

**ESTIMATION OF RUNOFF AND SOIL EROSION FROM
WATERSHED USING REMOTE SENSING AND GIS.**

A Thesis submitted to the

**DR. BALASAHEB SAWANT KONKAN KRISHI VIDYAPEETH
DAPOLI - 415 712
Maharashtra State (India)**

In the partial fulfillment of the requirements for the degree

**of
MASTER OF TECHNOLOGY
(AGRICULTURAL ENGINEERING)**

**in
SOIL AND WATER CONSERVATION ENGINEERING**

**by
Vidya Vijayrao Deshmukh**



**DEPARTMENT OF SOIL AND WATER CONSERVATION ENGINEERING,
COLLEGE OF AGRICULTURAL ENGINEERING AND TECHNOLOGY,
DR. BALASAHEB SAWANT KONKAN KRISHI VIDYAPEETH,
DAPOLI- 415 712, DIST. RATNAGIRI, M. S. (INDIA)**

**ESTIMATION OF RUNOFF AND SOIL EROSION FROM
WATERSHED USING REMOTE SENSING AND GIS**

A Thesis submitted to the

**DR. BALASAHEB SAWANT KONKAN KRISHI VIDYAPEETH
DAPOLI - 415 712
Maharashtra State (India)**

In the partial fulfillment of the requirements for the degree

of
**MASTER OF TECHNOLOGY
(AGRICULTURAL ENGINEERING)**
in
SOIL AND WATER CONSERVATION ENGINEERING

Approved by the Advisory Committee
Chairman and Research Guide


(H. N. Bhang)

Assistant Professor,
Dept. of SWCE,
C.A.E.T., Dapoli

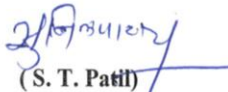
Members



(B. L. Ayare)
Agricultural Engineer,
AICRP on Water Management ,
Dept. of Agronomy,
C.o.A.,
Dapoli



(K. D. Gharde)
Assistant Professor,
Dept. of SWCE,
C.A.E.T., Dapoli



(S. T. Patil)
Assistant Professor,
Dept. of IDE,
C.A.E.T., Dapoli

CANDIDATE'S DECLARATION

I hereby declare that this thesis or part thereof has not been submitted

by me or any other person to any other

University or Institute

for a Degree or

Diploma.

Place: CAET, Dapoli

(Vidya Vijayrao Deshmukh)

Dated: / /2012

Prof. H. N. Bhange

B. Tech. (Agril.Engg.), M. Tech. (SWCE)
Chairman and Research Guide,
Assistant Professor,
Department of Soil and Water Conservation Engineering,
College of Agricultural Engineering and Technology,
Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth,
Dapoli- 415 712, Dist. Ratnagiri,
Maharashtra, India.

CERTIFICATE

This is to certify that the thesis entitled **“ESTIMATION OF RUNOFF AND SOIL EROSION FROM WATERSHED USING REMOTE SENSING AND GIS”** submitted to the Faculty of Agricultural Engineering, Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli, Dist. Ratnagiri (Maharashtra State) in the partial fulfillment of the requirements for the award of the degree of **Master of Technology (Agricultural Engineering)** in **Soil and Water Conservation Engineering**, embodies the record of a piece of bonafied research work carried out by **Miss Vidya Vijayrao Deshmukh** under my guidance and supervision. No part of the thesis has been submitted for any other degree, diploma or publication in any other form.

The assistance and help received during the course of this investigation and source of the literature have been duly acknowledged.

Place: CAET, Dapoli

(H. N. Bhange)

Date: / /2012

Prof. dilip MAHALE

B. Tech. (Agril.Engg.), M. Tech. (SWCE)
Professor and Head,
Department of Soil and Water Conservation Engineering,
College of Agricultural Engineering and Technology,
Dr. Balsaheb Sawant Konkan Krishi Vidyapeeth,
Dapoli 415 712, Dist. Ratnagiri,
Maharashtra, India.

CERTIFICATE

This is to certify that the thesis entitled “**ESTIMATION OF RUNOFF AND SOIL EROSION FROM WATERSHED USING REMOTE SENSING AND GIS**” submitted to the Faculty of Agricultural Engineering, Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli, Dist. Ratnagiri (Maharashtra State) in the partial fulfillment of the requirements for the award of degree of Master of Technology (Agricultural Engineering) in Soil and Water Conservation Engineering is a record of bonafied research work carried out by **Miss Vidya Vijayrao Deshmukh** under guidance and supervision of **Shri. H. N. Bhange**, Assistant Professor, College of Agricultural Engineering and Technology, Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli. No part of the thesis has been submitted for any other degree, diploma or publication in any other form.

The assistance and help received during the course of this investigation and source of the literature have been duly acknowledged.

Place: CAET, Dapoli

Date: / /2012.

(dilip MAHALE)

Prof. dilip MAHALE

B. Tech. (Agril.Engg.), M. Tech. (SWCE)
Associate Dean,
Faculty of Agricultural Engineering,
Dr. Balsaheb Sawant Konkan Krishi Vidyapeeth,
Dapoli 415 712, Dist. Ratnagiri,
Maharashtra, India.

CERTIFICATE

This is to certify that the thesis entitled “**ESTIMATION OF RUNOFF AND SOIL EROSION FROM WATERSHED USING REMOTE SENSING AND GIS**” submitted to the Faculty of Agricultural Engineering, Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli, Dist. Ratnagiri (Maharashtra State) in the partial fulfillment of the requirements for the award of degree of Master of Technology (Agricultural Engineering) in Soil and Water Conservation Engineering is a record of bonafied research work carried out by **Miss Vidya Vijayrao Deshmukh** under guidance and supervision of **Shri. H. N. Bhange**, Assistant Professor, College of Agricultural Engineering and Technology, Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli. No part of the thesis has been submitted for any other degree, diploma or publication in any other form.

The assistance and help received during the course of this investigation and source of the literature have been duly acknowledged.

Place: CAET, Dapoli

Date: / /2012.

(dilip MAHALE)

ACKNOWLEDGEMENT

I take this privilege to express my deep sense of gratitude and sincere thanks to my research guide Er. H. N. Bhangе, Assistant Professor, Department of Soil and Water Conservation Engineering, College of Agricultural Engineering and Technology, Dapoli for his precious guidance, valuable suggestions, constant encouragement and help throughout the research work.

I express my profound sense of gratitude to Prof. dilip MAHALE, Associate Dean and Head of Department of Soil and Water Conservation Engineering , College of Agricultural Engineering and Technology, Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli who gave me an opportunity to complete my research work at Maharashtra Remote Sensing Applications Center, Nagpur and providing necessary facilities for completion of research work.

I express my sincere thanks to my research co-guide Dr. P. B. Rajankar Associate Scientist, Maharashtra Remote Sensing Applications Center (MRSAC), Nagpur for his valuable guidance and help throughout the research work. I am very much thankful to Dr. V. M. Bothale, Director, Maharashtra Remote Sensing Application Center, Nagpur for giving me opportunity and necessary facility for successful completion of project work at MRSAC, Nagpur. I am also thankful to Mr. Indal Ramteke, Resource Scientist and Mr. Sanjay Apturkar, Associate Scientist in MRSAC, Nagpur for giving me helping hand and necessary help during the research work.

I take this privilege to express my deep sense of gratitude to the members of advisory committee Dr. B. L. Ayare, Agricultural Engineer, AICRP on Water Management , Department of Agronomy, Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli , Er. K .D. Gharde, Assistant Professor, Department of Soil and Water Conservation Engineering, College of Agricultural Engineering and Technology,

Dapoli , Er. S. T. Patil Assistant Professor, Department of Irrigation and Drainage Engineering, College of Agricultural Engineering and Technology, Dapoli, for their valuable suggestions, precious guidance and all necessary help for completion of this research work.

I am also grateful to Dr. S. B. Nandgude, Associate Professor, Department of Soil and Water Conservation Engineering, College of Agricultural Engineering and Technology, Dapoli for his valuable guidance and necessary help for completion of this research work .

I am very much thankful to Prof. R. T. Thokal, Professor and Head, Department of Irrigation and Drainage Engineering, College of Agricultural Engineering and Technology, Dapoli for his precious guidance and constant help during the research work.

I also express my sincere thanks to Prof. S. A. Kadam, Assistant Professor, Irrigation and Drainage Engineering, Dr. Annasaheb Shinde College of Agricultural Engineering, Rahuri and Prof. B. K. Gavit, Assistant Professor, Soil and Water Conservation Engineering, Dr. Annasaheb Shinde College of Agricultural Engineering, Rahuri for their valuable guidance ,moral support and helping hand during the research work.

I am thankful to Miss. S. M. Palkar, Senior Research Assistant, Department of Soil and Water Conservation Engineering, College of Agricultural Engineering and Technology, Dapoli, Shri. S. S. Idate, Lab Assistant, Department of Soil and Water Conservation Engineering, College of Agricultural Engineering and Technology, Dapoli, for their good co-operation and helping hands during the entire course.

I am very glad to express my thanks to all my friends in M. Tech. for the constant encouragement and help during my project work. I am heartly thankful to my friends Jyoti Naik and Jheel Basthia in MRSAC, Nagpur who helps me during the research work.

Words and feelings will be insufficient to express my heartist gratitude to my beloved parents and family member for their inspiration, encouragement, and providing

me opportunities in building up my career. I express my sincere thanks to all whom directly and indirectly extended help during the research work.

Place : CAET, Dapoli

Date : / /2012.

(Vidya Vijayrao Deshmukh)

TABLE OF CONTENTS

Sr.No.	Title	Page No.
	CANDIDATES DECLARATION	iii
	CERTIFICATES	iv-vi
1.	Research Guide	iv
2.	Professor and Head	v
3.	Associate Dean	vi
	ACKNOWLEDGEMENT	vii-viii
	TABLE OF CONTENTS	ix-x
	LIST OF TABLES	xi
	LIST OF FIGURES	xii
	LIST OF SYMBOLS AND ABBREVIATIONS	xiii-xiv
	ABSTRACT	xv-xvi
1.	INTRODUCTION	1
2.	REVIEW OF LITERATURE	5
3.	MATERIALS AND METHODS	13
3.1	Location and Climatic Features of Study Area	13
3.2	Collection of Data	17
3.2.1	Remote Sensing Data	17
3.2.2	Collateral, Ancillary and Ground Data	21
3.2.3	Other Thematic Maps	21
3.2.4	Ground Truth Collection	21
3.2.5	Software and Systems	22
3.3	Methodology	22
3.3.1	Watershed Delineation	22
3.3.2	Land Use Land Cover	23
3.3.2.1	Geometric Correction / Image Rectification	24
3.3.2.2	Image Enhancement	25
3.3.2.3	Image Classification	25
3.3.3	Soil Mapping and Hydrological Soil Group	26
3.3.4	Slope Extraction from SRTM DEM	27
3.3.5	Runoff Estimation by SCS Curve Number Method	27
3.3.5.1	Generating CN Map	29
3.3.5.2	Antecedent Moisture Condition (AMC)	30
3.3.5.3	Slope-Adjusted CN	30
3.3.6	Soil Erosion by Revised Universal Soil Loss Equation (RUSLE)	31
3.3.6.1	R Factor (Rainfall Erosivity Factor)	33

3.3.6.2	K Factor (Soil Erodability Factor)	33
3.3.6.3	L and S Factor (Slope Length and Steepness Factor)	34
3.3.6.4	C Factor (Cover Management Factor)	35
3.3.6.5	P Factor (Support Practice Factor)	36
4.	RESULTS AND DISCUSSION	37
4.1	Runoff Estimation	37
4.1.1	Land Use Land Cover	38
4.1.2	Hydrologic Soil Groups	40
4.1.3	CN Values	43
4.1.4	Runoff Depth	46
4.2	Soil Loss Estimation	47
4.2.1	R Factor (Rainfall Erosivity Factor)	47
4.2.2	K Factor (Soil Erodibility Factor)	50
4.2.3	L and S Factor (Slope Length and Steepness Factor)	50
4.2.4	C Factor (Cover Management Factor)	52
4.2.5	P Factor (Support Practice Factor)	57
4.2.6	Estimation of Soil Loss	57
5.	SUMMARY AND CONCLUSION	60
6.	BIBLIOGRAPHY	64
7.	APPENDICES	75
I.	Rainfall data of Asthi Tahsil from 1998 to 2005	75
II.	Monthly Rainfall (mm) and Antecedent moisture condition(AMC) of Asthi Tahsil for the year 2005	76
III.	Runoff curve numbers for hydrologic soil cover complexes (for AMC II and $I_a = 0.2S$)	88
IV.	Micro-watershed wise mean CN	89
V.	Micro-watershed wise mean CN for different AMC Conditions	90
VI.	Runoff generated from sub watersheds of SA-13 Watershed based on rainfall data of Asthi Tahsil.	91
VII.	Area wise various factors required for Soil erodibility factor	93

LIST OF TABLES

Table No.	Title	Page No.
3.1	Annual Rainfall Around Study Area (2005)	14
3.2	Satellite Data Used in the study	17
3.3	Land Use Land Cover Classification (NRSA,1989)	24
3.4	Classification of Antecedent Moisture Condition	28
4.1	Land Use Land Cover Statistics in Study Area	38
4.2	Hydrologic Soil Groups in the Watershed	41
4.3	Curve Numbers for Hydrologic soil-Cover Complex for AMC Class II (Ia=0.2S)	43
4.4	Micro-watershed wise Mean CN	44
4.5	Rainfall and Runoff Depth for the Year 2005	46
4.6	Area Statistics of K - Factor in SA-13 Watershed	50
4.7	P Factor values for different support practices for watershed	57
4.8	Rainfall, Runoff Depth and soil loss for the Year 2005	59

LIST OF FIGURES

Fig. No.	Title	Page No.
3.1	Location Map of study area	15
3.2	Location of Raingauge Stations	16
3.3	IRS P6,LISS-III satellite image of SA-13 Watershed, 8 November 2005	18
3.4	IRS P6, LISS-III satellite image of SA-13 Watershed, 19 January 2006	19
3.5	IRS P6, LISS-III satellite image of SA-13 Watershed, 25 April 2006	20
3.6	Flow Chart for Runoff Estimation	28
3.7	Flow Chart for Estimation of Annual Soil Loss	32
4.1	Land Use Land Cover Map of SA-13 Watershed	39
4.2	Dominant Land Use	40
4.3	Hydrological Soil Group (HSG) Map of SA-13 Watershed	42
4.4	Micro-watershed wise Mean CN Map of SA-13 Watershed	45
4.5	Distribution of Mean Annual Precipitation (2005) in SA-13 Watershed	48
4.6	R Factor Map of SA-13 Watershed	49
4.7	K Factor Map of SA-13 Watershed	51
4.8	Slope Map of SA-13 Watershed	53
4.9	Topographic Factor Map of SA-13 Watershed	54
4.10	NDVI Image (Nov, 2005) of SA-13 Watershed	55
4.11	C Factor Map of SA-13 Watershed	56
4.12	Average Soil Loss in SA-13 Watershed	58

LIST OF ABBREVIATIONS AND SYMBOLS

Abbreviations	Meanings
%	Percentage
⁰ C	Degree Celcius
A	Gross amount of soil erosion
Agril.	Agricultural
AIS and LUS	All India Soil and Land Use Survey
AMC	Antecedent Moisture Condition
BES	Bureau of Economics and Statistics
C Factor	Cover management factor
C.A.E.T.	College of Agricultural Engineering and Technology
CN	Curve number
DEM	Digital Elevation Model
Dept.	Department
DIP	Digital Image Processing
Dr. B.S.K.K.V.	Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth
E	East
e.g.	For Example
Engg.	Engineering
ERDAS	Earth Resources Data Analysis Systems
ESRI	Environmental Systems Research Institute
<i>et al.</i>	And others
etc	Etcetera
Fig.	Figure
GIS	Geographic Information System
Govt	Government
ha	Hectare
HSG	Hydrologic Soil Group
i.e.	That is

IDW	Inverse Distance Weighted
ISODATA	Iterative Self Organizing Data Analysis Technique
K Factor	Soil erodibility factor
km ²	Square Kilometer
L and S Factor	Slope length and Steepness factor
LULC	Land Use Land Cover
m	Meter
M ha	Million Hectare
m/m	Meter per meter
MJ-mm	Mega Joule-millimeter
mm	Millimeter
MRSAC	Maharashtra Remote Sensing Applications Center
MUSLE	Modified Universal Soil Loss Equation
N	North
NBSS and LUP	National Bureau of Soil Survey and Land Use Planning
NDVI	Normalized Difference Vegetation Index
NIR	Near Infrared
NRCS	Natural Resource Conservation Service
NRSA	National Remote Sensing Agency
OM	Organic matter
P Factor	Support practice factor
Pt	Permeability Code
R	Red
R Factor	Rainfall erosivity factor
RUSLE	Revised Universal Soil Loss Equation
SCS	Soil Conservation Service
SRTM	Shuttle Radar Topography Mission
St	Soil Structure Code
t/ha/year	Tons per hectare per year
TGA	Total Geographical Area
U.S.	United States
UNEP	United Nations Environment Programme
USDA	United States Department of Agriculture
USLE	Universal Soil Loss Equation

β	Beta
θ	Theta

TABLE OF CONTENTS

Sr.No.	Title	Page No.
	CANDIDATES DECLARATION	iii
	CERTIFICATES	iv-vi
1.	Research Guide	iv
2.	Professor and Head	v
3.	Associate Dean	vi
	ACKNOWLEDGEMENT	vii-viii
	TABLE OF CONTENTS	ix-x
	LIST OF TABLES	xi
	LIST OF FIGURES	xii
	LIST OF SYMBOLS AND ABBREVIATIONS	xiii-xiv
	ABSTRACT	xv-xvi
1.	INTRODUCTION	1
2.	REVIEW OF LITERATURE	5
3.	MATERIALS AND METHODS	13
	3.1 Location and Climatic Features of Study Area	13
	3.2 Collection of Data	17
	3.2.1 Remote Sensing Data	17
	3.2.2 Collateral, Ancillary and Ground Data	21
	3.2.3 Other Thematic Maps	21
	3.2.4 Ground Truth Collection	21
	3.2.5 Software and Systems	22
	3.3 Methodology	22
	3.3.1 Watershed Delineation	22
	3.3.2 Land Use Land Cover	23
	3.3.2.1 Geometric Correction / Image Rectification	24
	3.3.2.2 Image Enhancement	25
	3.3.2.3 Image Classification	25
	3.3.3 Soil Mapping and Hydrological Soil Group	26
	3.3.4 Slope Extraction from SRTM DEM	27
	3.3.5 Runoff Estimation by SCS Curve Number Method	27
	3.3.5.1 Generating CN Map	29
	3.3.5.2 Antecedent Moisture Condition (AMC)	30
	3.3.5.3 Slope-Adjusted CN	30

3.3.6	Soil Erosion by Revised Universal Soil Loss Equation (RUSLE)	31
3.3.6.1	R Factor (Rainfall Erosivity Factor)	33
3.3.6.2	K Factor (Soil Erodability Factor)	33
3.3.6.3	L and S Factor (Slope Length and Steepness Factor)	34
3.3.6.4	C Factor (Cover Management Factor)	35
3.3.6.5	P Factor (Support Practice Factor)	36
4.	RESULTS AND DISCUSSION	37
4.1	Runoff Estimation	37
4.1.1	Land Use Land Cover	38
4.1.2	Hydrologic Soil Groups	40
4.1.3	CN Values	43
4.1.4	Runoff Depth	46
4.2	Soil Loss Estimation	47
4.2.1	R Factor (Rainfall Erosivity Factor)	47
4.2.2	K Factor (Soil Erodability Factor)	50
4.2.3	L and S Factor (Slope Length and Steepness Factor)	50
4.2.4	C Factor (Cover Management Factor)	52
4.2.5	P Factor (Support Practice Factor)	57
4.2.6	Estimation of Soil Loss	57
5.	SUMMARY AND CONCLUSION	60
6.	BIBLIOGRAPHY	64
7.	APPENDICES	75
I.	Rainfall data of Asthi Tahsil from 1998 to 2005	75
II.	Monthly Rainfall (mm) and Antecedent moisture condition(AMC) of Asthi Tahsil for the year 2005	76
III.	Runoff curve numbers for hydrologic soil cover complexes (for AMC II and $I_a = 0.2S$)	88
IV.	Micro-watershed wise mean CN	89
V.	Micro-watershed wise mean CN for different AMC Conditions	90
VI.	Runoff generated from sub watersheds of SA-13 Watershed based on rainfall data of Asthi Tahsil.	91
VII.	Area wise various factors required for Soil erodibility factor	93

LIST OF TABLES

Table No.	Title	Page No.
3.1	Annual Rainfall Around Study Area (2005)	14
3.2	Satellite Data Used in the study	17
3.3	Land Use Land Cover Classification (NRSA,1989)	24
3.4	Classification of Antecedent Moisture Condition	28
4.1	Land Use Land Cover Statistics in Study Area	38
4.2	Hydrologic Soil Groups in the Watershed	41
4.3	Curve Numbers for Hydrologic soil-Cover Complex for AMC Class II ($I_a=0.2S$)	43
4.4	Micro-watershed wise Mean CN	44
4.5	Rainfall and Runoff Depth for the Year 2005	46
4.6	Area Statistics of K - Factor in SA-13 Watershed	50
4.7	P Factor values for different support practices for watershed	57
4.8	Rainfall, Runoff Depth and soil loss for the Year 2005	59

LIST OF FIGURES

Fig. No.	Title	Page No.
3.1	Location Map of study area	15
3.2	Location of Raingauge Stations	16
3.3	IRS P6,LISS-III satellite image of SA-13 Watershed, 8 November 2005	18
3.4	IRS P6, LISS-III satellite image of SA-13 Watershed, 19 January 2006	19
3.5	IRS P6, LISS-III satellite image of SA-13 Watershed, 25 April 2006	20
3.6	Flow Chart for Runoff Estimation	28
3.7	Flow Chart for Estimation of Annual Soil Loss	32
4.1	Land Use Land Cover Map of SA-13 Watershed	39
4.2	Dominant Land Use	40
4.3	Hydrological Soil Group (HSG) Map of SA-13 Watershed	42
4.4	Micro-watershed wise Mean CN Map of SA-13 Watershed	45
4.5	Distribution of Mean Annual Precipitation (2005) in SA-13 Watershed	48
4.6	R Factor Map of SA-13 Watershed	49
4.7	K Factor Map of SA-13 Watershed	51
4.8	Slope Map of SA-13 Watershed	53
4.9	Topographic Factor Map of SA-13 Watershed	54
4.10	NDVI Image (Nov, 2005) of SA-13 Watershed	55
4.11	C Factor Map of SA-13 Watershed	56
4.12	Average Soil Loss in SA-13 Watershed	58

LIST OF ABBREVIATIONS AND SYMBOLS

Abbreviations	Meanings
%	Percentage
⁰ C	Degree Celcius
A	Gross amount of soil erosion
Agril.	Agricultural
AIS and LUS	All India Soil and Land Use Survey
AMC	Antecedent Moisture Condition
BES	Bureau of Economics and Statistics
C Factor	Cover management factor
C.A.E.T.	College of Agricultural Engineering and Technology
CN	Curve number
DEM	Digital Elevation Model
Dept.	Department
DIP	Digital Image Processing
Dr. B.S.K.K.V.	Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth
E	East
e.g.	For Example
Engg.	Engineering
ERDAS	Earth Resources Data Analysis Systems
ESRI	Environmental Systems Research Institute
<i>et al.</i>	And others
etc	Etcetera
Fig.	Figure
GIS	Geographic Information System
Govt	Government
ha	Hectare
HSG	Hydrologic Soil Group
i.e.	That is

IDW	Inverse Distance Weighted
ISODATA	Iterative Self Organizing Data Analysis Technique
K Factor	Soil erodibility factor
km ²	Square Kilometer
L and S Factor	Slope length and Steepness factor
LULC	Land Use Land Cover
m	Meter
M ha	Million Hectare
m/m	Meter per meter
MJ-mm	Mega Joule-millimeter
mm	Millimeter
MRSAC	Maharashtra Remote Sensing Applications Center
MUSLE	Modified Universal Soil Loss Equation
N	North
NBSS and LUP	National Bureau of Soil Survey and Land Use Planning
NDVI	Normalized Difference Vegetation Index
NIR	Near Infrared
NRCS	Natural Resource Conservation Service
NRSA	National Remote Sensing Agency
OM	Organic matter
P Factor	Support practice factor
Pt	Permeability Code
R	Red
R Factor	Rainfall erosivity factor
RUSLE	Revised Universal Soil Loss Equation
SCS	Soil Conservation Service
SRTM	Shuttle Radar Topography Mission
St	Soil Structure Code
t/ha/year	Tons per hectare per year
TGA	Total Geographical Area
U.S.	United States
UNEP	United Nations Environment Programme
USDA	United States Department of Agriculture
USLE	Universal Soil Loss Equation

β
 θ

Beta
Theta

ABSTRACT

ESTIMATION OF RUNOFF AND SOIL EROSION FROM WATERSHED USING REMOTE SENSING AND GIS

By

Deshmukh Vidya Vijayrao

Department of Soil and Water Conservation Engineering,

College of Agricultural Engineering and Technology,

Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli

Dist.- Ratnagiri, Maharashtra

2012

Research Guide : **Er. H. N. Bhange**
Department : **Soil and Water Conservation Engineering**

The watershed based approach for planning of conservation measure to conserve water and soil resources is considered to be effective since excess rainfall or runoff from the watershed is drained to a common outlet. Inventory on soil loss and prediction of soil erosion hazards are playing vital role for effective soil conservation planning of a watershed for sustainable development. Soil conservation is now a necessity in almost every country of the world under virtually every type of land use.

