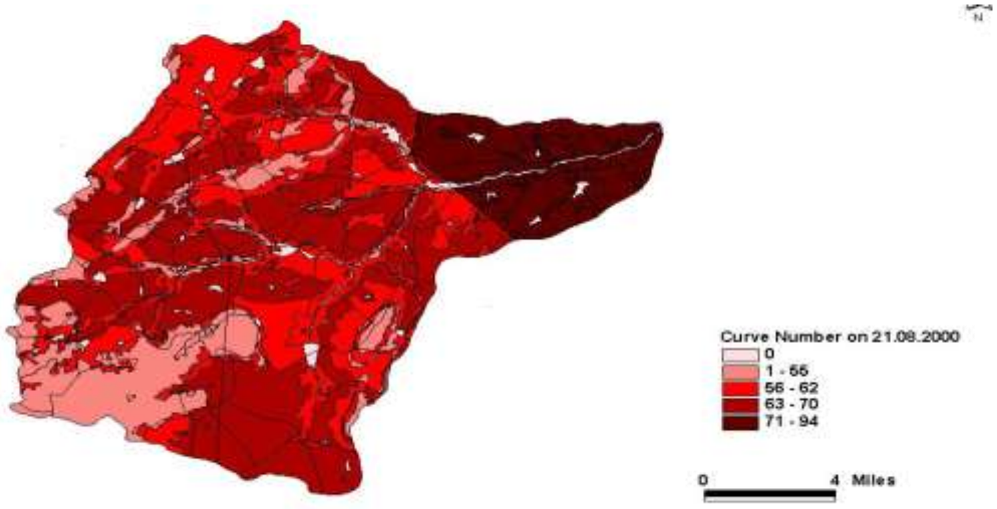


Figure 4.11. Modified curve number map generated for sub-catchment Msa5 for the day of 21.08.2000

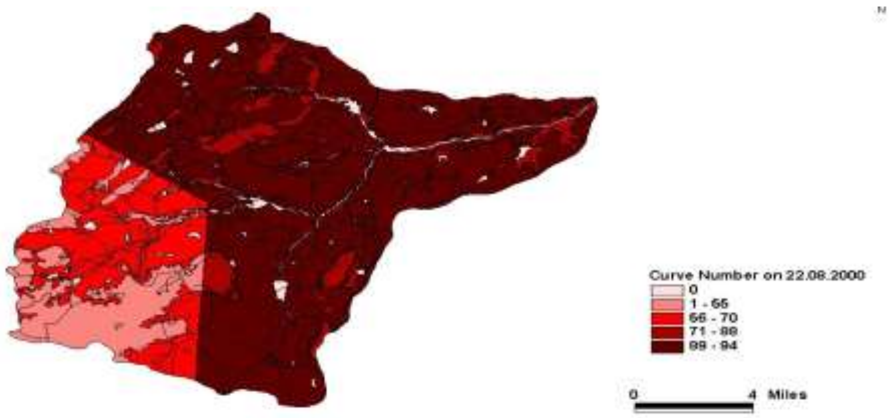


Figure 4.12. Modified curve number map generated for sub-catchment Msa5 for the day of 22.08.2000

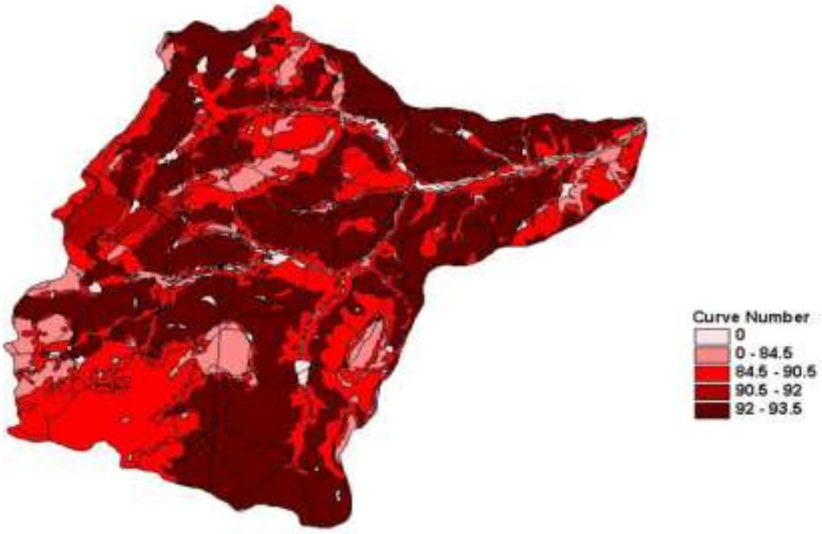


Figure 4.13. Modified curve number map generated for sub-catchment Msa5 for the day of 23.08.2000