Remote sensing data and GIS techniques have been used to compute runoff and soil erosion from the SA-13 watershed occupying an area of 213 km², which is 14.48 percent of the total geographical area of the Ashti tahsil and 2 percent of the Beed district. The runoff volume of the SA-13 watershed is calculated by SCS Curve Number method and soil erosion is calculated by Revised Universal Soil Loss Equation using Remote sensing and GIS techniques.

Information obtained using remote sensing techniques can help decision makers to prepare resource map accurately in less time and cost. GIS, on other hand, helps in

linking those maps with other information related to geographic location and helps modelling, analysing and solving complex problems.

While determining the results the data sets such as IRS P-6 LISS III (23.5 m resolution) satellite image, 1:50000 standard topographic map, SRTM DEM (90 m resolution), soil map on 1:500000 scale, Administrative Boundary maps, Slope map, Land Use Land Cover map and meteorological data based rainfall maps were the main inputs for this study.

Using ERDAS Imagine 9.1 software, IRS P-6 LISS III image is classified by using digital image techniques for extracting Land Use and Land Cover and integrated into Arc GIS 9.2 with hydrological soil map. Soil Conservation Curve Number method is used to determine Curve Numbers and runoff volume distribution of the basin area. Annual spatial soil loss estimation was computed using the Revised Universal Soil Loss Equation model (Renard *et al.*, 1997) in conjunction with remote sensing data and GIS techniques.

The results of the present study show that the average rainfall for the year 2005 in the SA-13 watershed was 406.50 mm whereas average annual runoff was 96.07 mm, amounting 23.63 percent of the total rainfall received. Also, the result of the analysis about soil erosion revealed that the average annual soil loss of the SA-13 watershed is 8.2 tons/ha/year. Soil erosion in the present study is in moderate erosion risk class.

This approach could be applied easily for other watersheds for efficient and effective planning and implementation for various conservation measures.

INTRODUCTION

A watershed is the area covering all the land that contributes runoff water to a common point. It is a natural physiographic or ecological unit composed of interrelated parts and functions.

Runoff means the draining or flowing off of precipitation from a catchment area through a surface channel after satisfying all surface and sub surface losses. Rainstorms generate runoff, and its occurrence and quantity are dependent on the characteristics of the rainfall event, i.e. the intensity, duration and distribution. Apart from these rainfall characteristics, there are number of catchments specific factors, which have a direct effect on the occurrence and volume of runoff. These include soil type, vegetation cover, slope and catchments type.

Runoff is one of the most important hydrologic variables used in most of the resources applications. Reliable prediction of quantity and rate of runoff from land surface into stream and river is difficult and time consuming to obtain for ungauged watershed. However, this information is needed in dealing with many watershed development and management problems. Conventional methods for prediction of river discharge require considerable hydrological and meteorological data. Collection of these data is expensive, time consuming and a difficult process.

In India, the availability of accurate information on runoff is scarcely available and that too in a few selected sites where recording and automatic hydrologic gauging stations are installed. Thus, there is an urgent need to generate information on basin runoff and sediment yield for the acceleration of the watershed development and management programmes (Zade *et al.*, 2005). In India, most of the agricultural watersheds are ungauged, having no past record whatsoever of rainfall-runoff processes (Sarangi *et al.*, 2005a, b). Non-availability of continuous rainfall and runoff records in majority of Indian watersheds has led to the development of techniques for estimation of surface runoff from ungauged basins (Chattopadhyay and Choudhury, 2006).

However, quickening of the watershed management programme for conservation and development of natural resources management has necessitated the runoff information. Runoff estimation from Remote Sensing data so as to provide a quick result

for decision-makers, before any experimentation of quantification is taken up. This is a less time consuming method and also gives reliable results. Advances in computational power and the growing availability of spatial data have made it possible to accurately predict the runoff. The possibility of rapidly combining data of different types in a Geographic Information System (GIS) has led to significant increase in its use in hydrological applications. Out of several methods for runoff estimation from ungauged watershed, the Curve Number (CN) is an index developed by the Natural Resource Conservation Service (NRCS), to represent the potential for storm water runoff within a drainage area. The curve number method (SCS, 1972), also known as the hydrologic soil cover complex method, is a versatile and widely used procedure for runoff estimation. The CN for a drainage basin is estimated using a combination of land use, soil's permeability, and antecedent soil moisture condition (AMC). In the present study, the runoff from SCS (Soil Conservation Services) Curve Number method modified for Indian conditions is used to determine runoff volume with the aid of remote sensing and GIS techniques.

Soil erosion is one of the most critical environmental hazards of modern times. Assessing the severity of soil erosion is difficult due to the fact that land often erodes at an imperceptible rate. In addition, some areas may be more susceptible to soil erosion than others and the rate of erosion is not the same everywhere. Vast areas of land now being cultivated may be rendered economically unproductive if the erosion of soil continues unabated.

Soil erosion is a complex phenomenon as it is governed by various natural processes, and it, in turn, results in decrease of soil fertility and reduction of crop yields. India is one of the few countries in the world to have estimated the loss of topsoil due to erosion (Narayana and Babu, 1983). An estimated 329 Mha, constituting about 53% of the total geographical area suffers from deleterious effect of soil erosion with an annual average soil erosion rate of 16 t/ha/year (Dabral *et al.* 2008). The process of soil erosion involves detachment, transport and subsequent deposition (Meyer and Wischmeier, 1969). The consequence of soil erosion occur both on-site and off-site (Morgan, 1986). On site effects are particularly important on agricultural land, where the redistribution of soil within a field, the loss of soil from a field, the breakdown of soil structure and the

decline in organic matter and nutrient result in a reduction of cultivable soil depth and decline in soil fertility. Erosion also reduces available soil moisture, resulting in more drought prone conditions. The net effect is a loss of productivity which, at first; restricts what can be grown and results in increased expenditure on fertilizers to maintain yields but later, ultimately leads to land abandonment. Off-site problems result from sedimentation down stream, which reduces the capacity of the rivers, enhance the risk of flooding, blocks irrigation canals and shortens the design life of reservoirs.

The prevention of soil erosion, which means reducing the rate of soil loss to approximately that which would occur under natural conditions, relies on selecting appropriate strategies for soil conservation and this, in turn, requires a thorough understanding of the processes of erosion. The factors, which influence the rate of soil erosion, are rainfall, runoff, soil, slope, plant cover and the presence or absence of conservation measures (Morgan, 1986).

Several parametric models have been developed by various scientists to predict soil erosion from drainage basins, hill slopes and field levels etc. With a few exceptions, these models are based on soil type, land use, climatic and topographic information. Remote Sensing technique makes it possible to measure hydrologic parameters on spatial scales. Scientific management of soil, water and vegetation resources on watershed basis is, very important to arrest erosion and rapid siltation in rivers, lakes and estuaries.

It is, however, realized that due to financial and organizational constraints, it is not feasible to treat the entire watershed within a short time. Prioritization of watersheds on the basis of those sub-watersheds within a watershed which contribute maximum sediment yield obviously should determine our priority to evolve appropriate conservation management strategy so that maximum benefit can be derived out of any such money time-effort making scheme. Within any particular area there will be a considerable variation in erosion rates but if the rates are grouped into those related to natural vegetation, cultivated land and bare soil, each group follows a broadly similar pattern of similar variation.

Erosion is not only a function of climate alone but also depends on the frequency at which potentially erosive events coincide with ground conditions that accelerate the erosion. The most vulnerable time for erosion is the early part of the wet season when the

rainfall is high but the vegetation has not grown sufficiently to protect the soil. Generally, the period between ploughing and the growth of the crop beyond the seedling stage contains an erosion risk if it coincides with heavy rainfall (Morgan, 1986).

Erosion and land use change are very closely related. Rates of soil loss accelerate quickly to unacceptably high levels whenever land is misused. Erosion is a natural process but that its rate and spatial and temporal distribution depends on the interaction of physical and human circumstances.

Simple methods such as the Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1965; Wischmeier and Smith, 1978), the Modified Universal Soil Loss Equation (MUSLE) (Williams, 1975), or the Revised Universal Soil Loss Equation (RUSLE) (Renard *et al*, 1991) are frequently used for the estimation of surface erosion from catchment areas (Ferro and Minacapilli 1995; Ferro 1997; Kothyari and Jain, 1997; Ferro *et al*, 1998). Both of these quantities are found to have large variability due to the spatial variation of rainfall and catchment heterogeneity.

With this view in mind, the project titled, “Estimation of runoff and soil erosion from watershed using Remote sensing and GIS” with the following objectives has been undertaken.

1. Estimation of runoff from watershed using SCS-CN by Remote Sensing and GIS.
2. Estimation of soil erosion from watershed using RUSLE by Remote Sensing and GIS.

II. REVIEW OF LITERATURE

The work carried out by various research workers related to estimation of runoff and soil loss by using Remote Sensing and Geographic Information System is reviewed and presented in this chapter.

Wischmeier and Smith (1978) had developed Universal Soil Loss Equation (USLE) method for plot scale soil loss estimation, including all the relevant terrain and climatic factors like topography, soil types, rainfall etc. This method was given by $A=RKLSCP$, Where, A = average annual soil loss in tons/ha, R = rainfall erosivity factor and is equal to $\sum EI/100$, K = soil erodibility factor, L=slope length factor, S= slope steepness factor, C = crop management factor and P = supporting conservation practice factor.

Narayana and Babu (1983) tried to estimate soil erosion and sediment loads of rivers and sedimentation in reservoirs. They utilized data of annual soil loss from 20 different land resource regions of the country, 36 different river basins and 17 catchments of major reservoirs and developed statistical regression equation for predicting sediment yield.

De Jong (1994) described the use of vegetation indices in order to extract vegetation parameters for erosion models. Based on his work following statement can be assumed to be valid in general: i) NDVI and RULSE C-factor was correlated, ii) There was a linear relation between NDVI and RULSE C-factor.

McCool *et al.* (1995) studied the Revised Universal Soil Loss Equation (RUSLE). In this study the Universal Soil Loss Equation has been revised to more accurately estimate soil loss from both crop and rangeland areas. All factors R, K, LS, C and P have received attention. R-values for the western United States were developed from hourly precipitation data. A time-variant K factor was included for the eastern United States. New length and steepness (LS) factor relationships were developed. C factors are now computed by a sub factor approach, and P factors were developed using the CREAMS model. The USLE has been revised to reflect new technology and analysis of data required since 1978 when Agriculture Handbook 537 was completed.

Atawoo and Heerasing (1997) studied estimation of soil erodibility and erosivity of rainfall patterns in Mauritius. Empirical studies on the erosivity (R) of 3 rainfall patterns in Mauritius were conducted to test two models for predicting R. The erodibility factor (K) of soils from five erosion-prone areas was calculated in parallel using the nomograph developed by Wischmeier et al (1971). Results in the first case showed that the model developed by Arnoldus (1977) gives a close approximation to calculated R. In the other case there were indications that the soils tested are relatively resistant to soil erosion.

Renard *et al.* (1997) derived an improved equation widely known as Revised Universal Soil Loss Equation (RUSLE). This equation was improved form of soil erosion equation widely known as Universal Soil Loss Equation (USLE) developed by Wischmeier and Smith (1965, 1978) in United State Department of Agriculture (USDA) The revised equation was expressed as, $A=RKLSCP$, Where, R = average annual energy and intensity of rainstorms.

Huang *et al.* (1999) have carried out series of experiments to determine detachment and deposition processes in process based erosion models. It was observed from experimental results that at 5 percent slope under drainage conditions, deposition occurred at low rainfall intensities.

Jasrotia *et al.* (2002) studied Rainfall-Runoff and Soil erosion Modeling using Remote Sensing and GIS technique for Tons Watershed. SCS curve method was used to calculate coefficient of determination (R^2) which is 0.99, and which indicates a high correlation between rainfall and runoff. The average soil loss for all the four subwatersheds was calculated, and it was found that the maximum average soil loss of 24.1 t/ha occurred in the sub-watershed. Hence for soil conservation, very high priority should be given to sub-watershed.

Nayak and Jaiswal (2003) studied Rainfall-Runoff Modeling using Satellite Data and GIS for Bebas River in Madhya Pradesh. Remote Sensing technology combined with Geographical Information System (GIS). The remote sensing data provides spatial information on land cover, soils as input to SCS model. ILWIS 2.2 GIS has been used to store, manipulate and estimate sub-basin wise weighted average rainfall and runoff curve numbers. These curve numbers were finally used as input to the SCS model for runoff

estimation. In general good correlation was found between the measured and estimated runoff volume. The seasonal correlation coefficient varies between 0.92 to 0.94.

Kulkarni *et al.* (2004) proposed Modified Soil Conservation Services (Modified SCS) Model for estimating runoff for Warasgaon Catchment which is located in the Pune district of Maharashtra state. Catchment area was divided into fifteen watersheds and runoff of each sub-watershed was estimated. In this study runoff varied from 320.93 mm to 3914.76 mm from East to West of the study area.

Pandey *et al.* (2006) studied the methodology for determination of Runoff for Karso watershed using GIS and SCS model and the calculated runoff was found out to be 244.40 mm for monsoon season of the year 1993 which was approximately 35.52 per cent of the total rainfall.

Dabral *et al.* (2008) studied soil erosion assessment of Dikrong river basin of Arunachal Pradesh (India). A quantitative assessment of average annual soil loss on grid basis was made using the well-known USLE with a view to know the spatial distribution in the study watershed. The use of GIS and remote sensing data enabled the determination of the spatial distribution of the USLE parameters. The average annual soil erosion for Dikrong river basin was found to be 51 t/ha/ year.

Gupta and Panigrahy (2008) studied SCS model and overland flow models for runoff modeling over major land mass of India. It was observed that there was a great difference between the runoff generation (SCS model) and its actual accumulation (overland flow model) in the field because of flow of runoff water to the down gradient.

Patil *et al.* (2008) had developed accurate surface runoff estimation techniques from ungauged watersheds, relevant to Indian condition due to the non-availability of hydrologic gauging stations in majority of watersheds. This was the first study that developed the ArcGIS based interface using the in-built macro programming language to estimate the surface runoff using four different curve number based runoff estimation techniques. Moreover, the developed interface need to be operated under different watershed conditions to ascertain the predictability of the modified CN techniques for runoff estimation from ungauged watersheds.

Rojas-González (2008) proposed that a number of parametric models have been developed to predict soil erosion at drainage basins, yet USLE (Wischmeier and Smith,

1978) is most widely empirical equation used to estimate annual soil loss from agricultural basins. This methodology can be applied to the island and small basins. The application of Remote Sensing Images and GIS tools are useful to approximate the land cover and potential soil erosion of a basin.

Amutha and Porchelvan (2009) studied Surface Runoff in Malattar Sub-watershed using SCS-CN Method. The SCS– CN method integrated with GIS can be used in watershed management effectively. The results of the study show that from the monthly runoff values and the seasonal runoff in the watershed can be studied for reliable accuracy along with the spatial variation of soil type and land use type.

Ebrahimian *et al.* (2009) studied the runoff depth using NRCS-CN method with GIS and the effect of slope on runoff generation. The USDA NRCS-CN method was applied for estimating the runoff depth in the semi-arid Kardeh watershed. The results indicated that the combined GIS and CN method can be used in ungauged watershed with the same condition to Kardeh with about 60 percent accuracy only for management and conservation purposes not for computation of design floods.

Ramakrishnan *et al.* (2009) studied SCS-CN and GIS-based approach for identifying potential water harvesting sites in the Kali Watershed, Mahi River Basin, India. In this study augmentation of water resource is proposed by construction of runoff harvesting structures like check dam, percolation pond, farm pond, well and subsurface dyke. The site suitability for different water harvesting structures is determined by considering spatially varying parameters like runoff potential, slope, fracture pattern and micro-watershed area. GIS is utilised as a tool to store, analyse and integrate spatial and attribute information pertaining to runoff, slope, drainage and fracture. The runoff derived by SCS-CN method is a function of runoff potential which can be expressed in terms of runoff coefficient (ratio between the runoff and rainfall) which can be classified into three classes, viz., high (>40 percent), moderate (20–40 percent) and low (<20 percent).

Samah *et al.* (2009) studied watershed having a geographical area of 1.87 km² and the average annual rainfall was around 500 mm. The study showed that the average annual runoff depth for the study area (Wadi Su'd watershed) was 36.3 mm, and the average volume of runoff from the same watershed was 67840.2 m³/year. The amount of

runoff represents 7.3 per cent of the total annual rainfall. In this study, the methodology for determination of runoff for Wadi Su'd using GIS and SCS method was described. This approach could be applied in other Palestinian watersheds for planning of various conservation measures.

Arekhi *et al.* (2010) predicted potential annual soil loss and sediment yield using the Revised Universal Soil Loss Equation (RUSLE) model with adaptation in a Geographic Information System (GIS) for Ilam dam watershed located in the western Iran. The study indicates that the slope length and steepness of the RUSLE model are the most effective factors controlling soil erosion in the region. So, the RUSLE model integrated with RS and GIS techniques has a great potential for producing accurate and inexpensive erosion and sediment yield risk maps in Iran.

Karaburun (2010) studied C factor for soil erosion modeling using NDVI in Buyukcekmece watershed. A regression analysis was performed between NDVI and C factor. C factor values were assigned to pixels of NDVI image through regression equation. The C factor map of Buyukcekmece watershed was produced to use in soil erosion methods such as USLE and RUSLE based on an assumption that NDVI and C factor values are correlated with each other. The results revealed that large parts of areas were assigned to C factor classes that vary between 0.2 and 0.4.

Pradhan *et al.* (2010) studied SCS model for estimating runoff using land cover, soil type and predicted rainfall value. Estimated runoff is compared with the runoff calculated with the actual rainfall data for the year 2009, in general good correlation has been found between observed and computed runoff. The analysis can be extended further to assess the impact of change in land cover over a period of time on rainfall runoff and impact of change in runoff on morphology of river Teesta.

Shadeed and Almasri (2010) studied application of GIS-based SCS-CN method in West Bank catchments, Palestine. A GIS-based SCS-CN approach was developed in this study to calculate the composite curve number of West Bank catchments. The insufficiency of rainfall runoff records has limited the verification of the validity of the proposed approach to generally arid to semi-arid catchments. However, four rainfall events were simulated in the Al-Badan sub-catchment of the Al-Faria Catchment using the generated curve number map. Estimated and observed runoff depths of the four

events were close enough to assume the applicability of the GIS-based SCS-CN approach for the region.

Sundar Kumar *et al.* (2010) studied SCS-CN method for predicting direct runoff volume for a given rainfall event. There is a strong correlation between the CN values obtained from measured runoff and the rainfall depth. The results indicated that combination of remote sensing and SCS model makes the runoff estimate more accurate and fast.

Elangovan and Seetharaman (2011) studied Rainfall Erosivity using Revised Universal Soil Loss Equation from daily rainfall depth in Krishanagiri Watershed region of Tamil Nadu, India. Rainfall depth for every 15 minutes from self recording raingauges was measured at four locations in the watershed and a simple model was established between rainfall erosivity and depth of rainfall. It is established that the relationship between the erosivity and rainfall depth can be expressed in a potential form. The regression model and the erosivity map here provided to represent a helpful mean for soil erosion assessment and mapping, both at watershed and at regional scale.

Kefi *et al.* (2011) studied assessment and mapping of soil erosion risk by water in Tunisia which is located in the North of the African continent bordering the Mediterranean Sea. The results indicated that Tunisia has a serious risk of soil erosion. Indeed, about 24.57 percent of the study area had a soil loss rate more than 30 t/ha. This study focused only on the prediction of soil loss useful to identify areas with high risk of soil erosion by water but this phenomenon is not necessarily a dominant geomorphic process in Tunisia.

Pal and Samanta (2011) studied RS and GIS techniques to estimate soil loss on the Kaliaghai river basin under Purbo and Paschim Medinipur district of West Bengal using RUSLE (Revised Universal Soil Loss Equation) model. Soil loss is very high in the river basin area, calculated as 1927779 tons/year using RUSLE model. Thus, the RUSLE model integrated with RS and GIS technologies has great potential for producing accurate and inexpensive erosion and sediment yield assessment map in the Kaliaghai river basin.

Prasannakumar *et al.* (2011) proposed Soil erosion risk by remote sensing, GIS and RUSLE approach, a case study of Siruvani river watershed in Attapady valley, Kerala, India. The result can serve as basic data to assist water and soil conservation

management and land use planning. The study also proves the usefulness of RUSLE model in conjunction with remote sensing data in a GIS platform for determining erosion hazards and to pinpoint high-risk areas where soil conservation practices are essential.

Saleh *et al.* (2011) studied a large ungaged catchment area (Hemren basin) of 10953.261 km². Practically the Hemren basin was divided into three sub-basins according to the tributary. The rainfall-runoff relationship were found for each sub-basin, also the results obtained showed the strong connection between the runoff and the varying topography and land cover for each sub-basin. The relationship (runoff-rainfall) was verified by using the field data which recorded by the Hemren dam project management, acceptable coincidence between observed and calculated runoff depth was found.

Shiferaw (2011) studied that the rate of soil erosion is severe in the highlands of Ethiopia. The study demonstrates that the RUSLE together with satellite remote sensing and geographical information systems are useful tools to estimate soil loss over areas and facilitate sustainable land management through conservation planning.

Shinde *et al.* (2011) studied quantitative determination of soil erosion and prioritization of micro-watersheds using Remote Sensing and GIS. This study focuses application of most widely used Universal Soil Loss Equation (USLE) to determine soil erosion and prioritization of micro-watersheds of Upper Damodar Valley Catchment (UDVC) of India. The result shows that, annual average soil loss for the entire basin is 23.17 t/ha/year; for micro-watersheds. The main advantage of the GIS methodology is in providing quick information on the estimated value of soil loss for any part of the investigated area.

Yue-Qing *et al.* (2011) studied the RUSLE and GIS to model soil erosion risk in a mountains karst watershed, Guizhou Province, China. The RUSLE model and GIS and RS techniques were very effective in this study to assess soil loss and erosion risk. The methods and results described in this study are valuable for understanding the relationship between soil erosion risk and environmental factors and are useful for managing and planning land use that will avoid soil erosion.

Gist of List

Various scientists have conducted research work in India and abroad for estimation of runoff and soil erosion from watershed by using Remote Sensing and Geographic Information System.

The research work was conducted for estimation of runoff from watershed by using SCS-CN method by using Remote Sensing and Geographic Information System. Nayak and Jaiswal (2003), Pandey *et al.* (2006), Amutha and Porchelvan (2009), Samah *et al.* (2009) and Sundar Kumar *et al.* (2010) studied SCS-CN method for estimation of runoff from watershed using Remote Sensing and Geographic Information System. From the above reviews it is found that the remote sensing data provides spatial information on land cover, soils as input to SCS-CN method. Geographic Information System has been used to store, manipulate and estimate sub-basin wise weighted curve numbers which finally estimate runoff volume distribution of the basin area. This application will help for planning of various conservation measures for watershed. Ramakrishnan *et al.* (2009) studied SCS-CN and GIS-based approach for identifying site suitability for different water harvesting structure in Kali Watershed, Mahi River Basin, India. Ebrahimian *et al.* (2009) studied the runoff depth using NRCS-CN method with GIS and the effect of slope on runoff generation for watershed. Patil *et al.* (2008) studied the modified CN techniques for runoff estimation from ungauged watersheds.

The research work was conducted for estimation of soil erosion by using Revised Universal Soil Loss Equation (RUSLE) by using Remote Sensing and Geographic Information System. McCool *et al.* (1995) and Renard *et al.* (1997) studied Revised Universal Soil Loss Equation (RUSLE) was improved form of soil erosion equation widely known as Universal Soil Loss Equation (USLE) developed by Wischmeier and Smith (1978) to estimate soil loss from both crop and rangeland areas. Kefi *et al.* (2011) and Prasannakumar *et al.* (2011) studied the RUSLE model for prediction of accurate soil loss and to identify areas with high risk of soil erosion. Pal and Samanta (2011), Shiferaw (2011) and Yue-Qing *et al.* (2011) studied the RUSLE model for accurate prediction of soil loss.

The above reviews indicate that combination of Remote Sensing and GIS is useful to estimate runoff volume more accurately and fast by SCS-CN method and also have great potential to estimate accurate soil erosion and mapping using RUSLE equation.

Therefore, this tool will be helpful to predict maximum runoff volume and to estimate soil loss over areas and facilitate sustainable land management through conservation planning.

III. MATERIALS AND METHODS

The research work was conducted to estimate the runoff and soil erosion from watershed using Remote Sensing and GIS for identification of soil erosion prone areas. The quantitative estimation of soil loss with sufficient accuracy are of extreme importance for designing and implementing appropriate soil and water conservation practices. The research work was conducted at Maharashtra Remote Sensing Applications Center, Nagpur. The details of material used and methods adopted for analysis for present study are discussed in this chapter.

3.1 Location and Climatic Features of Study Area

Watershed SA - 13 selected for the study is located in Ashti tahsil, Beed district of Maharashtra. Beed district is located almost at the center of the Maharashtra State covering an area of about 10432 km². Area represents typical semi-arid region of Maharashtra state and associated agro-ecological setup. The entire area is covered by basaltic lava flows belonging to the Deccan Traps of upper Cretaceous to Eocene age. The river Godavari flows along the Northern boundary of the district and has deposited alluvium along its course, which is overlying the Deccan Traps.

Watershed SA - 13 spans from 75^o 04' 55" to 75^o 16' 25" E longitude and 18^o 40' 11" to 18^o 56' 20" N latitude occupying an area of about 21,300 ha, which is about 14.48 percent of the total geographical area of the Ashti tahsil and about 2 percent of the Beed district. Watershed is divided into 15 micro-watersheds having approximate size of about 1000 to 1400 ha. It consists of 28 census villages covered fully and or partially as delineation of the watershed boundary was done by following the natural parameters such as contour configuration, drainage network and underneath rock types. The elevation of the watershed ranges from 730 m above mean sea level at north-east border and gradually decreasing down to 575 m at the confluence of Sina and Talwar river

Mehkari and Bokadi are the two tributaries of Sina river flowing through the watershed. Ruti talav is constructed on Bokadi river near village Ruti. Mehkari river flows on north-west corner of watershed and meets Sina near village Nagalwadi. Talwar river flowing from north-eastern side of watershed and meets Sina near Kharkat village.

Watershed in general exhibits dendritic to sub-dendritic drainage pattern, commonly seen in basaltic topography. General pattern of drainage directions are north-east to south-west in upper half and southward in lower half of the watershed. The location and spatial extent of the study area is as shown in Fig. 3.1.

In general the climate of the study area is very dry. The maximum temperature ranges between 40⁰ C to 42⁰ C and minimum temperature ranges between 12⁰ C to 13⁰ C. The rainfall data of the study area is available from 1998 to 2005 and the average rainfall from the available data is 794 mm. Area comes under agro-climatic zone No. IX as per classification of Agriculture Department, Govt. of Maharashtra. The mean relative humidity was approximately 52.6 percent, but varies from 82.3 percent in February to 32.1 percent in August. Annual rainfall of stations surrounding SA - 13 watershed is given in Table 3.1.

Table 3.1: Annual Rainfall Around Study Area (2005)

Sr. No.	District	Tahsil	Rainfall (mm)
1	Ahmednagar	Newasa	479
		Pathardi	451
		Nagar	500
		Shrigonda	484
		Jamkhed	634
		Karjat	606
2	Beed	Shirur-Kasar	675
		Ashti	406.5
		Patoda	741

The rainfall data from 9 surrounding meteorological stations were used for estimating the average annual precipitation and location map of raingauge stations is as shown in Fig.3.2.

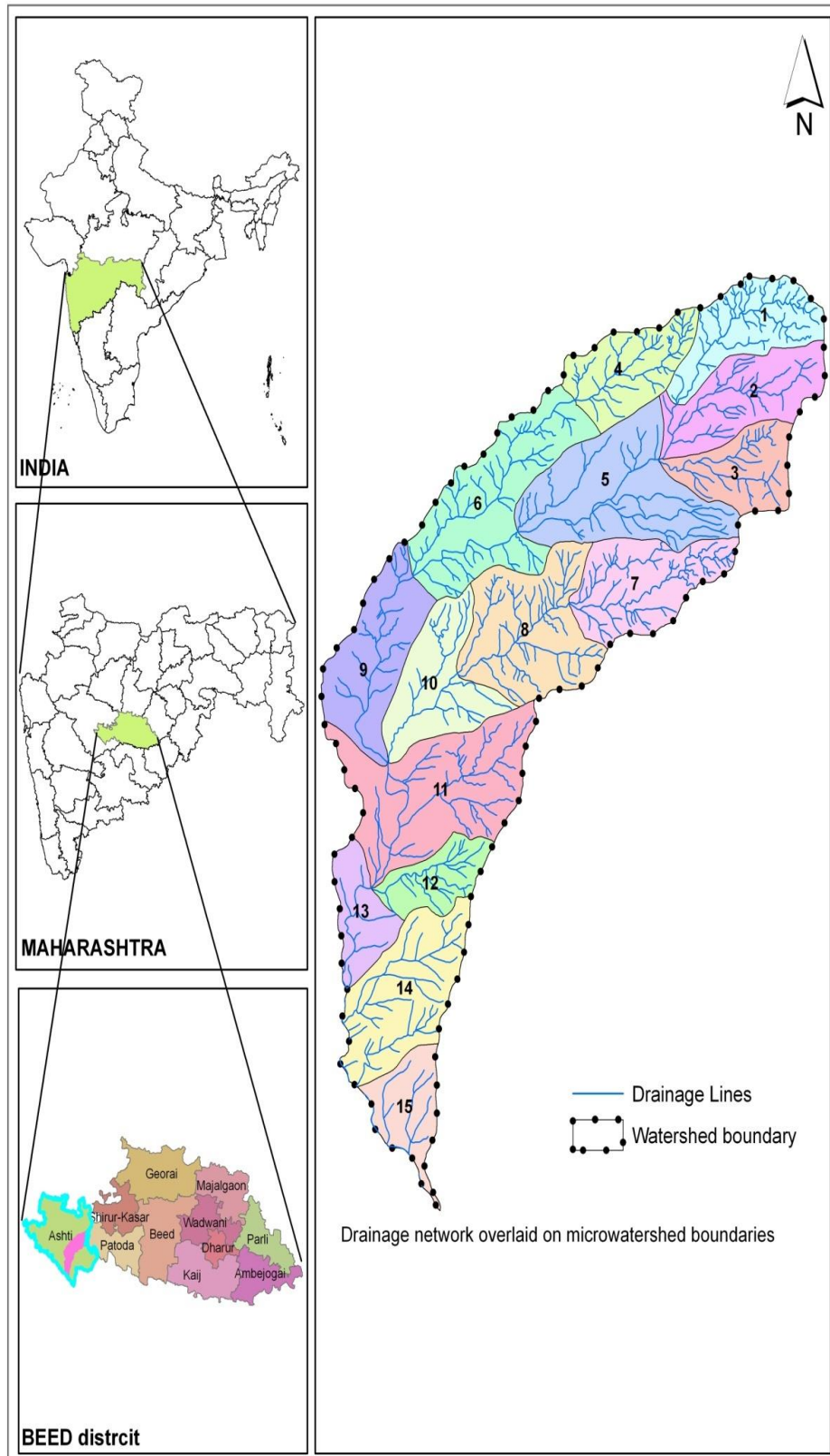


Fig 3.1: Location map of SA – 13 Watershed

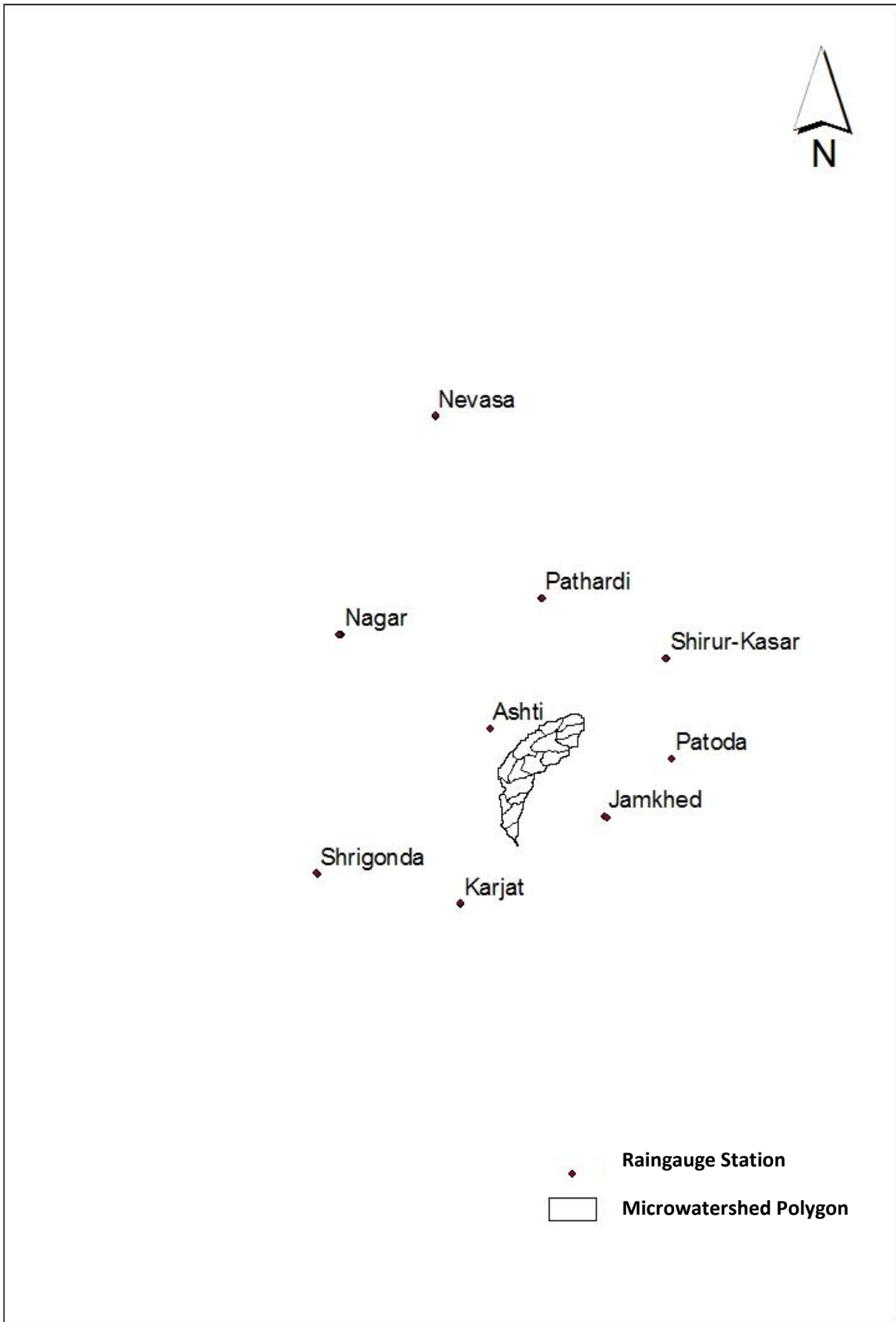


Fig 3.2: Location of Raingauge Stations

3.2 Collection of Data

Keeping in view the requirements of the present study, data from multiple sources in different formats was collected and used for analysis as per the need of the study. Ancillary data was collected in different formats, whereas the map database was generated by following Department of Space designed codification scheme. It was envisaged to use a range of datasets as detailed below:

- Multi-date satellite image of IRS-P6 (Resourcesat-1)
- Survey of India Topographic mapsheets on 1:50,000 scale.
- Ground truth information during different field validation visits.
- Administrative Boundary maps, Census and Other attribute data.

3.2.1 Remote Sensing Data

Multi-date Indian Remote Sensing satellite data (IRS-P6, Resourcesat-1) had been used for the present investigation having different spectral bands viz. red, infrared, near infrared etc. The data provided by IRS-P6 with spatial resolutions of 23.5 m depict a wide range of heterogeneity while homogeneity occurring in the watershed area owing to a synoptic coverage of Remote Sensing data. The details of the satellite datasets used in the present investigation are as given in Table 3.2.

Table 3.2: Satellite Data Used in the study

Sr.No.	Satellite	Sensor	Path / Row	Date of Pass	Resolution
1	IRS P6	LISS-III	096 / 059	8-Nov-05	23.5 m
2	IRS P6	LISS-III	096 / 059	19-Jan-06	23.5 m
3	IRS P6	LISS-III	096 / 059	25-Apr-06	23.5 m

IRS-P6 multi-sensor satellite offers a temporal resolution of 18 days. A pictorial view of SA -13 watershed in different seasons (multi season/multi-date), i.e. in November 2005, January 2006 and April 2006 as viewed from space is shown in Fig. 3.3, Fig 3.4 and Fig 3.5, respectively.