4.7 Runoff Map

After generating the CN maps, the next step was to calculate maximum potential retention (S) Initial abstraction (Ia) and Runoff depth (Q). They were computed for each polygon using equations (1), (2), (3), (4), (5) and finally the runoff was mapped. The runoff maps generated for subcatchment Msa5 are given in the following figures 4.14 to 4.16.

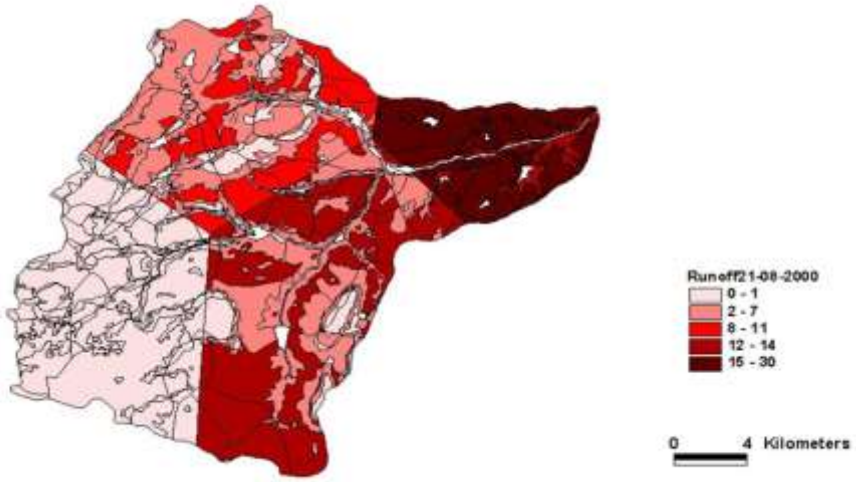


Figure 4.14. Runoff map generated for sub-catchment Msa5 for the storm of 21.08.2000

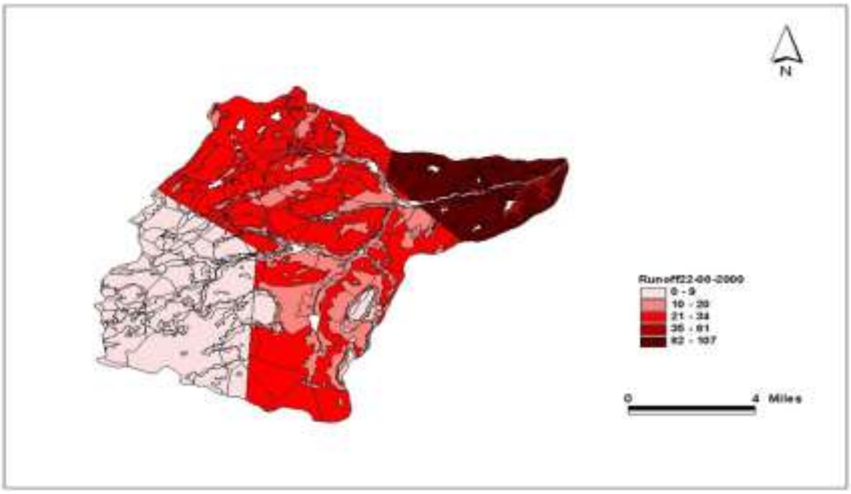


Figure 4.15. Runoff map generated for sub-catchment Msa5 for the storm of 22.08.2000

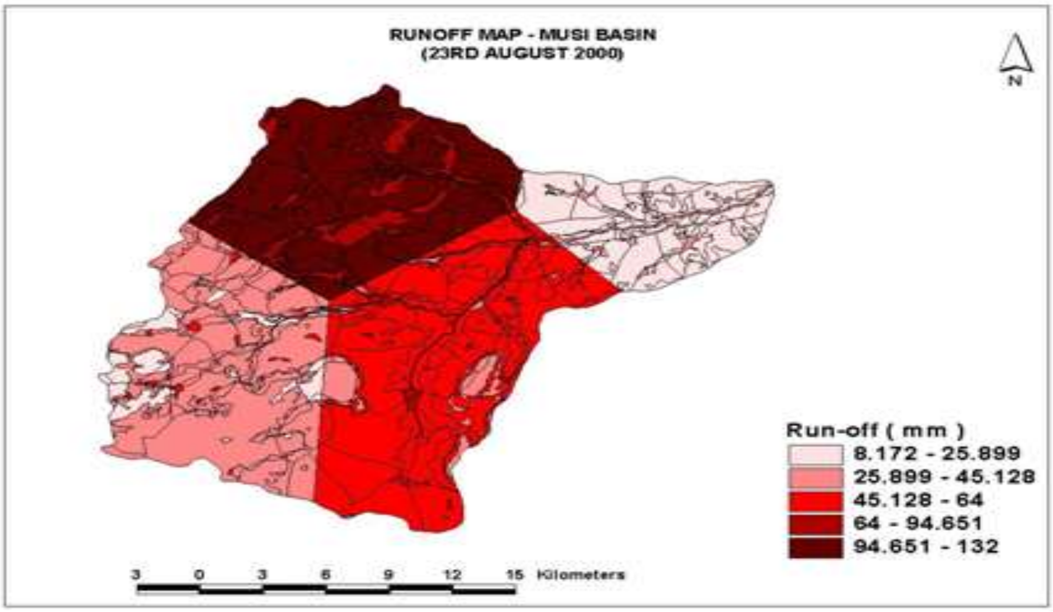


Figure 4.16. Runoff map generated for sub-catchment Msa5 for the storm of 23.08.2000

4.8 Generation of Dimensionless Unit Hydrograph

A unit hydrograph of 0.5 hrs rainfall duration and one centimetre rainfall excess has been created using the NRCS dimensionless hydrograph. This method requires the calculation of time to peak and the peak discharge which can be computed using the following equations.

$$\text{Lag time } (T_l \text{ ; in hours}) = \frac{L^{0.8}\left(1000/CN\right)-9)^{0.7}}{734.45Y^{0.5}} \quad ...(6)$$

$$\text{Peak discharge (Qp; cumecs)} = \frac{2.612A}{T_l} \quad ...\ (7)$$

L = Hydraulic length (m) = 890 (A) $^{0.65.}$;

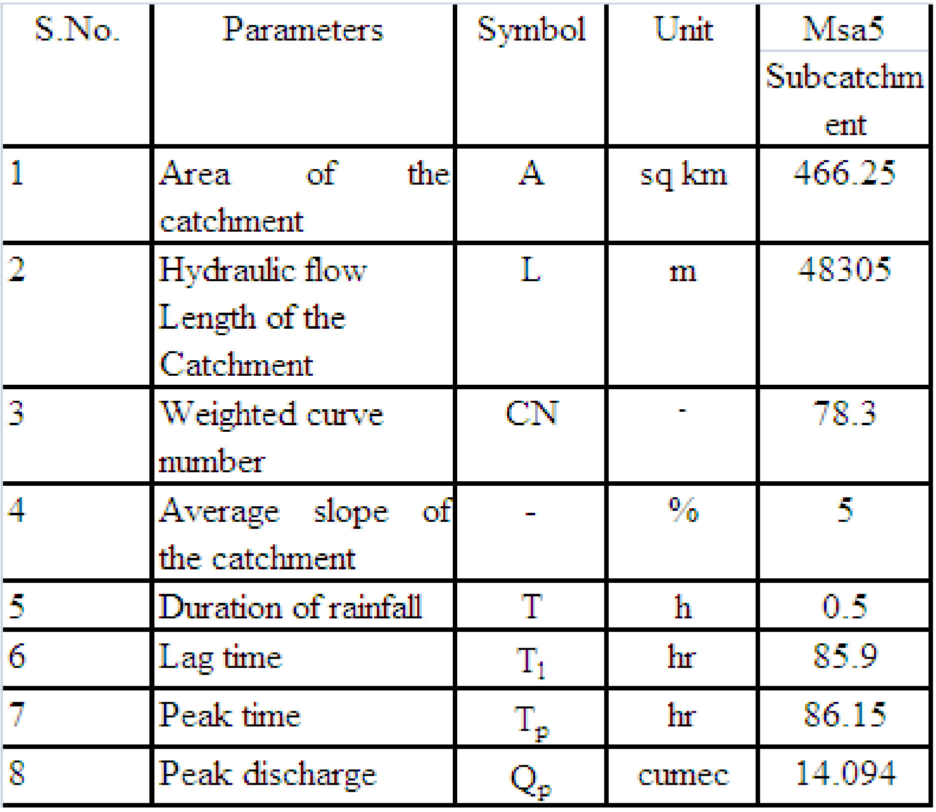
A = Area of the catchment in Sq. Km.;