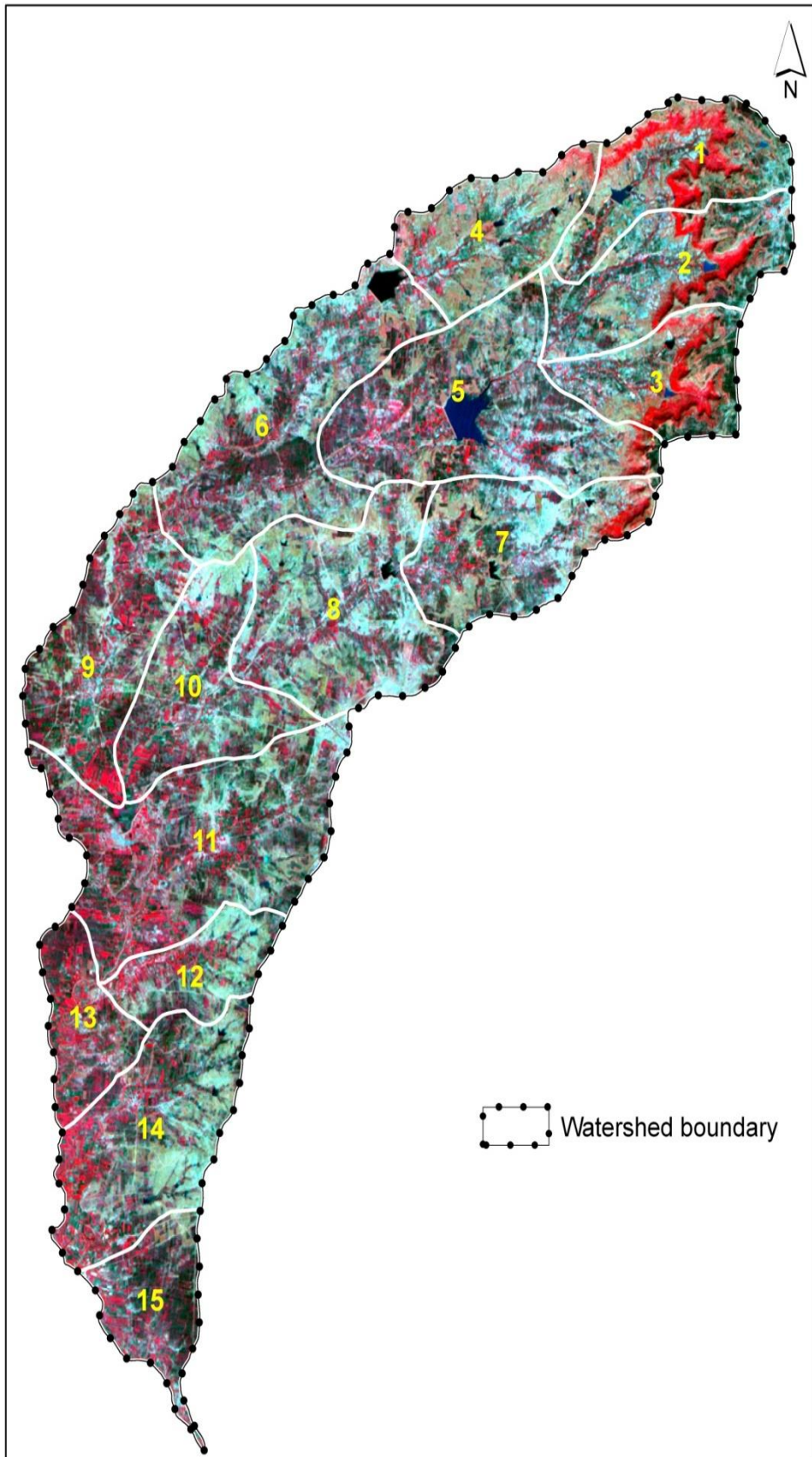


Fig 3.3: IRS P6, LISS-III satellite image of SA -13 Watershed, 8 November 2005

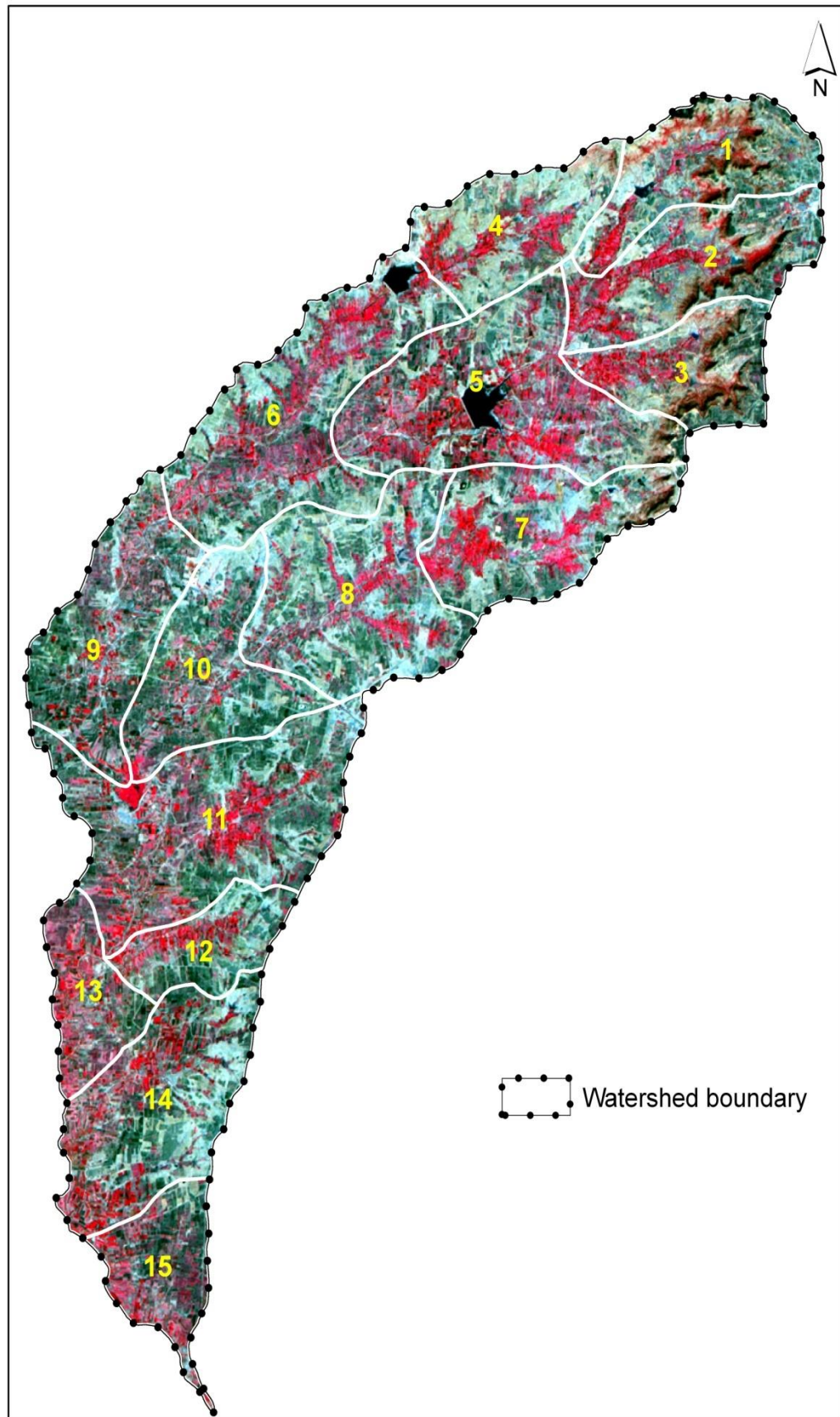


Fig 3.4: IRS P6, LISS-III satellite image of SA -13 Watershed, 19 January 2006

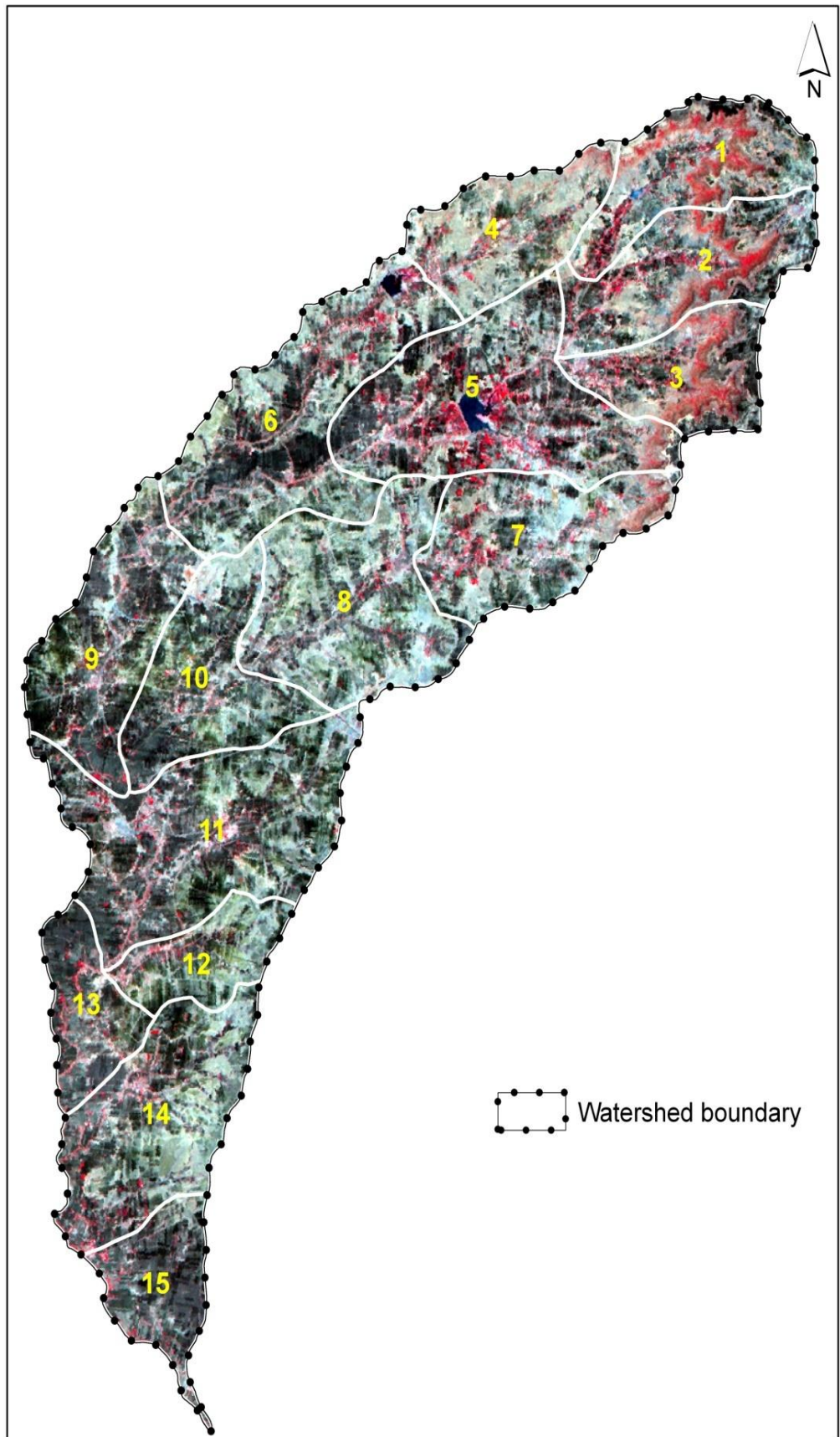


Fig 3.5: IRS P6, LISS-III satellite image of SA -13 Watershed 25 April 2006
3.2.2 Collateral, Ancillary and Ground Data

Collateral, ancillary and ground data increase the interpretation accuracy and reliability of remotely sensed data by enabling verification of interpreted details and by supplementing it with information which cannot be obtained directly on satellite imagery.

Survey of India Toposheets on 1:50,000 scales numbering 47 N/1, 47 N/2 and 47 N/5, corresponding to study area were used for base map preparation, locating field verification sites and to extract ground control points to rectify satellite data. Published data of BES (Bureau of Economics and Statistics) on land utilization pattern of different districts were also used for comparison and reconciliation of the area statistics.

3.2.3 Other Thematic Maps

Thematic maps such as land use map, soil map, slope map, Digital Elevation Model (DEM), watershed delineation and meteorological data based rainfall maps are the main inputs for hydrological studies.

- Land use map was prepared using IRS P6, LISS-III (23.5 m resolution) images in consultation with MRSAC, Nagpur and are updated and validated through field observations during present study period.
- Soil map prepared by MRSAC is used to derive the hydrological soil groups.
- SRTM (90 m resolution) data downloaded from the website of <http://glcf.umiacs.umd.edu/index.shtml> and processed to derive slope map.
- Daily rainfall data of Ashti raingauge station for the year 2005 was downloaded from Agriculture Department, Govt. of Maharashtra web site of <http://www.mahaagri.gov.in>

These thematic maps were prepared using remote sensing data, DEM data and rainfall data. Methodology adopted and database used are described in subsequent sections of this chapter.

3.2.4 Ground Truth Collection

Ground truth depends upon the extent of doubtful areas verified, the sampling procedure adopted during field traverses, accessibility, classification accuracy, etc.

During ground truth verification, abstraction of ground photographs of various categories of land use; enabled to compare the identification of each category on imagery with ground relevance were snapped. Interactions with local official / individuals were also made during ground visit. Detailed information like geology and rock type, growth stage of crop, ground cover percentage, soil type, moisture condition, ground water condition etc. was collected during field visit.

3.2.5 Software and Systems

ERDAS - Imagine 9.1, ARC-GIS 9.2, Arc-Info workstation, ArcView and MS-office suit were used for digital analysis, data creation and output generation. ArcGIS 9.2 is a suite of integrated applications that allow to perform GIS tasks, from simple to advanced, including mapping, geographic analysis, hydrology and spatial analysis, data editing and compilation, data management, visualization, and geo-processing, (ESRI User Manual, 1994). ERDAS-Imagine 9.1 is the image processing software, which supports pre processing of satellite data, (ERDAS Imagine Field Guide, 1998). MS-Office suite was used for statistical analysis, documentation and for presentation purpose. The high-end workstations equipped with the above packages available at MRSAC, were used for all above purpose.

3.3 Methodology

Various interpretation techniques and methodologies were adopted to prepare thematic maps for this hydrological studies which includes estimation of runoff and soil loss from the watershed.

3.3.1 Watershed Delineation

Concept of watershed as planning unit for development of land and water resources is widely accepted. A drainage basin or watershed is a natural unit draining runoff water to a common point. Watershed forms a convenient, clearly defined unambiguous topographic unit conceived on the basis of stream network, contour configuration and rock types. The size of watershed is dependent on the stream size, point of interception of stream, the drainage density, contour configuration and application project need.

Survey of India toposheets (1:50,000 scale) in combination with satellite image were used for watershed delineation, as toposheet provides location, drainage network and contours, satellite image helps in updating the information on waterbodies and drainage. Survey of India toposheets numbering 47 N/1, 47 N/2 and 47 N/5 had been used for watershed delineation. Contours, spot heights and elevation along with drainage pattern exhibited on the toposheets were the guiding features for micro-watershed delineation. 15 micro-watershed were delineated for the project area. Hierarchical 9 fold internationally adopted watershed classification nomenclature and codification system devised by AIS and LUS are adopted while delineating the watershed. Hierarchy started from Region, Basin, Catchment, Sub-catchment, Watershed, Sub-watershed, Mini-watershed up to Micro-watershed. Region was Bay of Bengal, Basin was Krishna while catchment spreads from upper Bhima to Sina.

3.3.2 Land Use Land Cover

Land use land cover was one of the most important thematic input in any study as it provide the present status of land utilization and its pattern. The change in the land use land cover is very dynamic that is why satellite remote sensing is widely used for its mapping. Land use refers to “man’s activities and the various uses which are carried on land”. Land cover refers to “natural vegetation, water bodies, rock/soil, artificial cover and others resulting due to land transformations”. Land use encompass several different aspects of man’s relationships to the environment e.g., activity, ownership and land quality.

Satellite data interpretation is defined as, “the art of examining images for the purpose of identifying surface features and their relationships through logical deductive process. Interpretation/analysis is carried in conjunction with other collateral and ground data”, (Lilliesand and Kiefer, 1987). Interpretation of multi-season satellite data had been carried out to generate the land use land cover map of the study area. Classification system suggested by NRSA 1989, was adopted in this study and given in Table 3.3. These detailed categories so delineated are further grouped into broad land use classes so as to make it compatible with classes suggested by Soil and Water Conservation Service 1972, to assign the CN numbers. The pre-processing techniques needs to be employed on

the satellite data before it can be used for actual interpretation. Pre-processing and image processing techniques of satellite data interpretation were elaborated below.

Table 3.3: Land Use Land Cover Classification (NRSA, 1989)

LEVEL-I	LEVEL-II	LEVEL-III
1. Built-up land	1.1 Towns/ Cities / Villages	1.1.1 Residential
2. Agricultural Land	2.1 Crop Land	2.1.1 Kharif 2.1.2 Rabi 2.1.3 Kharif + Rabi
	2.2 Fallows	2.2.1 Current fallow
3. Forests	3.1 Deciduous	3.1.1 Dense 3.1.2 Open 3.1.3 Scrub Forest
4. Wastelands	4.1 Gullied/Ravinous 4.2 Land with Scrub 4.3 Land without Scrub 4.4 Barren Rocky / Stony Waste	
5. Waterbodies	5.1 River 5.2 Tank	

3.3.2.1 Geometric Correction / Image Rectification

Geometric correction of satellite images involved modeling the relationship between the image and ground coordinate systems. There are both systematic and non-systematic geometric errors present in satellite imagery (Jenson, 1996). The systematic errors in satellite imagery were well documented, and were primarily functions of scan skew, mirror scan velocity, panoramic distortion, platform velocity, perspective and earth

rotation (Mather, 1999; Jenson, 1996). Satellite images were geo-corrected using 1:50000 topographic map and were projected by Lambert Conical Conformal projection, which is a real world coordinate system by giving appropriate projection parameters in terms of datum, spheroids, northing and easting, origin of centre latitude etc. The digital image was then resampled at 23.5 m pixel size.

3.3.2.2 Image Enhancement

Enhancement is the modification of an image to alter its impact on the viewer, (Sabins,1987). Enhancement is also used as a preprocessing step in applications where human viewing of an image is required for further processing. Overall, image enhancement methods are used to make images look better, (Schowengerdt,1983). Contrast enhancement and Histogram equalization were applied on the images of study to improve the appearance so as to aid in interpretation. Contrast enhancement, or stretching, expands the original brightness values to make use of the total range of the display device and may be linear or nonlinear. Histogram equalization seeks to distribute an equal number of pixel values to each interval. (Johnson,2009).

3.3.2.3 Image Classification

The purpose of classification is to link the spectral characteristics of the image to a meaningful information class value, which can be displayed as a map so that resource managers or scientist can evaluate the landscape in an accurate and cost effective manner (Weber and Dunno, 2001). Image classification is the process of establishing a link between a category of interest and a related spectral class. In the present study, hybrid classification approach (supervised, unsupervised and NDVI threshold) was adopted to classify the area into different land use classes. Supervised and Unsupervised classification is based on the fact that most remotely sensed image composed of spectral classes that are reasonably uniform with respect to reflectance across one or more spectral channels and can therefore be defined and mapped (Tou and Gonzalez, 1974). ISODATA (Iterative Self Organizing Data Analysis Technique) clustering or unsupervised approach had been adopted to separate out agriculture and non-agriculture

areas. Within the agriculture areas, combination of raw bands and various other indices were attempted and finally best separable bands were selected for analysis. Spectral vegetation indices that measure NIR and R radiance in visible and infrared bands were excellent inputs for characterization of agricultural area and helps in differentiating them from wasteland, water bodies and built-up areas. Multi-date classified images were further integrated to derive kharif, rabi and double crop areas. Survey of India forest boundaries were used to separate out notified forest areas and were further grouped into dense, open and scrub forest based on their NDVI thresholds and canopy cover.

3.3.3 Soil Mapping and Hydrological Soil Groups

The soil map of the study area has been prepared by MRSAC under the project IMSD (Integrated Mission for Sustainable Development) as per the guidelines of NBSS and LUP, 1995, AIS and LUS and Ministry of Agriculture was used for this purpose. Soil classification systems organize soils based on their characteristics and use. Soil scientist, hydrologist, construction designers, builders, engineers use soil classification systems, including hydrological groups, to determine soil's suitability for projects. Hydrological soil groups define and describe the rate at which water enters the soil surface and the rate at which it transmits through the soil. Soil properties greatly influence the amount of runoff. In the SCS method, these properties are represented by a hydrological parameter such as rate of infiltration obtained for a bare soil after prolonged wetting. The influence of both the soil's surface condition (infiltration rate) and its horizon (transmission rate) were important consideration in hydrological groupings. This parameter, which indicates a soil's runoff potential, was the qualitative basis of the classification of all soils into four groups. The Hydrological Soil Groups defined by the SCS are:

Group A: Soils having high infiltration rates when thoroughly wetted and a high rate of water transmission. Examples are deep, well to excessively drained sands or gravels.

Group B: Soils having moderate infiltration rates when thoroughly wetted and a moderate rate of water transmission. Examples are moderately deep to deep, moderately well to well drained soils with moderately fine to moderately coarse textures.

Group C: Soils having low infiltration rates when thoroughly wetted and a low rate of water transmission. Examples are soils with a layer that impedes the downward movement of water or soils of moderately fine to fine texture.

Group D: Soils having very low infiltration rates when thoroughly wetted and a very low rate of water transmission. Examples are clay soils with a high swelling potential, soils with a permanently high water table, soils with a clay pan or clay layer at or near the surface, or shallow soils over nearly impervious material.

3.3.4 Slope Extraction from SRTM DEM

Digital Elevation Model (DEM) is the continuous representation of elevation values over a topographic surface by a regular array of z-values, referenced to a common datum. DEM represents a very important geospatial data type in the analysis and modeling of different hydrological studies such as runoff and soil loss estimation. DEMs are typically used to represent terrain relief and are relevant for many applications such as lake and water volumes estimation, soil erosion volumes calculations, flood estimate, quantification of earth materials to be moved for channels, roads, dams, embankment etc. Surface-water hydrologic applications begin with raster data of the terrain due to the wide availability of DEMs and intrinsic GIS software functions to conduct digital terrain processing, (Johnson, 2009).

In this study, DEM data which was acquired by Shuttle Radar Topography Mission (SRTM) was downloaded from (<http://glcf.umiacs.umd.edu/index.shtml>) website and was used after re-projecting it into Lambert Conical Conformal projection and clipping to study area boundary. SRTM DEM is used to understand the drainage networks, elevation and generate slope by using Spatial Analyst module of GIS. Many hydrological functions were supported by this module.

3.3.5 Runoff Estimation by SCS Curve Number Method

The Soil Conservation Service (SCS) Curve Number (CN) method (SCS, 1972), also known as the Hydrologic Soil Cover Complex Method was developed by the Soil SCS, U.S. Department of Agriculture for hydrological studies. It is a versatile and widely

used procedure for runoff estimation. The requirements for this method are rainfall amount and curve number. CN is dimensionless and its value varies from 0 to 100. The curve number is based on the hydrologic soil group, land use treatment and hydrologic condition. As defined by SCS soil scientists, soil were classified into four hydrologic groups (A, B, C and D), (USDA, 1985), depend on infiltration and soil classification. Land use and treatment classes were used in the preparation of hydrological soil-cover complex. It is used in estimating direct runoff. Overall methodology adopted in the study for estimating runoff is depicted in the Fig.3.6

Antecedent Moisture Condition (AMC) is an indicator of watershed wetness and availability of soil moisture storage prior to a storm, and has a significant effect on runoff volume. Recognizing its significance, SCS developed a guide for adjusting

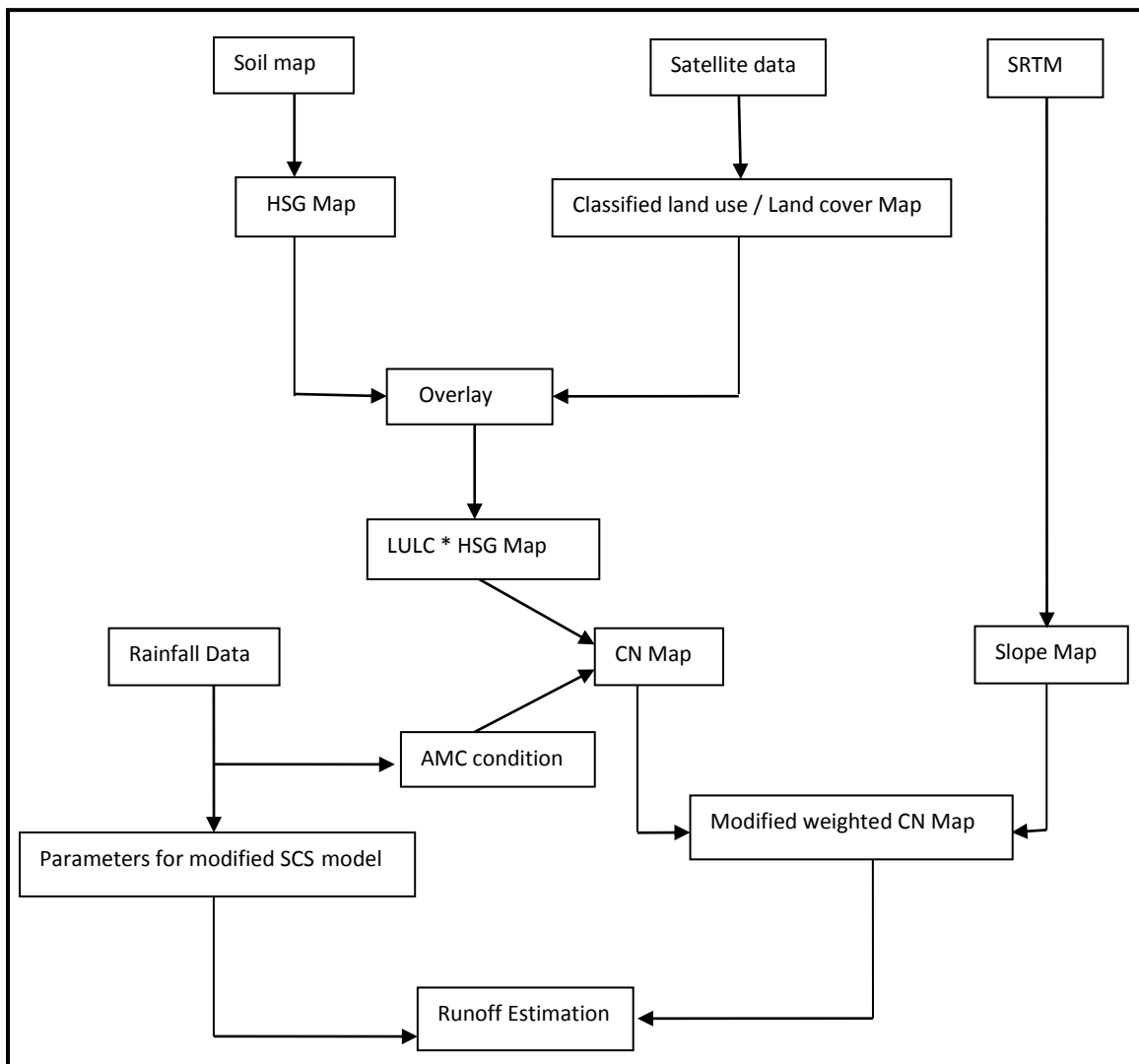


Fig. 3.6: Flow Chart for Runoff Estimation

CN according to AMC based on the total rainfall in the 5-day period preceding a storm. Three levels of AMC are used in the CN method: AMC-I for dry, AMC-II for normal, and AMC-III for wet conditions. Table 3.4 gives seasonal rainfall limits for these three antecedent moisture conditions.

Table 3.4: Classification of Antecedent Moisture Condition

AMC	5-days Antecedent Rainfall (mm)	
	Active growing season	Dormant season
I	Dry (< 35)	Dry (< 12.5)
II	Medium (35 to 52.5)	Medium (12.5 to 27.5)
III	Wet (> 52.5)	Wet (> 27.5)

The CN method is based on the recharge capacity of the watershed. The recharge capacity is determined by antecedent moisture conditions and physical characteristics of the watershed. The storage capacity (S) can be obtained from CN by using the following relationship

$$S = \frac{24500}{CN} - 245 \quad \dots(3.1)$$

Where,

S = Maximum recharge capacity of watershed after 5 days rainfall antecedent, mm

CN = Curve Number.

In the past 30 years the SCS method has been used by a few researchers because it gives consistently usable results (Rao *et. al.*, 1996; Sharma *et al.*, 2001; Chandramohan and Durbude, 2001; Sharma and Kumar, 2002) for runoff estimation. Putting the value of Curve Number in above, the recharge capacity 'S' was calculated. The direct runoff of the watershed was calculated using following equation.

$$Q = 0, \quad \text{If } P \leq 0.2S$$

$$Q = \frac{(P-0.2S)^2}{P+0.8S} \quad \text{If } P > 0.2S \quad \dots(3.2)$$

Where,

Q = Runoff depth, mm

P = Rainfall, mm

S = Maximum recharge capacity of watershed after 5 days rainfall antecedent, mm

3.3.5.1 Generating CN Map

The SCS-CN method is the most popular method for computing surface run off for rainfall event. This approach involves the use of simple empirical formula and readily available data. SCS-CN method is a viable method for estimating the effects of land treatment and land use changes on volumes of run-off under the wide range of climatic conditions. The advantages of this method are its simplicity, predictability, stability and its reliance on only one parameter namely the Curve Number (CN).

To generate the CN map, the hydrologic soil group and land use maps were integrated in GIS environment. An integrated, hydrological soil-cover complex map with new polygons representing the merged soil hydrologic group and land use was generated. Hydrological soil-cover complex map generated were compared with CN Table given by SCS and appropriate CN is assigned to each polygon with due consideration to hydrologic condition of the terrain and land use present in the watershed. The CN values for different land uses and hydrologic soil groups were adopted from Technical Release 55, (USDA-NRCS, 1986). Weighted CN map was generated using following equation

$$CN = \frac{\sum CN_i \times A_i}{A} \quad \dots(3.3)$$

Where,

CN = weighted curve number.

CNi = curve number from 1, 2, 3,...i.

Ai = area with curve number CNi

A = total area of the watershed.

3.3.5.2 Antecedent Moisture Condition (AMC)

The CN values for each polygon was calculated for average conditions (i.e. Antecedent Moisture Condition Class II). To determine which AMC class was the most

appropriately related to study area, the use of rainfall data is necessary. The CN values are documented for the case of AMC-II (USDA, 1985). To calculate CN values for AMC-I and AMC-III conditions, the following equations are used (Chow, 2002):

$$\text{CN for AMC I,} \quad \text{CN}_{\text{I}} = \frac{4.2 * \text{CN}_{\text{II}}}{10 - (0.058 * \text{CN}_{\text{II}})} \quad \dots (3.4)$$

$$\text{CN for AMC III,} \quad \text{CN}_{\text{III}} = \frac{23 * \text{CN}_{\text{II}}}{10 + (0.13 + \text{CN}_{\text{II}})} \quad \dots (3.5)$$

Where,

$\text{CN}_{\text{(II)}} =$ curve number for normal condition,

$\text{CN}_{\text{(I)}} =$ curve number for dry condition, and

$\text{CN}_{\text{(III)}} =$ curve number for wet condition.