CN = Weighted Curve Number

Y = Average slope of the watershed in percent

The computed values of lag time and peak discharge are given in table 4.

Table 4.1. Calculation of lag time and peak discharge for sub-catchment Msa5



S.No.	Parameters	Symbol	Unit	Msa5 Subcatchment
1	Area of the catchment	A	sq km	466.25
2	Hydraulic flow Length of the Catchment	L	m	48305
3	Weighted curve number	CN	-	78.3
4	Average slope of the catchment	-	%	5
5	Duration of rainfall	T	h	0.5
6	Lag time	T_l	hr	85.9
7	Peak time	T_p	hr	86.15
8	Peak discharge	Q_p	cumec	14.094

The dimensionless unit hydrographs derived for Msa5 subcatchment is given in figure 4.17.

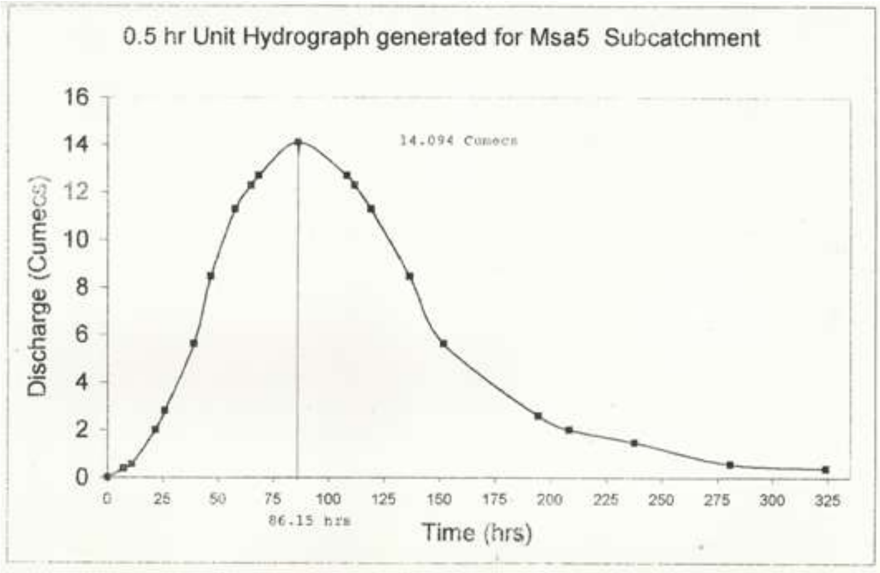


Figure 4.17. Dimensionless unit hydrograph generated for sub-catchment Msa5

By deriving a unit hydrograph of a particular duration, it is very easy to determine flood hydrograph of any duration for any amount of rain fall excess. Any change in land use or rainfall can be incorporated in the prepared spatial and non - spatial data base to monitor the change in the scenario.

5. RESULTS AND VALIDATION

The results obtained are tabulated below. Runoff in mm and M.cum and yield per sq.km are computed and tabulated. The computed yield rate is compared with observed yield rate which was collected from nearby gauged catchments with similar conditions applicable to the study area. The percentage of variation between computed and observed runoff is found to be with in ±10%. The validation of results are presented in table 5.1.