3.3.5.3 Slope-Adjusted CN

Slope has profound impact on determination of CN values therefore incorporating slope values in CN and adjusting CN values accordingly is essential from hydrology study point of view. To achieve this slope and CN maps were intersected to get slopes of each polygon. Since each polygon has different slopes, calculating weighted slope is needed for each polygon. Weighted slope of a polygon was computed using formula (3.6).

$$\text{Weighted slope} = \frac{\sum_{i=1}^n a_i \times s_i}{A} \quad \dots (3.6)$$

Where,

$a_i =$ area of slope, ha.

$s_i =$ slope in percent

$A =$ polygon area, ha

Weighted slope of polygon was applied in equation (3.8) to compute slope adjusted CN values. The Huang *et al.* (2006) approach was used because of the improvement made to incorporate the slope factor into the analysis.

The CN values for AMC II condition is calculated by formula (3.8) considering the slope correction and then CN II modified is converted in to CN values for AMC I and AMC III condition by using following equations (3.7) and (3.9),

$$CN_I = CN_{II} - \left(\frac{20(100 - CN_{II})}{(100 - CN_{II} + \exp[2.533 - 0.0636(100 - CN_{II}])]} \right) \quad \dots(3.7)$$

$$CN_{II} \text{ Mod-II} = CN_{II} \left(\frac{322.79 + 15.63\alpha}{\alpha + 323.52} \right) \quad \dots(3.8)$$

$$CN_{III} = CN_{II} \times \exp [0.00673(100 - CN_{II})] \quad \dots(3.9)$$

The daily rainfall data for the years 2005 for the study area and the values of maximum potential retention, S obtained from the CN for the watershed area were used for the estimation of runoff from SCS (model).

3.3.6 Soil Erosion by Revised Universal Soil Loss Equation (RUSLE)

The Revised Universal Soil Loss Equation (RUSLE) (Renard *et. al*, 1997) is a modified and revised version of Universal Soil Loss Equation (USLE) suggested by Wischmeier and Smith, 1978, originally developed to predict erosion on croplands in the United States. With the revision, the equation can be employed in a variety of environments including rangeland, mine sites, construction sites, etc. In this study RUSLE an empirical equation is used and estimated annual soil loss in croplands (tons / ha / year) resulting from sheet and rill erosion. The RUSLE is based on series of factors, each quantifying one or more processes and their interactions, are combined to estimate overall soil loss. The overall schema of estimating annual soil loss using remote sensing and GIS techniques are given in Fig. 3.7.

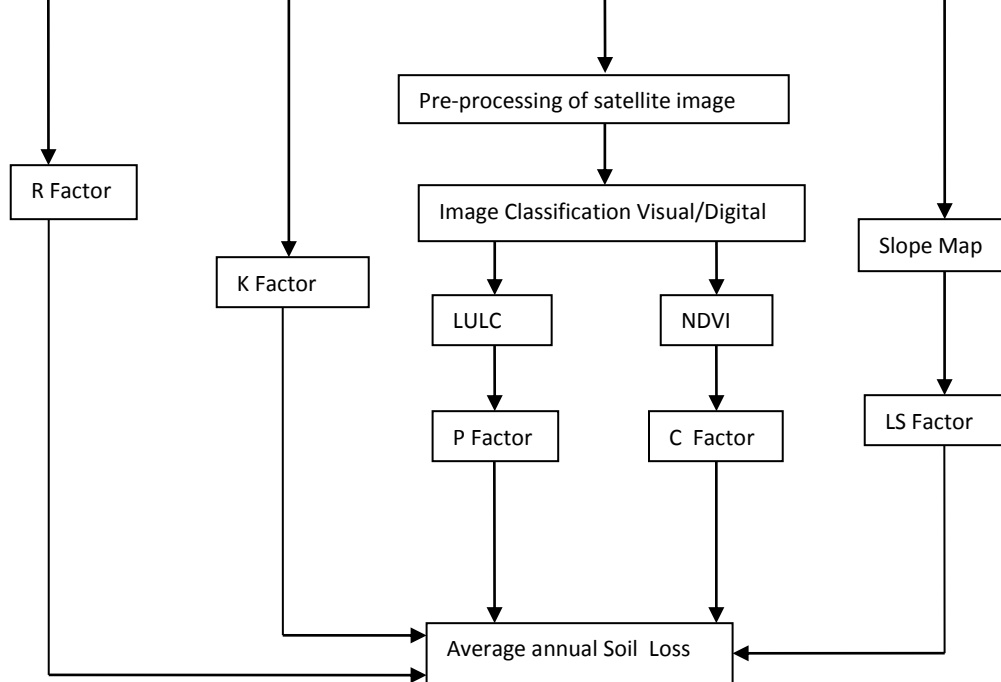


Fig. 3.7: Flow Chart for Estimation of Annual Soil Loss

Annual soil loss potential from different categories of land uses has been calculated using RUSLE equation, as under:

$$A = R \times K \times L \times S \times C \times P \quad \dots(3.10)$$

Where,

- A = Gross amount of soil erosion (t / ha / year);
- R = Rainfall erosivity factor (MJ -mm /ha-hr-yr);
- K = Soil erodibility factor (t-ha- hr/ ha-MJ- mm);
- L = Slope length factor (dimensionless);
- S = Slope steepness / gradient factor
- C = Cover management factor (dimensionless) and
- P = Support practice factor (dimensionless)

3.3.6.1 R-Factor (Rainfall Erosivity Factor)

Soil loss is closely related to rainfall partly through the detaching power of raindrops striking the soil surface and partly through the contribution of rain to runoff (Morgan, 1994). Rainfall data from nine rainfall stations surrounding the SA - 13 watershed (Newasa, Shrigonda, Jamkhed, Pathardi, Nagar and Karjat of Ahmednagar district and Ashti, Patoda and Shirur kasar of Beed) were used in this study to calculate rainfall erosivity factor (R-value). Monthly precipitation for these stations were collected

for the year 2005 from the website <http://www.mahaagri.gov.in>. An equivalent R factor had been developed for the climatic conditions of the SA - 13 watershed. The monthly precipitation surface was interpolated to determine the value of each cell. Inverse Distance Weighted (IDW) technique was adopted to generate interpolated rain image (rain.img) to find the R-factor. The R-factor was calculated in the raster calculator module of ArcGIS incorporating following formula. (Ram Babu *et. al.*, 2004.)

$$R \text{ Factor} = 81.5 + [0.380 \times (R_N)] , 340 \leq R_N \leq 3500 \text{mm} \quad \dots(3.11)$$

Where,

R-Factor = Rainfall erosivity factor

R_n = Average annual rainfall, mm

3.3.6.2 K-Factor (Soil Erodibility Factor)

The erodibility of a soil is an expression of its inherent resistance to particle detachment and transport by rainfall. The K factor accounts for the susceptibility of soil particles to detachment and movement by water (Romkens *et al.*, 1997). Soil erodibility index (g / J) is the weight of soil detached from the soil mass per unit of rainfall energy. It is integrated effect of the processes that regulate rainfall acceptance and the resistance of the soil to particle detachment and subsequent transport. These processes are influenced by soil particle, of which soil texture is an important factor that influences erodibility. It is determined by the cohesive force between the soil particles, and may vary depending on the presence or absence of plant cover, the soil's water content and the development of its structure (Wischmeier and Smith, 1978). K values had been estimated for all the vertical layers of the soil series by using the analytical relationship for the nomograph by Atawoo and Heerasing (1997) given as below,

$$100K = (2.1 \times 10^4 \times (2 - OM) \times m^{1.14} + 3.25 \times (St - 2) + 2.5 \times (Pt - 3)) \quad \dots(3.12)$$

Where,

K = Soil erodibility (tons-yr/MJ-mm),

OM = % Organic Matter,

Pt = Permeability Code,

St= Soil Structure Code,

M = A function of the primary particle size function given by
M = (% silt+% sand content)

3.3.6.3 L and S Factor (Slope Length and Steepness Factor)

The L and S factor (topographic factor) accounts for the effect of topography on erosion in RUSLE method. The slope length factor (L) represents the effect of slope length on erosion, and the slope steepness factor (S) reflects the influence of slope gradient on erosion. For this study L is the flow length and S is slope steepness which is given by meter and percent, respectively. Basically, the LS factor can be estimated through field measurement. In the present investigation LS factors were computed in Spatial Analyst module of ArcGIS using SRTM DEM of 90 m resolution. Slope gradient (S) and slope length (L) were determined and combined to form a single factor known as the topographic factor. The accuracy of estimation depends on the resolution of DEM. The Topographic factor in the present study was therefore computed by using the equation stated by Moore & Wilson (1992).

$$LS = (A_s/22.13)^n \times (\sin\beta/0.0896)^m \quad \dots(3.13)$$

Where,

A_s = the specific area (=Alb), defined as the upslope contributing area for an overland cell (A) per unit width normal to the flow direction (b);

β = the slope gradient in degrees;

$n = 0.4$; for 3 to 4 % slope

$m = 1.3$

The slope steepness factor S, is evaluated by relationship developed by McCool et al. (1987, 1993),

$$S = 10.8\sin\theta + 0.03 \quad S < 9\% \quad (\text{i.e. } \tan\theta \leq 0.09) \quad \dots(3.14a)$$

$$S = (\sin\theta/\sin 5.143)^{0.6} \quad S \leq 9\% \quad (\text{i.e. } \tan\theta \geq 0.09) \quad \dots(3.14b)$$

β is calculated as,

$$\beta = (\sin\theta/0.0896)/[3.0(\sin\theta)^{0.8} + 0.56] \quad \dots(3.15)$$

Where,

θ = slope angle

The combined topographic (LS) factor was computed rather than the individual slope length and slope angle factors. The inputs for the computation include the slope in percent and the slope length as a flow length.

3.3.6.4 C-Factor (Cover Management Factor)

The C factor is the cover management factor. The cover management factor (C) represents the effects of vegetation, management and erosion control practices on soil erosion. The C factor, the second most important factor (after topography) that controls soil erosion risk, reflects the effects of cropping and management practices on soil erosion rates as the soil loss decreases when the vegetation cover increases (Lu *et al.* 2004). It is defined as the ratio of soil loss from land cropped under specific cover to the corresponding loss from identical area clean-tilled, continuous fallow (Wischmeier and Smith 1978). Currently, due to the variety of land cover patterns with spatial and temporal variations, satellite remote sensing data sets were used for the assessment of C factor (Karydas *et al.* 2009; Tian *et al.* 2009). The Normalized Difference Vegetation Index (NDVI), an indicator of the vegetation vigor and health are used along with the following formula to generate the C factor image for the study area (Zhou *et al.* 2008; Kouli *et al.* 2009).

$$\text{NDVI} = \frac{\text{NIR}-\text{R}}{\text{NIR}+\text{R}} \quad \dots(3.16)$$

Where,

NDVI = Normalized Difference Vegetation Index (ratio varying from -1 to +1).

NIR = Near Infrared Band.

R = Red Band

As the cover management factor is the ratio of soil loss from an area with specified cover and management to that of an area in tilled continuous fallow. De Jong (1994) in his PhD thesis described the use of NDVI in order to extract vegetation parameters for erosion models. He assumed that there is linear correlation exist between NDVI and C-factor. Based on these assumptions the NDVI map was generated for the watershed to formulate the linear equation between NDVI and C-factor. The NDVI values less than zero indicates water and other non-vegetated features, so the negative

values are not considered in preparing the C-factor equation. With these boundary conditions the regression equation for C factor was developed.

$$C = 0 \quad \text{NDVI} \leq 0 \quad \dots(3.17a)$$

$$C = -0.50 \text{NDVI} + 1 \quad 0 < \text{NDVI} \leq 0.68 \quad \dots(3.17b)$$

$$C = 0 \quad \text{NDVI} \geq 0.68 \quad \dots(3.18c)$$

Raster Calculator tool of the Spatial Analyst extension of ArcGIS software was used to calculate C - factor from NDVI. NDVI is a spectral ratio between near infrared (NIR) and red (R) reflectance and was extracted from IRS P6, LISS-III satellite image of rabi season (19 January 2006) and the linear equation developed (Van der Knijff *et al.*, 2000).

3.3.6.5 P-Factor (Support Practice Factor)

The management practice factor (P-factor) reflects the effects of practices that will reduce the amount and rate of runoff thereby reducing the erosion (Renard *et al.* 1997; Dabral *et al.* 2008; Yue-qing *et al.* 2008). The P-factor represents the ratio of soil loss by a support practice to that of straight-row farming up and down the slope. In the study the watershed was broadly divided into three zones by considering the present land use land cover practices and support factors (rabi season image reflects the management practices undertaken in the watershed in terms of soil moisture and vegetation cover). The values of P-factor ranges from 0.25 to 1, in which the highest value is assigned to areas with no conservation practices (forest / natural vegetation) and the minimum values corresponds to crop land with strip and contour cropping. P values were determined by the extent of individual conservation practices, such as contouring, strip cropping and terracing, which can also be used in combination. The values of conservation practice factor for different management practices were adopted for the SA - 13 watershed as suggested by Hann *et al.* (1994). The P-factor was assumed by using the Conservation practice of the study area and the value of P factor for strip cropping was taken as 0.37. (Stone and Hilborn, 2000).

IV. RESULTS AND DISCUSSION

In the present study, an attempt has been made to estimate the runoff volume due to the rainfall occurred in watershed SA-13 area. The Revised Universal Soil Loss Equation (RUSLE) was used for estimating erosion from SA-13 watershed. The runoff and soil erosion of watershed SA-13 was analyzed as described in the various sections of previous chapter to understand quantity of the runoff and soil erosion for the watershed management programme for conservation and development of natural resources.

The results and the interpolations of the analysis for planning of watershed programme are presented in the following sections of this chapter.

4.1 Runoff Estimation

Rainfall runoff is an important component contributing significantly to the hydrological cycle, design of hydrological structures and morphology of the drainage system. Rainstorms generate runoff, and its occurrence and quantity are dependent on the characteristics of the rainfall event, i.e. the intensity, duration and distribution. Apart from these rainfall characteristics, there are number of watershed specific factors, which have a direct effect on the occurrence and volume of runoff. Estimation of direct rainfall-runoff relationship is always needed but is not possible for most of the location at desired time. Use of remote sensing and GIS technology can be used to overcome the problem over conventional method for estimating runoff caused due to rainfall. In this study, modified Soil Conservation System (SCS) CN model was used for rainfall-runoff estimation that considers parameter like soil type, vegetation cover, slope and watershed characteristics. SCS-CN provides an empirical relationship for estimating initial abstraction and runoff as a function of soil type and land use. Rainfall runoff relationship can be visualized by the factors such as initial abstraction, runoff and actual retention. The Curve Number (CN) is an index developed by the Natural Resource Conservation Service (NRCS), to represent the potential for storm water runoff within a drainage area. The CN for a drainage basin was estimated using a combination of land use, soil, and antecedent soil moisture condition (AMC).

4.1.1 Land Use Land Cover

Major land use land cover classes identified in SA - 13 watershed using three season satellite data is depicted in Fig. 4.1. There were eight land use land cover categories viz. kharif, rabi, seasonal fallow, double crop, forest, wasteland, water bodies and settlement in the study area.

Watershed was dominantly agrarian in nature with other categories such as forest, wasteland, settlement and water bodies. Agriculture categories observed in the watershed were kharif season crops, rabi season crops, seasonal fallows and area cropped twice in a year called as double crop area. Area statistics of delineated land use / land cover categories is given in Table 4.1 and depicted in Fig. 4.2.

Table 4.1: Land Use Land Cover Statistics in Study Area

Sr. No.	Land Use Categories	Area (ha)	% of Total Geographical Area
1	Kharif	2777.32	13.04
2	Rabi	1839.04	08.63
3	Fallow	8775.55	41.20
4	Double crop	4455.65	20.92
5	Forest	1127.10	05.29
6	Wasteland	2039.26	09.57
7	Settlement	29.60	00.14
8	Waterbody	256.47	01.20
	Total	21300.00	100.00

Cropped areas were registered on satellite imagery in tones varying from pink to red and bright red depending on the greenness of crop vegetation, stage of growth, nature of canopy, status of health, crop management practices and kind and nature of soil exposed in inter-canopy slits etc. Agriculture land was also subdivided into cropland and fallow land. In this study, kharif, rabi and double crop (kharif + rabi) were interpreted along with seasonal fallow. In total 17,847.56 ha of area was demarcated as agriculture

land which was 83.79 per cent of the total area of the watershed. Seasonal cropping such as kharif, rabi and fallows occupy about 13.04, 8.63 and 41.20 percent, respectively.

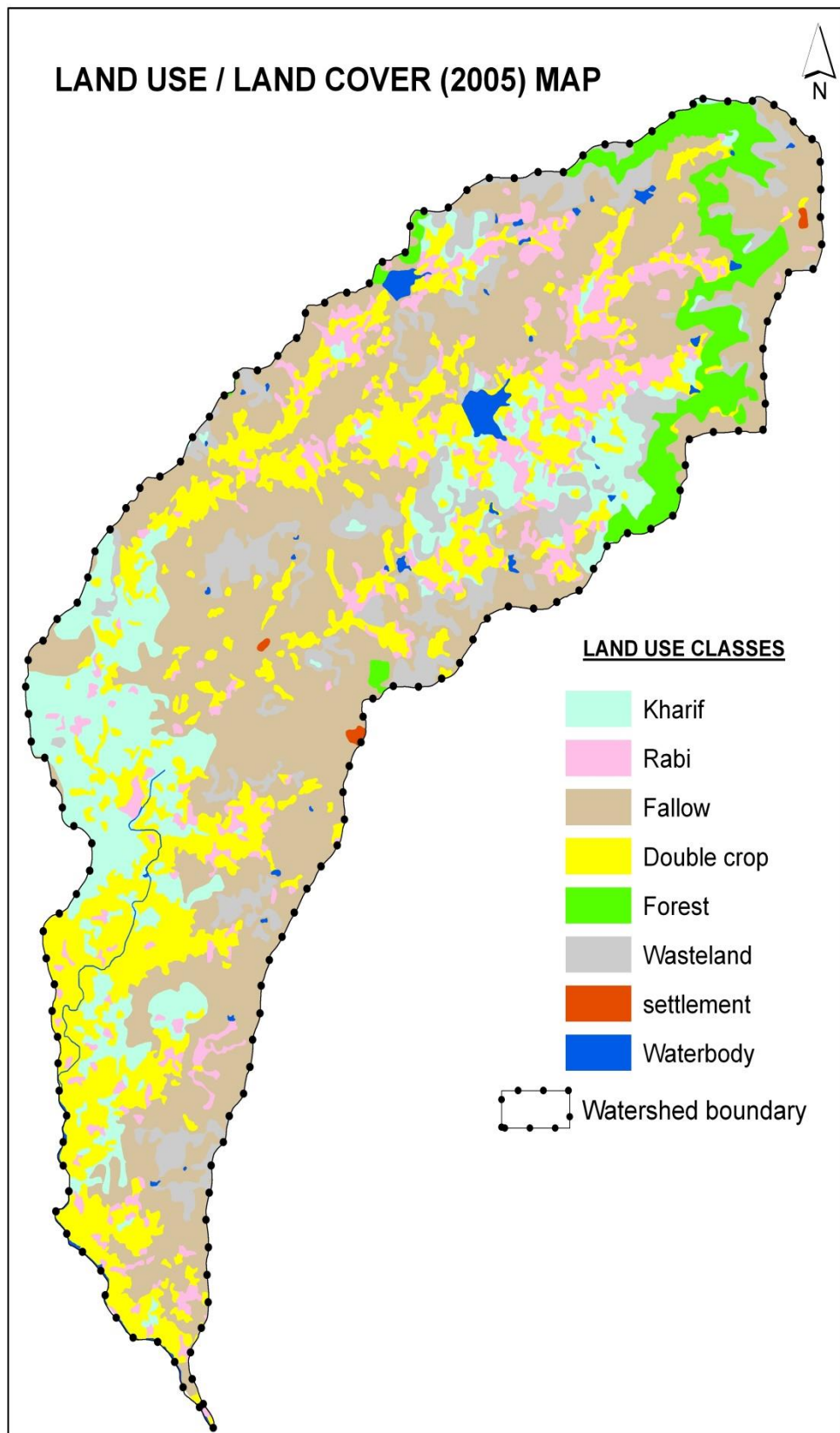


Fig 4.1: Land Use Land Cover Map of SA-13 Watershed

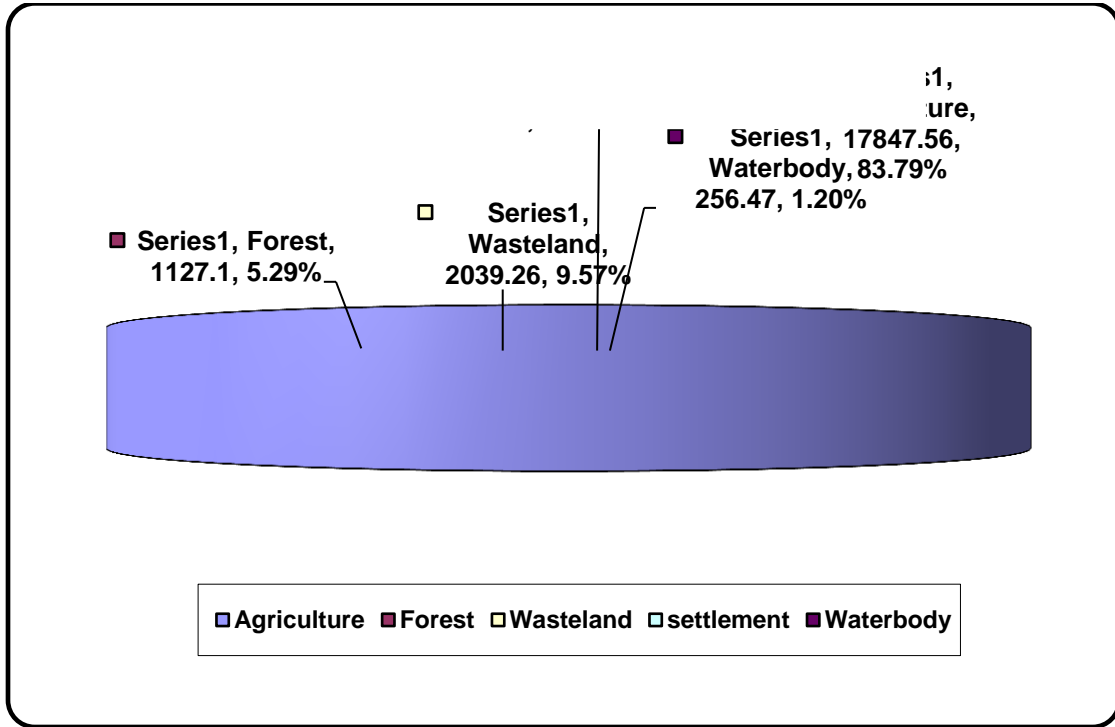


Fig. 4.2: Dominant Land Use

Watershed was dominated by dry deciduous type of forest, occupying the undulating areas and hills in northern part. Based on the canopy coverage the forest area was categorized as Dense, Open and Degraded forest (reported as total forest area). The total area under forest was 1127.10 ha, which was 5.29 per cent of the total watershed area.