Table 5.1. Runoff Results for Msa5 Sub-Catchment

Date	* Thiessen Rainfall in mm	Weighted Runoff in mm	Total Runoff Mcum	Runoff (Mcum) per sq.km	Computed yield per sq.km.	** Observed yield per sq.km.	% Variation
21-08-2000	55.24	7.818	3.647	0.0078	0.0312	0.0285	9.47
22-08-2000	57.17	26.69	12.45	0.0267			
23-08-2000	83.82	58.35	27.43	0.0588			

The runoff observed for Msa5 subcatchment for 55.24 mm of rainfall on 21-08-2000 is 7.818 mm (14.1%) with a volume of runoff of 3.647 Mcum. The runoff observed for Msa5 subcatchment for 57.17 mm of rainfall on 22-08-2000 is 26.69 mm (46.6%) with a volume of runoff of 12.45 Mcum. The runoff observed for Msa5 subcatchment for 83.82 mm of rainfall on 23-08-2000 is 58.35 mm (69.6%) with a volume of runoff of 27.43 Mcum. Very less rate of runoff yield on 21st August 2000 in Msa5 subcatchment can be attributed to prevailing AMC Conditions on that day. The rainfall-runoff relationships for the subcatchment Msa5 are plotted and shown in the following figures 5.1 to 5.4.