Wastelands was mainly the non-arable areas occupying undulating landforms and the hill slopes. The total 2039.26 ha area under this category, which was 9.57 per cent of the total watershed area. Other classes, such as settlement and water bodies occupy about 29.60 and 256.47 ha, respectively.

4.1.2 Hydrologic Soil Groups

The soils, located at atmosphere-lithosphere interface, plays an important role in determining the amount of precipitation that runs off the land and the amount that enters the soil for storage and for future use. Soils play a key role in water retention and storage.

Hydrologic soil groupings are based on the pretext that soils found within a climatic region that are similar in depth to a restrictive layer or water table, transmission rate of water, texture, structure, and degree of swelling when saturated, will have similar runoff responses. The classes are based on intake and transmission of water under the conditions of maximum yearly wetness (thoroughly wet).

Soils of the watershed were classified into hydrologic soil groups B, C and D based on infiltration and runoff generating potentials. Hydrologic group A was absent in the study area. Hydrologic soil groups occurring in the area are depicted in Fig. 4.3 and area statistics is presented in Table 4.2

Table 4.2: Hydrologic Soil Groups in the Watershed

Sr. No.	Hydrologic Soil Group	Area (ha)	% of Total Geographical Area
1	B	1885.5	8.85
2	C	14821.0	69.58
3	D	3759.7	17.65
4	Others(Habitation Mask, Waterbody Mask)	833.8	3.92
Total		21300.0	100.00

(Source: Integrated Mission for Sustainable Development, MRSAC, Nagpur)

It was observed from Table 4.2, that watershed consists of Hydrologic Soil Group (HSG) B, C and D. HSG-C occupies highest aerial extent of about 14,821 ha which is 69.58 percent of the total geographical area of the watershed. Dominance of HSG-C indicates that the soils in the watershed have moderately fine to fine texture with slow rate of water transmission, with slow rate of infiltration when thoroughly wetted. HSG-C soils are spread all over the watershed in inter-drainage areas where water divide line exist with moderate elevation. These areas are conspicuously cultivated for rainfed crops.

HSG-D spread over about 3759.7 ha covers 17.65 percent area of watershed. These soils have very slow rate of water transmission owing to their very high clay percentage with high swelling potentials with permanently high water table. Spatially, soils of this group occurred in drainage valleys of watershed and also in northern portion

of watershed where hills and elevated topography with soils of slow water transmission exist.

Area occupied by HSG-B was very less i.e. 1885.5 ha which was mere 8.85 percent of watershed area. Soils of HSG-B have moderate infiltration rate and are moderately deep to deep in nature, with moderate water transmission rate. These soil groups were seen mainly on first order drainages of watershed, occupying moderate elevation of watershed. They were forming catchment zones for smaller water bodies located in the watershed.

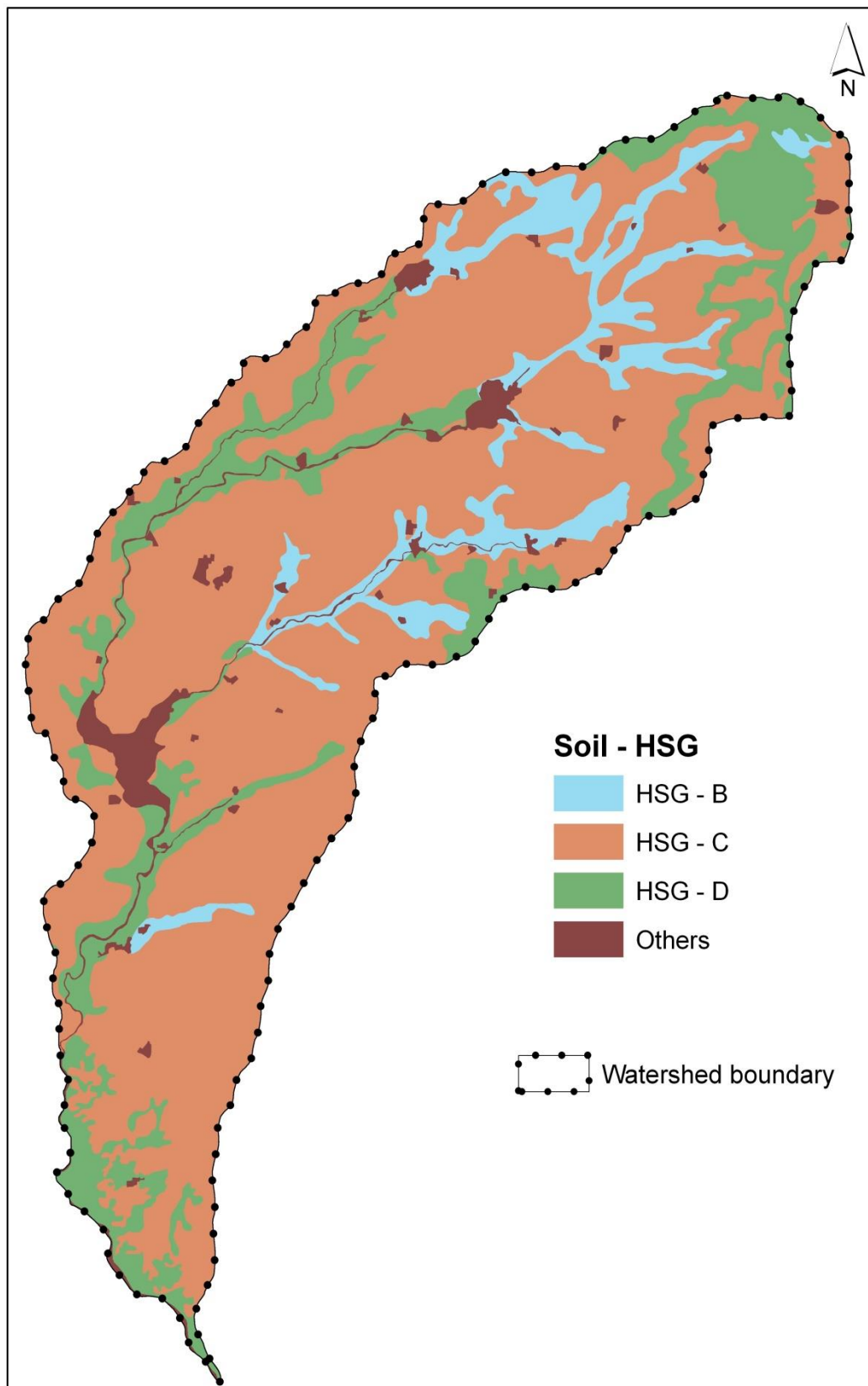


Fig.4.3: Hydrological Soil Group (HSG) Map of SA-13 Watershed

4.1.3 CN Values

The Soil Conservation Services (SCS) model developed by United States Department of Agriculture (USDA) computes direct runoff through an empirical equation that requires the rainfall and watershed coefficient as input. The watershed coefficient is called the Curve Number (CN), which represents the runoff potential of the land cover soil complex. This model involves relationship between land cover, hydrologic soil class and CN. The method is based on an assumption of proportionality between retention and runoff. Watershed under study (SA-13) was divided into 15 micro watersheds. Initially, after considering the land use classes, hydrologic conditions and HSG groups prevailing in the area, Curve Numbers were assigned to each micro-watershed (Table 4.3) for AMC condition II ($I_a=0.2S$), based on standard tables suggested by Soil Conservation Services, 1972). Composite curve number for each micro-watershed was calculated by multiplying weights according to the area occupied by each land use class and the corresponding curve numbers.

Table 4.3: Curve Numbers for Hydrologic soil-Cover Complex for AMC Class II ($I_a=0.2S$)

Sr.No.	Land Use Categories	Hydrologic Soil Groups		
		B	C	D
1	Kharif	81	88	91
2	Rabi	76	84	88
3	Fallow	86	91	94
4	Double Crop	77	85	89
5	Forest	66	77	83
6	Wasteland	82	87	89

(Source: Soil Conservation Service, 1972)

The weighted CN values were further corrected using slope in m/m (initially estimated in degrees and then converted to radians). Mean slope of each micro-watershed was

multiplied with weighted CN to derive slope corrected or slope adjusted CN values for each micro-watershed and are given in Table 4.4. Final CN values in each micro-watershed for AMC II are estimated and depicted in Fig.4.4.

Table 4.4: Micro-watershed wise Mean CN

Micro-watersheds in SA - 13 Watershed	Slope m/m	Average CN / AMC II	Modified CN
1	13.32	87	88
2	10.31	88	88
3	14.28	86	87
4	7.91	86	87
5	3.96	87	87
6	4.35	90	90
7	8.15	87	87
8	4.15	88	88
9	4.18	90	90
10	2.47	90	89
11	4.24	90	90
12	4.08	89	88
13	5.36	89	90
14	4.82	90	90
15	8.86	93	94

It was observed from Table 4.4 that final slope corrected CN values derived for each micro-watershed are varying from 88 to 94. Hydrological soil groups C and D leading to higher CN values whereas hydrologic soil group B leads to relatively low CN values. The lowest CN was found 88 whereas highest CN was 94. This indicates that SA-13 watershed generates higher runoff for these considerable high CN values, as CN values increase runoff would also increase. Any change in land use can alter CN values of the

watershed and accordingly the runoff response also favorable to generate more runoff volume.(Mellesse and Shih, 2002).

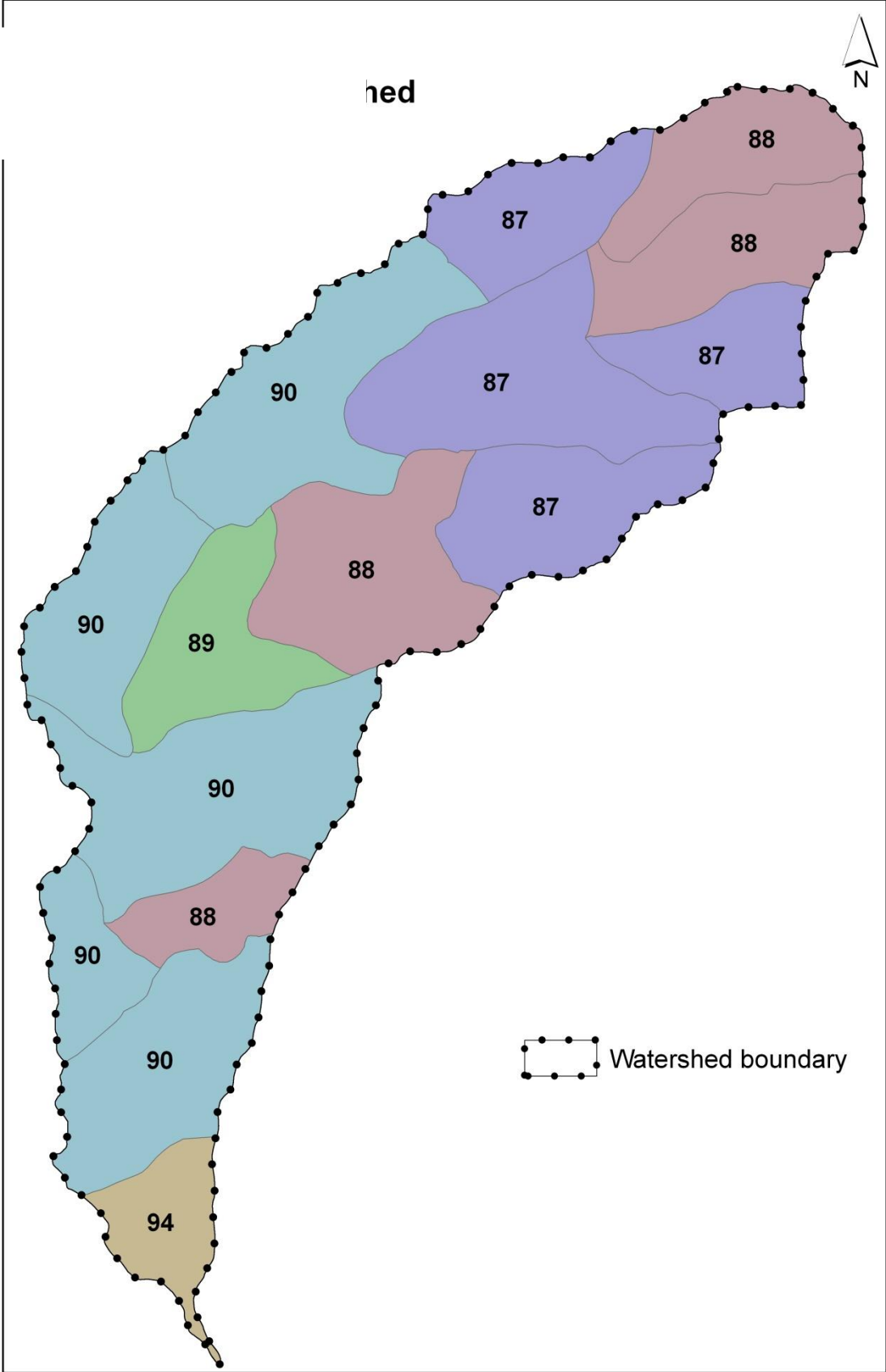


Fig.4.4: Micro-watershed wise Mean CN Map of SA-13 Watershed

4.1.4 Runoff Depth

The rainfall data of SA - 13 watershed was obtained for the year 2005 and runoff estimation based on SCS-CN method had been carried out for 15 micro-watershed areas. Daily estimations of runoff were aggregated on monthly basis and further cumulative scenario on rainfall, runoff and percent runoff depth are given in Table 4.5.

Table 4.5: Rainfall and Runoff Depth for the Year 2005

Micro-watershed	Rainfall (mm)	Runoff (mm)	% Runoff
1	406.5	89.05	21.91
2	406.5	89.05	21.91
3	406.5	83.32	20.50
4	406.5	83.32	20.50
5	406.5	83.32	20.50
6	406.5	102.54	25.23
7	406.5	83.32	20.50
8	406.5	89.05	21.91
9	406.5	102.54	25.23
10	406.5	95.42	23.47
11	406.5	102.54	25.23
12	406.5	89.05	21.91
13	406.5	102.54	25.23
14	406.5	102.54	25.23
15	406.5	143.46	35.29
Average	406.5	96.07	23.63

It was observed from Table 4.5 that, average annual rainfall in the watershed for the year 2005 was 406.50 mm and average annual runoff depth was 96.07 mm, amounting to 23.63 percent of the total rainfall. Micro-watershed numbering 3, 4, 5 and 7 generate lower runoff amounting 20.50 percent whereas micro-watershed no. 15 generated higher runoff of 35.29 percent. Micro-watershed No. 1, 2, 8 and 12 generate runoff amounting

21.91 percent. Micro-watershed No. 6, 9, 11, 13 and 14 generate runoff amounting 25.23 percent. Micro-watershed No. 10 generates runoff amounting 23.47 percent.

4.2 Soil Loss Estimation

Soil loss is defined as the amount of soil lost in a specified time period over an area of land. It is expressed in units of mass per unit area (t/ ha/ year). This study uses the RUSLE (Revised Universal Soil Loss Equation) to estimate annual soil loss from agricultural watershed. Soil loss values estimated using RUSLE depend upon six major parameters i.e. R-factor (rainfall and runoff), K-factor (soil erodibility), L-factor (slope length factor), S-factor (slope steepness), C-factor (cover and management) and P-factor (support practice factors). The result of individual RUSLE parameters and average annual soil loss estimated are as follows.

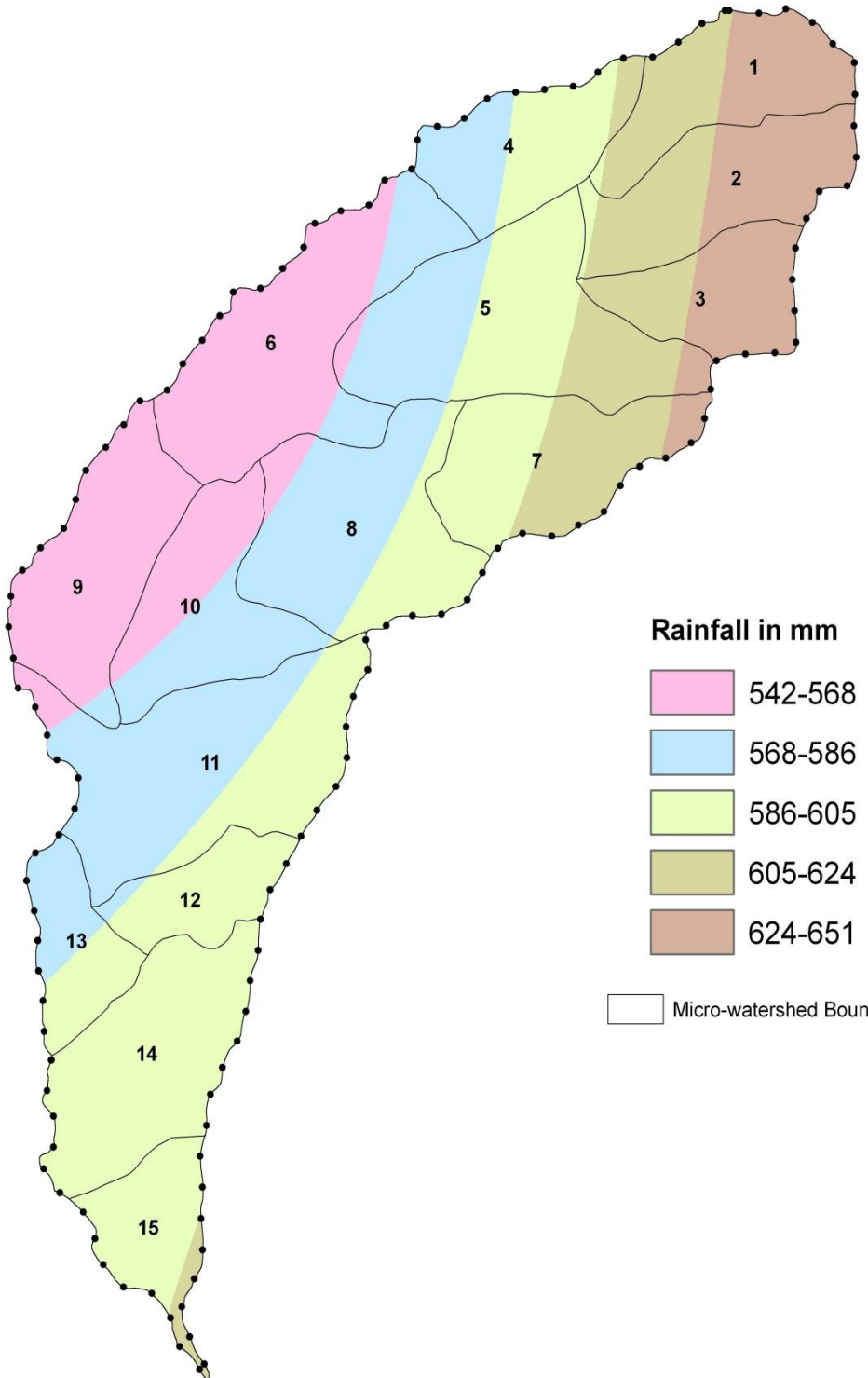
4.2.1 R-Factor (Rainfall Erosivity Factor)

The rainfall distribution was not homogeneous all over the study area, for this reason an interpolation of annual precipitation data was applied (using IDW interpolation technique) to have a more representative rainfall distribution. The rainfall data from 9 surrounding meteorological stations were used for estimating the average annual precipitation. Fig.4.5 indicates that overall variation of rainfall from 542 to 651 mm occurred in the watershed which was gradually decreasing from northeast to central-west region of the watershed. Highest rainfall zone of 624 to 651 mm seen in north-east corner of the watershed where forest and hill topography exist. Lower rainfall zone of 542 to 568 mm occupies central-west portion of the study area. The interpolated rainfall image had been further used for calculation of rainfall and runoff erosivity R-factor in raster calculator utility of 'Spatial Analyst' module of ArcGIS software.

Rainfall influences soil erosion in two distinct ways i.e. by the kinetic energy that each raindrop possesses, which causes soil particles to detach from one another due to impact. The intensity of the rainfall event, which is a function of the amount of rainfall deposited over a specific time interval. R-factor map of the SA-13 watershed is depicted in Fig.4.6, as R-factor is defined as the product of kinetic energy and the maximum 30 minute intensity and shows the erosivity of rainfall events (Wischmeier and Smith, 1978).

R - factor values for SA - 13 watershed varies from 287 to 329, tending higher values at northeast corner and gradually decreasing down to central-west part of the study area. This shows that the value of R factor varies according to rainfall distribution.

2005)



Rainfall in mm

-  542-568
-  568-586
-  586-605
-  605-624
-  624-651

 Micro-watershed Boundaries

**Fig.4.5: Distribution of Mean Annual Precipitation(2005) in SA-13
Watershed**

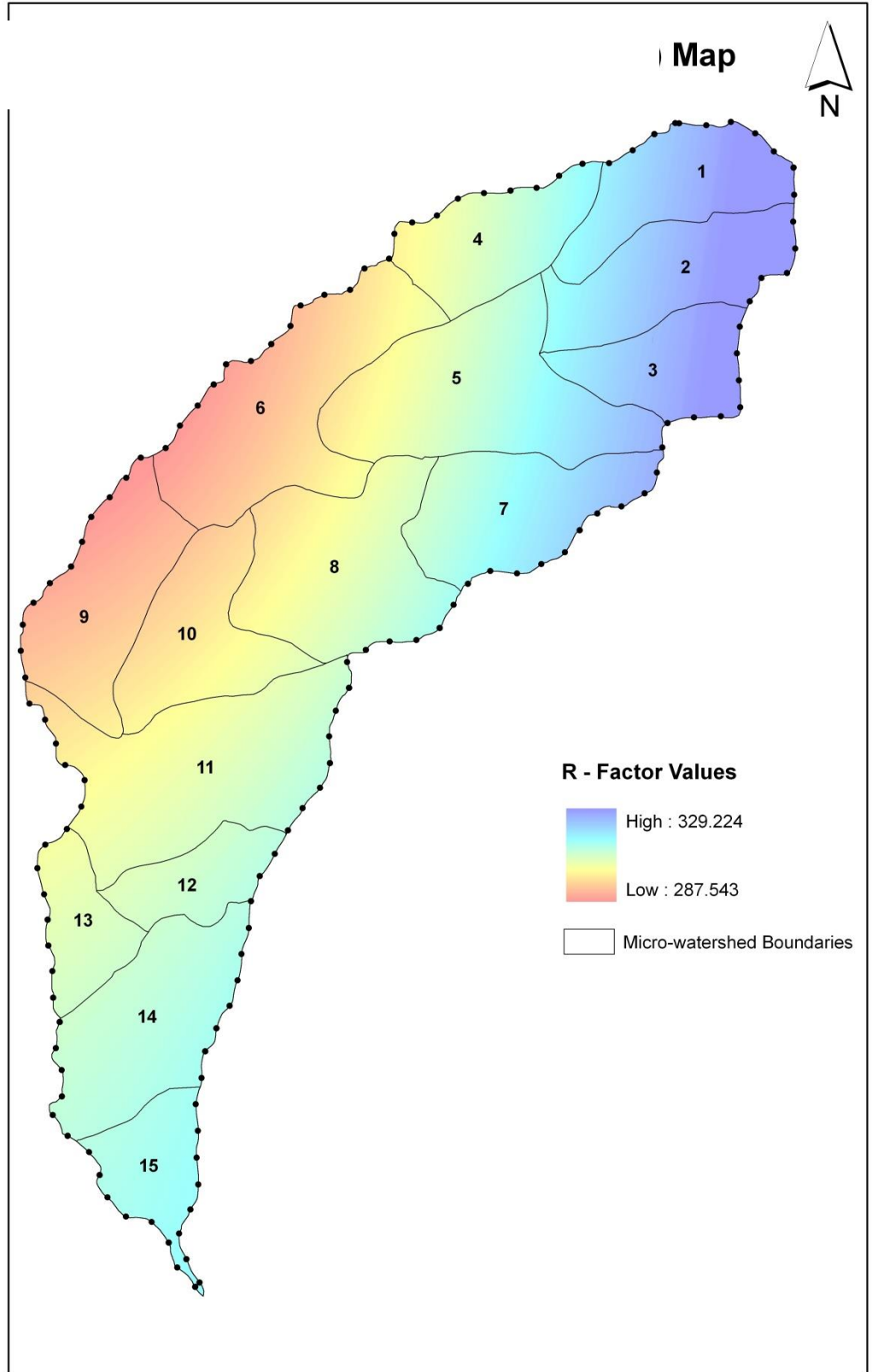


Fig 4.6: R Factor Map of SA-13 Watershed

4.2.2 K-Factor (Soil Erodibility Factor)

The K factor reflects the fact that different soils erode at different rates when the other factors affecting erosion remains the same. Soil texture was the principal cause affecting the K-factor along with soil structure, organic matter content, and permeability. A map for the K-factor was generated based on above soil parameters and presented in Fig. 4.7. For SA-13 watershed K-factors was varying between 0.00 and 0.32, which depict soil susceptibility to erosion, the sediment transportability and runoff rate. One assumption was made that only the top soil layer is the most susceptible to erosion. Therefore, only the K factor values for the top portion of each soil type was used. Area occupied by K factors in SA-13 watershed is given in Table 4.6.