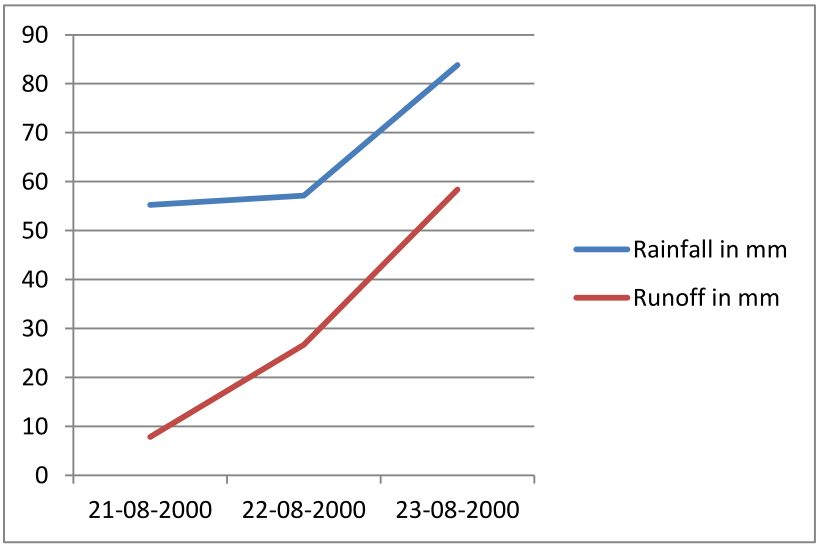


Figure 5.1. Rainfall – Runoff Relationship for Msa5 sub-catchment

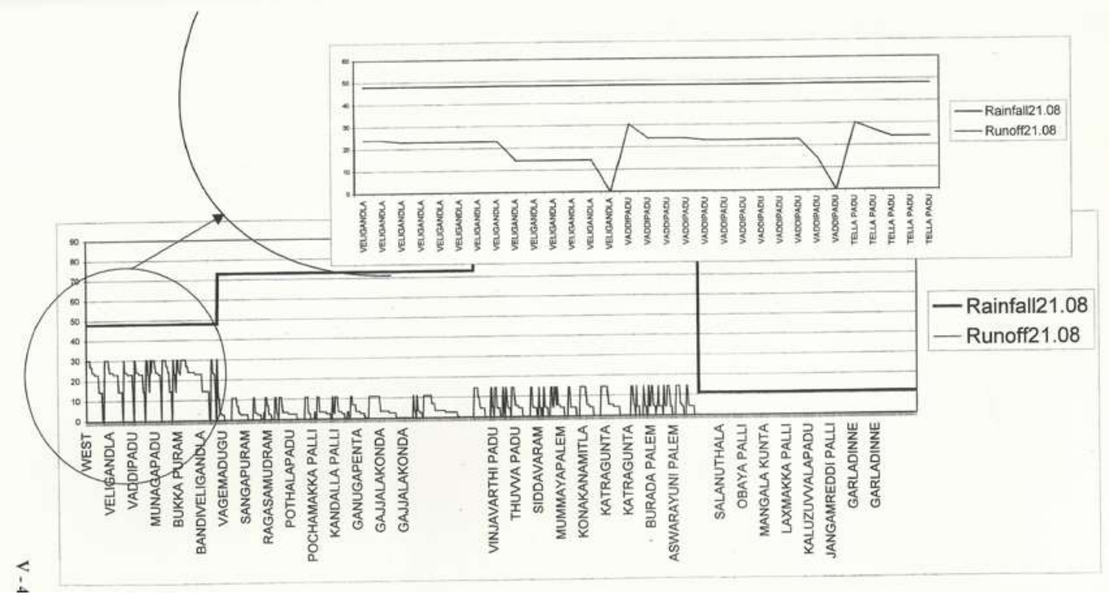


Figure 5.2. Rainfall – Runoff Relationship for sub-catchment Msa5 for Storm of 21st August, 2000

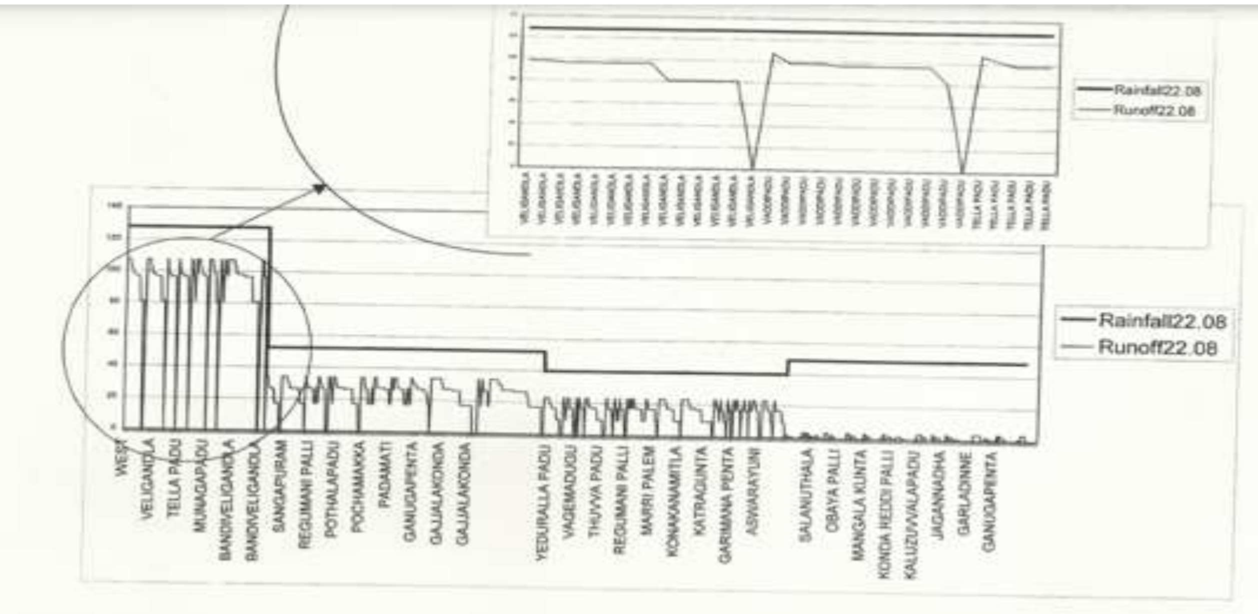


Figure 5.3. Rainfall – Runoff Relationship for sub-catchment Msa5 for Storm of 22nd August, **2000**