Table 4.6: Area Statistics of K - Factor in SA-13 Watershed

Sr.No	K – Factor	Area (ha)	% Total Geographical Area
1	0.00	936.88	4.40
2	0.22	18707.12	87.83
3	0.26	1288.92	6.05
4	0.32	367.10	1.72
Total		21300.00	100

It was observed from the above table that maximum area of the watershed i.e. 87.83 percent (18,707.12 ha) has K factor 0.22. K factor 0.26, 0.00 and 0.32 has area of 6.05 percent, 4.40 percent and 1.72 percent, respectively. K factor in the watershed ranges from 0.00 to 0.32. Mean K factor of the watershed is 0.25.

4.2.3 L and S Factor (Slope Length and Steepness Factor)

L and S factors in combination are called as topographic factor, both of which are determined using Digital Elevation Model (DEM). For the calculation of topographic factor filled DEM was required. Filling a DEM can be described as identifying any sinks or cells that have a lower elevation value than the surrounding cells and giving them a

higher elevation value (Jennings, 2001). When the sinks are filled the area is given an average value, which is calculated using the value of the neighboring cells. Hydrology functions in ArcGIS is used to derive topographical factor. Slope map was derived using SRTM DEM is given in Fig. 4.8.

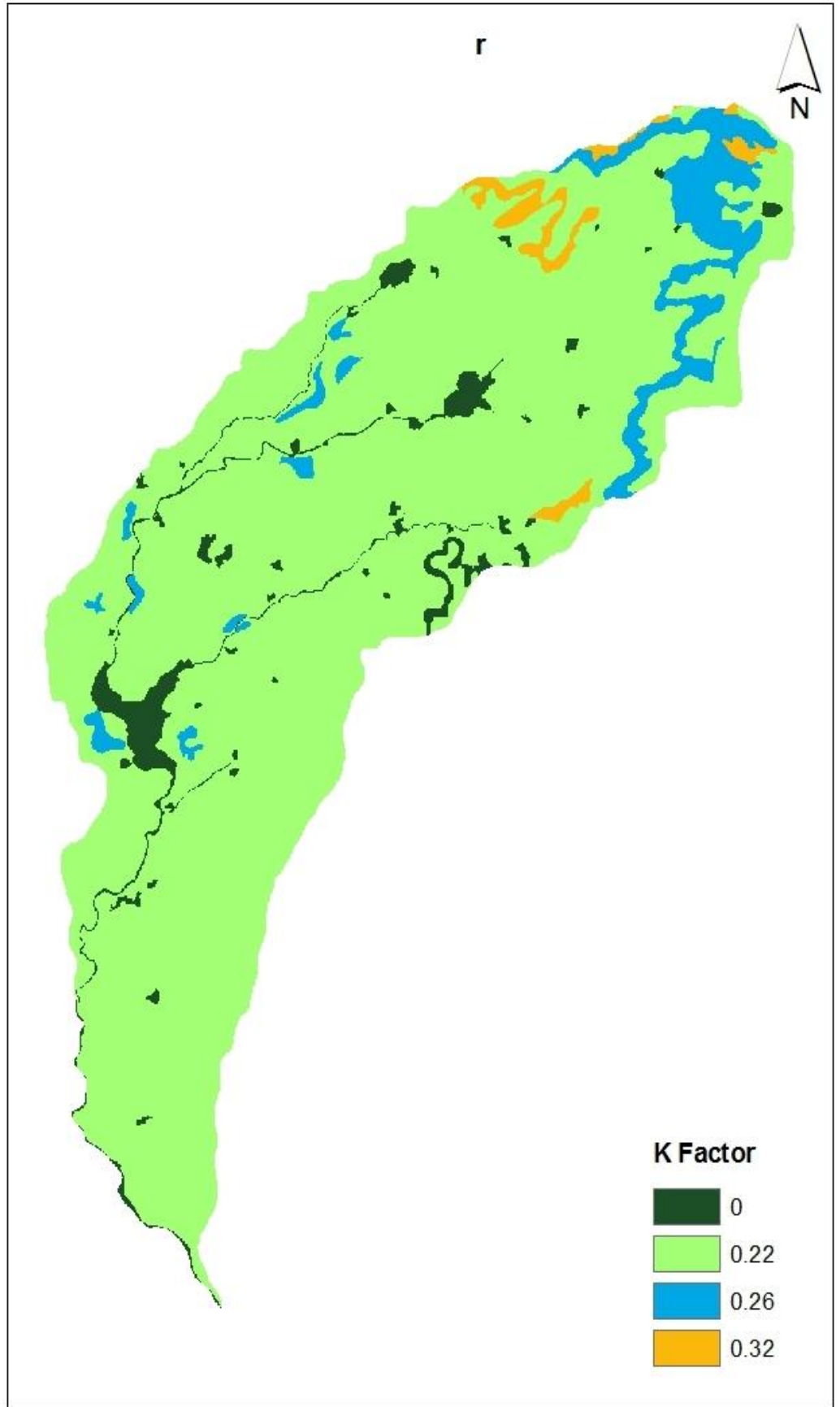


Fig.4.7: K Factor Map of SA-13 Watershed

Slope is varying from 0 to 79.45 degrees. Higher slopes are concentrated on northeastern part of the watershed whereas, it is gradually decreasing towards south. Slope length is defined as the horizontal distance from the origin of overland flow to the point where either the slope gradient decreases to a point where deposition begins, or runoff becomes concentrated in a defined channel (Renard et al., 1997).

The L and S factors in RUSLE reflect of topography of watershed. The LS factor in the present study was computed for overland cells by using the equation stated by Moore and Wilson (1972). The value of LS-factor varies from 0 to 10. The Topographic factor map of SA-13 watershed is depicted in Fig 4.9.

4.2.4 C-Factor (Cover Management Factor)

In the present study remote sensing techniques was employed for mapping vegetation condition of a watershed. Vegetation cover was one of the most important biophysical indicator to soil erosion. Vegetation cover can be estimated using vegetation indices derived from satellite images. Vegetation indices allow to delineate the distribution of vegetation and soil based on the characteristic reflectance patterns of green vegetation. The Normalized Difference Vegetation Index (NDVI), measures the amount of green vegetation. The spectral reflectance difference between Near Infrared (NIR) and Red (R) is used to calculate NDVI. NDVI image of SA-13 watershed is presented in Fig. 4.10, showing range of values between - 0.5 to 0.68.

Vegetation cover protects the soil by dissipating the raindrop energy before reaching soil surface. The C factor is the cover management factor. The cover management factor is the ratio of soil loss from an area with specified cover and management to that of an area in tilled continuous fallow. The value of C depends on vegetation type, stage of growth and cover percentage and varies between 0 and 1 (Gitas *et al.*, 2009). Soil erosion can be controlled by managing vegetation, plant residues, and soil tillage. Erosion and runoff are markedly affected by different types of vegetative cover and by cropping systems. Undisturbed forests and dense grass provide the best soil protection based on their canopy coverage. In the study, the cover management factor C reflects the effect of cropping and management practices on the soil erosion rate. C factor map of the

watershed is presented in Fig.4.11. The value of C-factor varies from 0.44 to 1 depending on the NDVI.

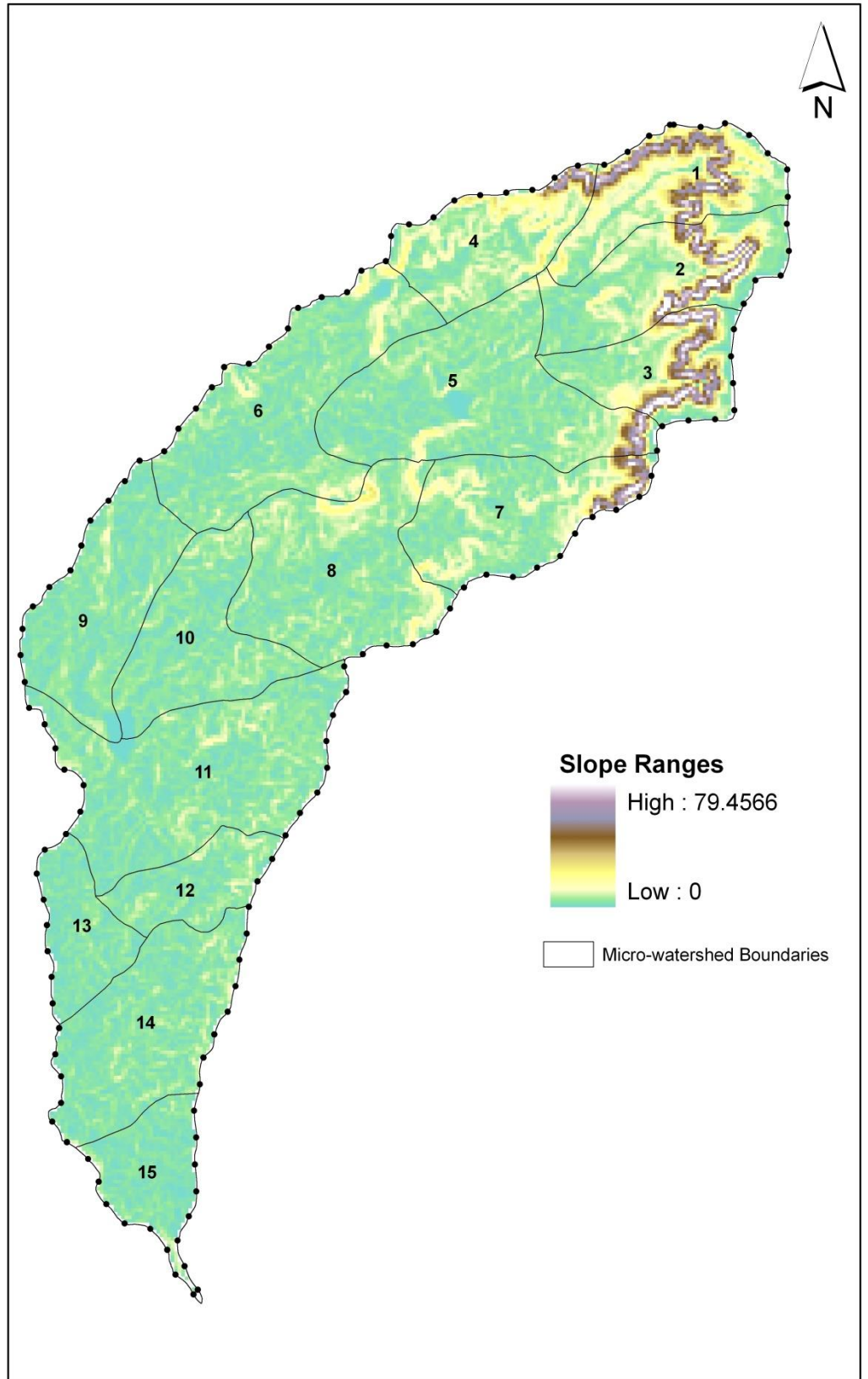


Fig.4.8: Slope Map of SA-13 Watershed

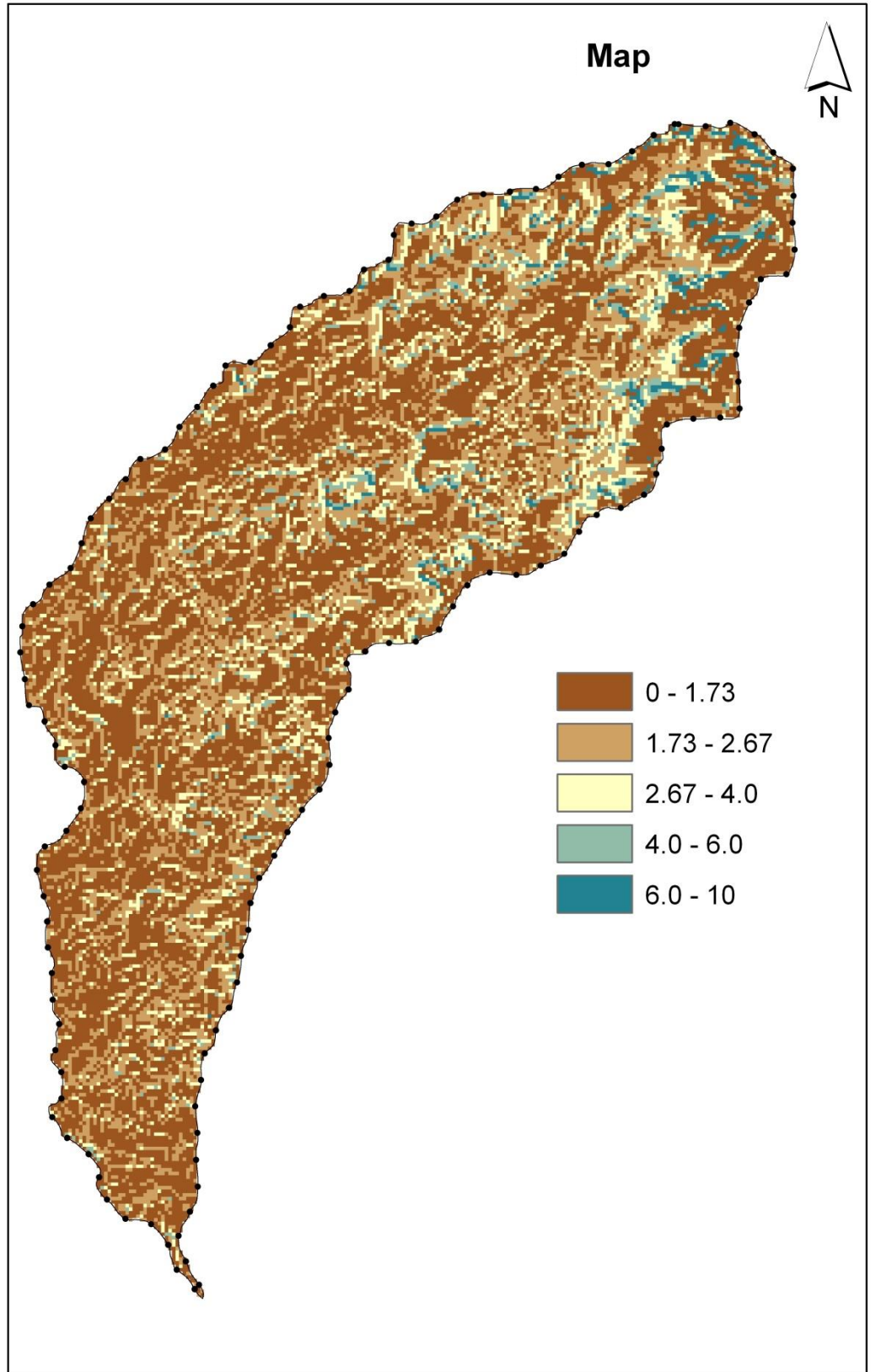


Fig.4.9: Topographic Factor Map of SA-13 Watershed

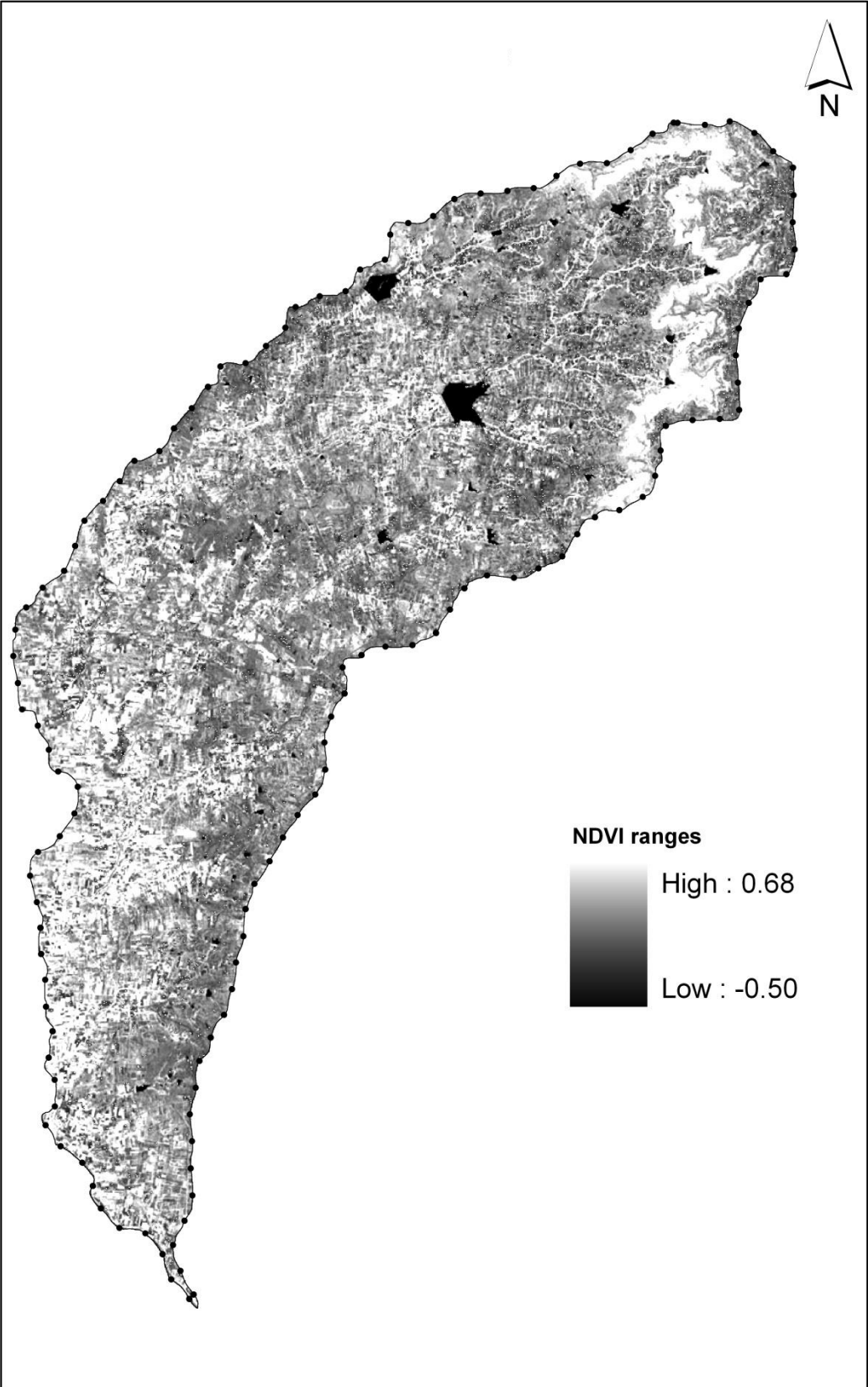


Fig 4.10: NDVI Image (Nov, 2005) of SA-13 Watershed

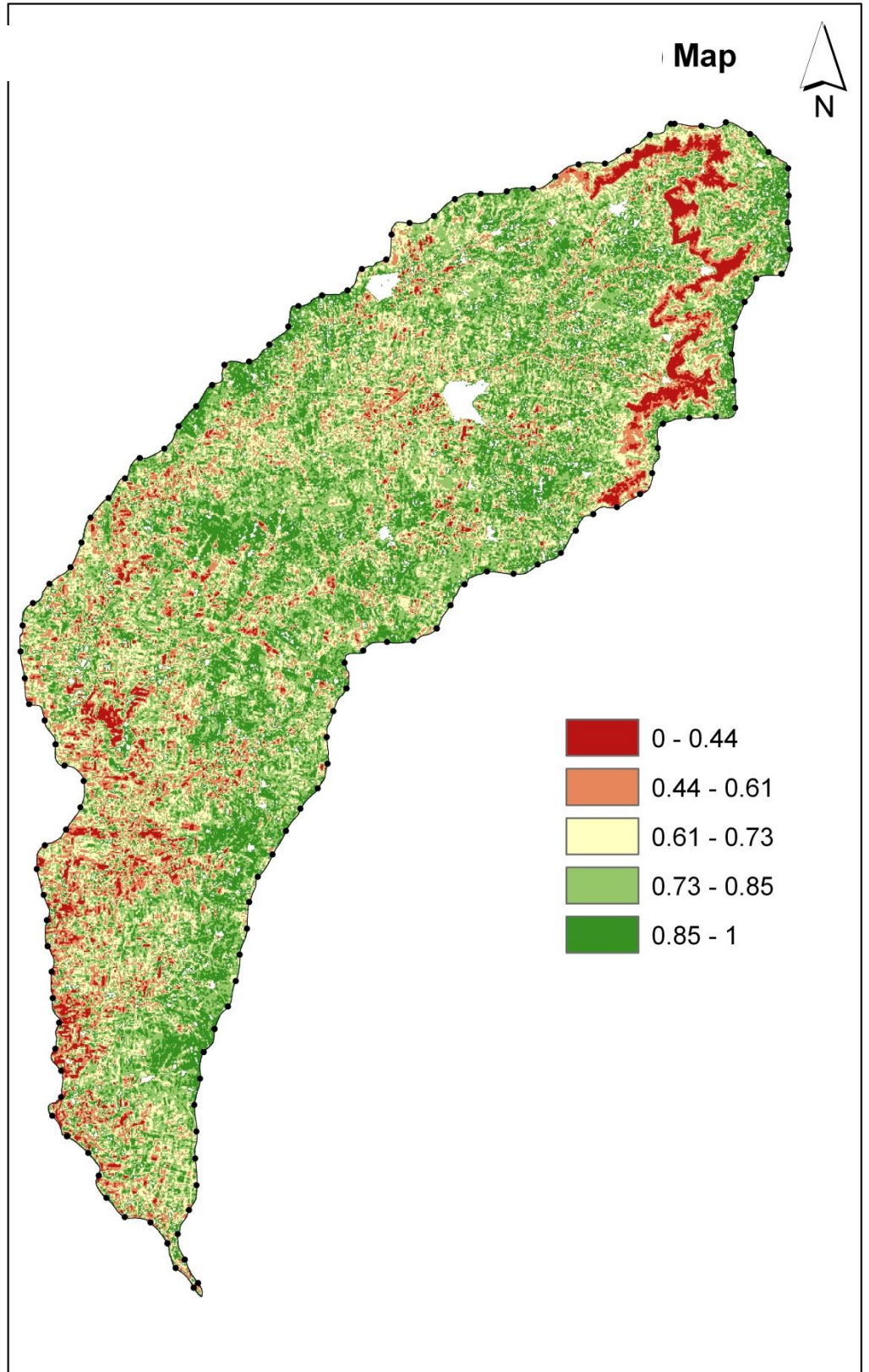


Fig 4.11: C Factor Map of SA-13 Watershed

4.2.5 P-Factor (Support Practice Factor)

The supporting practice P-factor described the effects of practices such as contouring, strip cropping, terraces, sediment basins, grass hedges and subsurface drainage. Supporting practices typically affect erosion by redirecting runoff around the slope so that it has less erosivity or by slowing down the runoff to cause deposition. The lower the P-factor value, the more effective the conservation practice was deemed to be at reducing soil erosion. If there are no support practices, the P-factor is 1.0. In this study, the value of P was calculated using land use maps and slope maps. In the study area, most of the agricultural area was occupied by rainfed crops as jowar, soybean, wheat and gram fields on strip farming method. In forest areas the P value 1 was assigned because there was no support practice. The P factor for strip cropping of the study area was taken 0.37 (Stone and Hilborn, 2000). The values of P factor for watershed according to support/control practice are shown in Table 4.7.