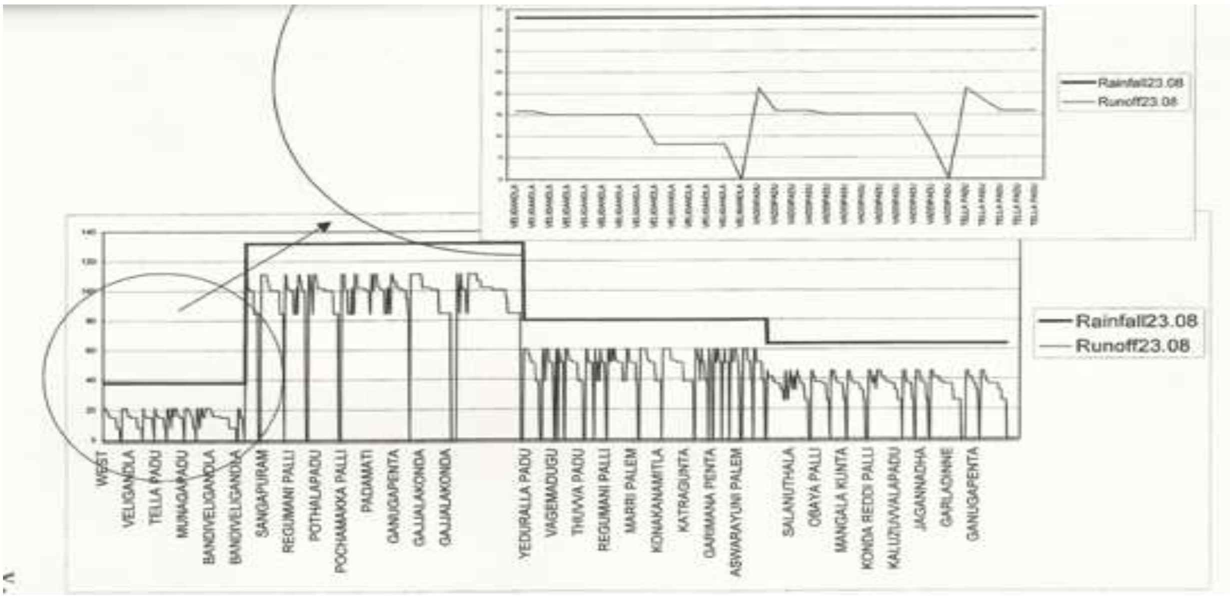


Figure 5.4. Rainfall – Runoff Relationship for sub-catchment Msa5 for Storm of 22nd August, 2000

6. FINDINGS AND CONCLUSION

In the present study area, 24 land use / land cover classes are identified. Agricultural lands are predominant in the study area. Soils of the study area are classified in to 12 categories. Two hydrological soil groups were observed in the study area.

Since the variation of yield rates are within acceptable range of ±10%, the methodology of runoff computation used in this study for Msa5 subcatchment using NRCS-CN-GIS model can be applied to other catchments and subcatchments in the region.
From the generated NRCS dimensionless parametric unit hydrograph, it is observed that the peak discharge and time to peak for a 0.5 h storm is found to be 14.094 cumecs and 86.15 hr respectively. These unit hydrographs serve as basis in all future applications for generating direct runoff hydrographs of any duration for any amount of rainfall excess in the study area.

As the complex hydrology of ungauged subcatchments is becoming increasingly computational to the water resources planners, the study proves that the advent of high speed digital computers has made it easy task for the planners and decision makers in carrying out hydrological analysis in GIS environment using remote sensing outputs for water resources management.

The study further validates the fact that the integration of satellite remote sensing and GIS techniques with topographical and other field data provide reliable, accurate and update information on land and water resources for an integrated approach in planning, development and management of subcatchments while taking up construction of water resources projects.

The study envisages that the remote sensing outputs can be used as inputs to many hydrological models to compute surface runoff at any location as well as to predict future runoff due to change in catchment characteristics.

REFERENCES

[1] Burrough. P. A (1986), “Principles of Geographical Information systems for and Resources Assessment” *Clarendon Press*, Oxford, UK

[2] Ivan Petras (2000), "Basin1 extension for ArcVIEW Spatial Analyst", Pretoria, South Africa

[3] Maidment, D. R. (1998), “GIS and Hydrological Modelling”, *In Environmental Modelling with GIS* in Hydro GIS 93 : Application of Geographic Information Systems in Hydrology and Water Resources, proceedings of the Vienna Conference.

[4] NRCS (1972), formerly Soil Conservation Service, “National Engineering Handbook, Section A. Hydrology”, Washington. DC.

[5] O'Callaghan, J. F. and D. M. Mark (1984) “The extraction of drainage networks from digital elevation data”, *Computer Vision, Graphics and Image Processing* 28:323-344.

[6] Singh, V.P. (1995), “Watershed Modelling in Computer Models of Watershed Hydrology” *Water Resources Publications* pp1-22.

[7] Sherman L K (1932) “Stream flow from rainfall by unit-graph method” Engineering News Record 108: pp501-505

[8] Todini E (1988) “Rainfall-runoff Modelling - Past, Present and Future”, Journal of Hydrology 100:341-352.