Table 4.7: P Factor values for different support practices for watershed

Sr. No.	Support Practice	P Factor
1	Up & Down Slope	1.0
2	Cross Slope	0.75
3	Contour farming	0.50
4	Strip cropping, cross slope	0.37
5	Strip cropping, contour	0.25

4.2.6 Estimation of Soil Loss

The composite term RKLSCP represents the soil erosion potential of different grid cells in the unit t/ha/yr. The GIS database generated for the estimation of soil erosion such as R-factor, K factor, L and S factor, C factor and P factor has been multiplied using “Raster Calculator” in Spatial Analyst of ArcGIS. The final soil loss map of the watershed is given Fig.4.12 and micro-watershed wise average soil loss computed is presented in Table 4.8. The average soil loss of the entire watershed was 8.2 t/ha/year. Highest soil

erosion potential of 9.97 t/ha/year was observed in micro-watershed number 4, whereas lowest potential of 5.59 t/ha/year was observed in micro-watershed number 13. The highest erosion was in areas of bare soils with upland topography where slope exceeds approximately 30 degrees.

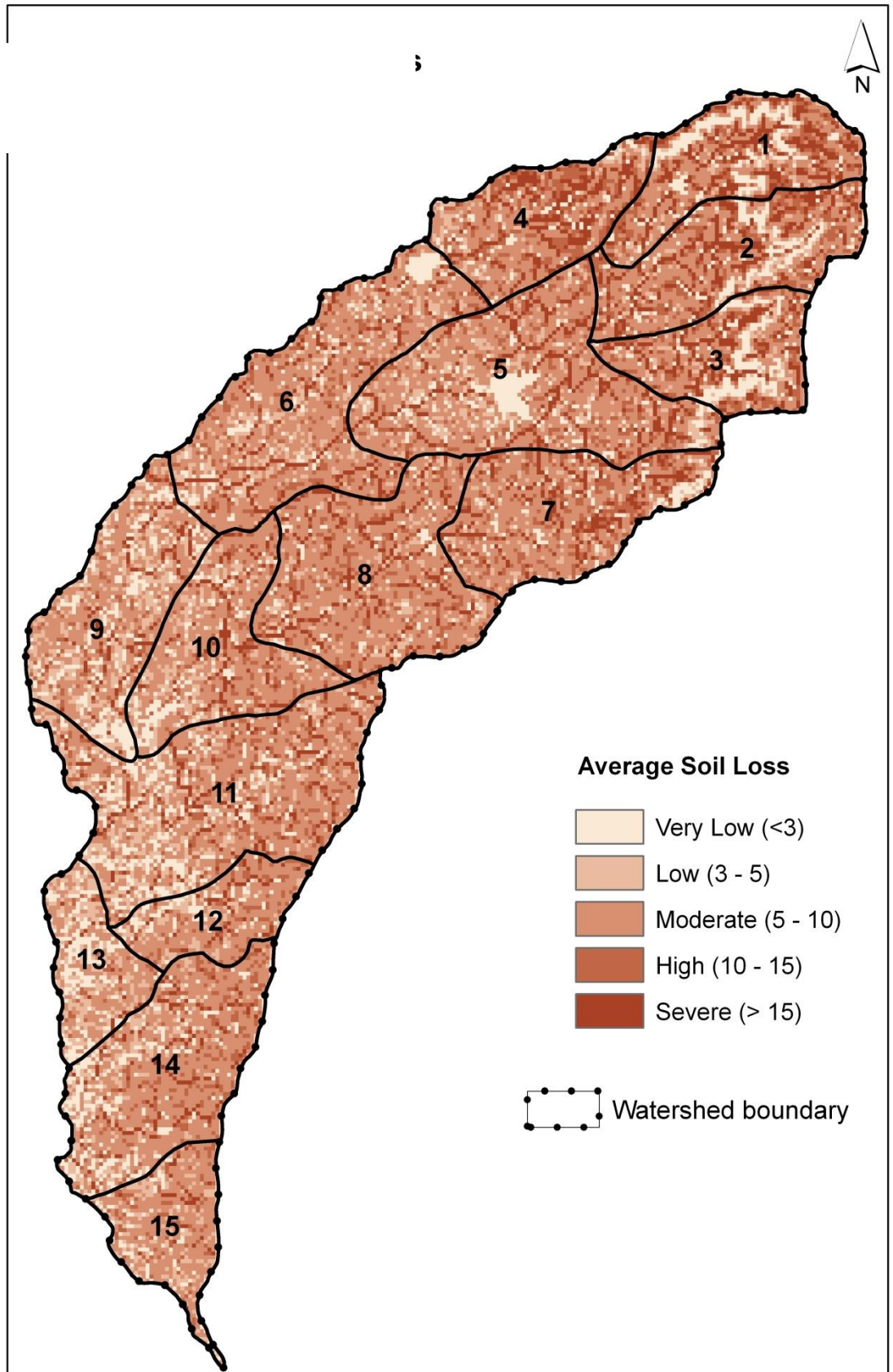


Fig.4.12: Average Soil Loss in SA-13 Watershed

Table 4.8: Rainfall, Runoff Depth and soil loss for the Year 2005

Micro-watershed	Rainfall (mm)	Runoff (mm)	% Runoff	Soil loss (t/ha/year)
1	406.5	89.05	21.91	9.35
2	406.5	89.05	21.91	9.87
3	406.5	83.32	20.50	9.01
4	406.5	83.32	20.50	9.97
5	406.5	83.32	20.50	8.67
6	406.5	102.54	25.23	8.22
7	406.5	83.32	20.50	9.10
8	406.5	89.05	21.91	8.85
9	406.5	102.54	25.23	6.75
10	406.5	95.42	23.47	7.84
11	406.5	102.54	25.23	7.50
12	406.5	89.05	21.91	7.82
13	406.5	102.54	25.23	5.59
14	406.5	102.54	25.23	7.75
15	406.5	143.46	35.29	6.66
Annual Avg.	406.5	96.07	23.63	8.20

Soil erosion is a natural process and the goal of any mitigation action should be for reducing erosion rates down to reasonable limits. Generally, watershed areas which have a soil erosion potential under 3 t/ha/year are within the expected tolerable soil loss level and should be excluded from any mitigation actions. Soil erosion in present study is in moderate erosion risk class (Stone and Hilborn, 2000).

V.SUMMARY AND CONCLUSIONS

5.1 Summary

A study was planned at College of Agricultural Engineering and Technology, Dr. BSKKV, Dapoli and conducted at Maharashtra Remote Sensing applications Centre, Nagpur with the objective of estimation of runoff for watershed using SCS-CN and estimation of soil erosion for watershed using RUSLE. Remote sensing and GIS techniques were used for fulfillment of this study. For this study SA-13 watershed was selected which was located at Asthi tahsil, Beed district of Maharashtra.

Runoff estimation depends on rainstorms and its occurrence and quantity, intensity, duration and distribution. Unlike the conventional methods for estimating runoff, tools like Remote sensing and GIS have proved to be truly unconventional method. Soil type, vegetation cover, slope and watershed characteristics were basic parameters to run the Modified Soil conservation service curve number (SCS-CN) model. Rainfall runoff relationship can be visualized by the factors such as initial abstraction, runoff and actual retention.

For the SA-13 watershed, land use/land cover has been classified into eight categories viz kharif, rabi, seasonal fallow, double crop, forest, wasteland, water bodies and built-up area. Total geographical area covered under agriculture has been found to be 17,847.56 ha which was 83.79 percent of the total area of the watershed in which seasonal cropping such as kharif, rabi, and fallows occupied about 13.04, 8.63 and 41.20 percent, respectively. The total area under forest was 1127.10 ha, which was 5.29 per cent of the total area. The total area under wastelands was 2039.26 ha, which was 9.57 per cent of the study area. Other classes such as settlement and water bodies occupied 29.60 ha and 256.47 ha which was 0.14 percent and 1.20 percent of the total area of watershed, respectively.

Physical properties of soil also play an important role in estimating amount of precipitation that runs off the land. Infiltration and runoff generating potentials of

watershed has been classified into hydrologic soil groups B, C and D and there were no soils of HSG group A in the study area. It was found that HSG-C covers the maximum 14821 ha area i.e 69.58 percent of total area of watershed while HSG-D and HSG-B covering 3759.7 ha and 8.85 ha area which was 17.65 and 8.85 percent, of the total area of watershed, respectively.

Curve Number for watershed represents the runoff potential of the land cover soil complex and involves relationship between land cover, hydrologic soil group and CN. For this study SA-13 watershed was divided into 15 micro-watersheds and by considering the land use classes, hydrological conditions and HSG prevailing in the area, Curve Number values were assigned to each micro-watershed. The curve numbers were assigned for AMC condition II ($I_a=0.2S$), based on standard tables of Soil Conservation Services (SCS, 1972). These values of curve numbers were further corrected by using slope in m/m. Final slope corrected CN values for each micro- watershed was observed in the range of 87 to 94.

It was observed that, average rainfall in the SA-13 watershed for the year 2005 was 406.50 mm whereas average runoff was 96.07 mm, i.e. 23.63 percent of the total rainfall received. Micro-watershed numbering 3, 4, 5 and 7 generate lower runoff amounting 83.32 mm whereas micro-watershed no. 15 generated higher runoff of 143.46 mm.

For this study, Soil Loss value was estimated using RUSLE (Revised Universal Soil Loss Equation), governed by major six parameters i.e. R-factor (rainfall erosivity factor), K-factor (soil erodibility), L-factor (slope length factor), S-factor (slope steepness factor), C-factor (cover and management factor) and P-factor (support practice factor).

Rainfall Erosivity Factor (R-Factor) for SA-13 watershed was calculated by using the IDW interpolation technique of ArcGIS 9.2 from the nine surrounding meteorological stations , it was found that overall variation of rainfall from 542 to 651 mm occurred in the watershed which was gradually decreasing from northeast to central-west region of the watershed. Highest rainfall zone of 624 to 651 mm seen in north-east corner of the watershed where forest and hill topography exist. Lower rainfall zone of 542 to 568 mm occupied central-west area of the study. R- factor values for SA - 13 watershed varies

from 287 to 329, tending higher values at northeast corner and gradually decreasing down to central-west part of the study area. This indicated that the value of R factor varies according to rainfall distribution.

The soil erodibility factor (K-Factor) reflects the fact that different soils erode at different rates when the other factors affecting erosion remains the same. A map for the K-factor was generated based on the soil parameters such as soil structure, organic matter content, and permeability. It was observed that 18,707.12 ha area of watershed i.e. 87.83 percent had k factor 0.22. The value of K factor for the watershed of 1288.92 ha ,936.86 ha and 367.10 ha area were 0.26, 0.20 and 0.32, respectively and total geographical area of 6.05 percent, 4.40 percent and 1.72 percent, respectively. K factor in the watershed ranges from 0.20 to 0.32. Mean K factor of the watershed is 0.25.

Length and Steepness factor in combination was called as topographic factor, both of which determined by using Digital Elevation Model (DEM). Slope map was derived from SRTM DEM. It has been observed that the slope was varying from 0 to 79.45 degrees. Higher slope was concentrated on northeastern part of the watershed whereas it was gradually decreasing towards south. The LS factor has been found out to be varying in the range of 0-10.

The Normalized Difference Vegetation Index (NDVI) was used to measure the amount of green vegetation. NDVI image of SA-13 watershed was showing range of values between -0.5 to 0.68. Cover management factor (C factor) used to represent the ratio of soil loss for a given cropping usually ranges from 0 and 1. For SA-13 watershed, it has been found in the range of 0.44 to 1 depending on the NDVI.

Support practice factor (P-factor) describes the effects of practices such as contouring, strip cropping, terraces, sediment basins, grass hedges and subsurface drainage. In the study area, most of the agricultural areas were occupied by rainfed crops as jowar, soybean, wheat and gram fields on strip farming method. The P factor for this study was assumed for strip cropping of the study area and the value for P factor was taken 0.37 from the Universal Soil Loss Equation (Stone and Hilborn, 2000) and for the forest areas the value of P factor was assigned 1 because there are no support practices.

The average annual soil erosion potential (A) was computed by multiplying the developed raster files for each factor ($A = R K L S C P$). The average annual soil loss of

the entire watershed is 8.2 tons/ha/year. Highest estimated soil erosion potential of 9.97 tons/ha/year was observed in microwatershed number 4, whereas lowest potential of 6.66 tons/ha/year was observed in micro-watershed number 15.

5.2. Conclusions

Specific conclusions related to the study are summarized below:

1. Average rainfall for the year 2005 in the SA-13 watershed was 406.50 mm whereas average runoff was 96.07 mm, amounting 23.63 percent to total rainfall received.
2. The result of the analysis depicted that the average soil loss of the SA-13 watershed is 8.2 tons/ha/year.
3. The highest estimates of soil erosion are in areas of bare soils with upland topography where slope exceeds approximately 30 degrees.

VI. BIBLIOGRAPHY

Amutha, R. and P. Porchelvan. 2009. Estimation of Surface Runoff in Malattar Sub-watershed using SCS-CN Method. *Journal of Indian Society Remote Sensing*, 37: 291–304.

Anonymous. 1972. National Engineering Handbook, Section 4, Hydrology, SCS. United State Department of Agriculture, Washington, DC.

Anonymous.1991. Methodology for priority delineation survey, AISLUS--All India Soil and Land Use Survey, Ministry of Agriculture, [Government of India](#), India.

Arekhi, S., Y. Niazi and A. M. Kalteh. 2010. Soil erosion and sediment yield modeling using RS and GIS techniques: a case study, Iran. *Arab Journal of Geoscience*, 0220(4):1-12.

Atawoo, M. A. and J. M. Heerasing.1997. Estimation of soil erodibility and erosivity of rainfall patterns in Mauritius. Food and Agricultural Research Council, Reduit, Mauritius.

Bandyopadhyay, D. A. and K. N. Kusuma. 2009. SCS-CN and GIS- based approach for identifying potential water harvesting sites in the Kali watershed, Mahi river basin, India. *Journal of Earth System Science*, 118(4):355-368.

Challa, O., S. Vadivelu and J. Sehgal.1996. National bureau of soil survey and land use planning ICAR, Nagpur.

http://eusoils.jrc.it/esdb_archive/EuDASM/Asia/lists/cin.htm

Chandramohan, T. and D. G. Durbude. 2001. Estimation of Runoff Using Small Watershed Models. *Hydrology Journal*, 24 (2):45-53.

Chattopadhyay, G. S. and S. Choudhury. 2006. Application of GIS and remote sensing for watershed development project – a case study. Map India 2006. <http://www.gisdevelopment.net>

Chow, V. T., D. K. Maidment and L.W. Mays. 2002. Applied Hydrology. McGraw-Hill Book Company, New York, USA.

Curran, P. J. 1983. Remote Sensing Terminology. *International Journal Of Remote Sensing*, 4(6): 835–842.

Dabral, P. P., N. Baithuri and A. Pandey. 2008. Soil Erosion Assessment in a Hilly Catchment of North Eastern India Using USLE, GIS and Remote Sensing. *Water Resource Management*, 22: 1783–1798.

De Jong, S. M. 1994. Application of Reflective Remote Sensing for Land Degradation Studies in a Mediterranean Environment. Utrecht: Netherlands Geographical Studies, University of Utrecht.

Ebrahimian, M., L. F. See, M. H. Ismail and I. A. Malek. 2009. Application of Natural Resources Conservation Service-Curve Number Method for Runoff Estimation With GIS In The Kardeh Watershed, Iran. *European Journal of Scientific Research*, 34(4): 575-590.

Elangovan, A. B. and R. Seetharaman. 2011. Estimating Rainfall Erosivity of the Revised Universal Soil Loss Equation from daily rainfall depth in Krishanagiri Watershed region of Tamil Nadu India. In: *International Conference on Environmental and Computer Science*, IACSIT Press, Singapore.

ERDAS Imagine Field Guide.1998. Przewodnik geoinformatyczny, GEOSYSTEMS Polska, Warszawa.

ESRI. 1994. Cell based modelling with GRID. Environmental Systems Research Institute Inc., Redlands, California, USA.

Ferro, V. and M. Minacapilli. 1995. Sediment delivery processes at basin scale. *Hydrological Science Journal* , 40(6): 703-717.

Ferro, V. 1997. Further remarks on a distributed approach to sediment delivery. *Hydrological Science Journal*, 42(5): 633-647.

Ferro, V., P. Porto and G. Tusa. 1998. Testing a distributed approach for modelling sediment delivery. *Hydrological Science Journal*, 43(3): 425-442.

Gitas, I. Z., K. Douros, C. Minakoul, G. N. Silleos. 2009. Multi-temporal soil erosion risk assessment In N. Chalkidiki Using A Modified USLE Raster Model. *Earsel Eproceeding*, 81: 40-52.

Gupta, P. K. and S. Panigrahy. 2008. Geo-spatial modeling of runoff of large land mass: analysis, approach and results for major river basins of India. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*. XXXVII(B2).

Haan, C. T., B. J. Barfield and J. C. Hayes. 1994. Design Hydrology and Sedimentology for Small Catchments. Academic Press, New York.

<http://glcf.umiacs.umd.edu/index.shtml>

<http://www.mahaagri.gov.in>

Huang, C., L. K. Well and L. D. Norton. 1999. Sediment transport capacity and erosion process: model concept and reality. *Earth Surface Process Landforms*, 24: 503-516.

Huang, M., G. Jacques, Z. Wang and G. Monique. 2006. A modification to the soil conservation service curve number method for steep slopes in the Loess Plateau of China. *Hydrological processes*, 20(3): 579-589.

Jain, M. K. and U. C. Kothiyari. 2001. Estimation of soil erosion and sediment yield using GIS. *Hydrological Sciences Journal*, 45(5): 771-746.

Jasrotia, A. S., S. D. Dhiman and S. P. Aggarwal. 2002. Rainfall-Runoff and Soil Erosion Modeling Using Remote Sensing and GIS Technique-A Case Study of Tons Watershed. *Journal of the Indian Society of Remote Sensing*. 30(3): 167-180.

Jennings, D. 2001. Surface water delineation for Moundsville. Spatial Analysis for Resource Management.

<http://www.nrsc.wvu.edu/rm493591/fall2001/students/jennings/revised.htm,May,2003>.

Jenson, J. R. 1996. Introductory Digital Image Processing: A Remote Sensing Perspective, 2nd Edition, Prentice Hall, New Jersey.

Johnson, L. E. 2009. Geographic Information Systems in Water Resources Engineering. CRC Press, New York.

Karaburun. 2010. Estimation of C factor for soil erosion modeling using NDVI in Buyukcekmece watershed. *Ozean Journal of Applied Sciences*. 3(1): 77-85.

Karydas, C. G., T. Sekuloska and G. N. Silleos. 2009. Quantification and site specification of the support practice factor when mapping soil erosion risk associated with olive plantations in the Mediterranean island of Crete. *Environ Monit Assess*. 149: 19–28.

Kefi, M., K. Yoshino and Y. Setiawan. 2011. Assessment and mapping of soil erosion risk by water in Tunisia using time series MODIS data. *Paddy Water Environ*. 0265 (3). DOI 10.1007/s10333-011-0265-3.

Kothiyari, U. C. and S. K. Jain. 1997. Sediment yield estimation using GIS. *Hydrological Science Journal*. 42(6): 833-843.

Kouli, M., P. Sopiopos and F. Vallianatos. 2009. Soil erosion prediction using the Revised Universal Soil Loss Equation (RUSLE) in a Geographic Information System. framework, Chania, Northwestern Crete, Greece. *Environmental Geology*.57: 483–497.

Kulkarni, A. A., S. P. Aggarawal and K. K. Das. 2004. Estimation of Surface Runoff using Rainfall – Runoff Modeling of Warasgaon Dam Catchment. In: *Map India Conference*, New Delhi, India.

Lilliesand, T. M. and R. W. Kiefer 1987. Remote Sensing and Image Interpretation. John Wiley and Sons, New York.

Lu, D., G. Li, G. S. Valladares and M. Batistella. 2004. Mapping soil erosion risk in Rondonia, Brazilian Amazonia using Revised Universal Soil Loss Equation, remote sensing and Geographic Information System. *Land Degradation and Development*, 15: 499–512.

Mather, P. M. 1999. Computer Processing of Remotely Sensed Images: *An Introduction*, 2nd Edition, John Wiley and Sons, West Sussex.

McCool, D. K., G. R. Foster, C. K. Mutchle and L. D. Meyer. 1987. Revised slope steepness factor for the universal Soil Loss Equation. *Transactions of American Society of Agricultural Engineers*, 30(5): 1387–1396.

McCool, D. K., G. R. Foster, K.G. Renard, D. C .Yoder and G. A. Weesies.1995. Revised Universal Soil Loss Equation. Department of Defense/Interagency Workshop on Technologies to Address Soil Erosion on Department of Defense Lands San Antonio, TX.

Melesse, A. M. and S. F. Shih. 2002. Spatially distributed storm runoff depth estimation using Landsat Images and GIS. *Computers and Electronics in Agriculture*, 37: 173-183.

Meyer, L. D. and W. H. Wischmeier .1969. Mathematical simulation of the processes of soil erosion by water. *Transactions of the American Society of Agricultural Engineers*, 12(6): 754-758.

Moore, I. D. and J. P. Wilson .1992. Length slope factor for the Revised Universal Soil Loss equation: simplified method of solution. *Journal of Soil and Water Conservation*, 47(5): 423-428.

Morgan, R. P. C. 1986. *Soil Erosion and Conservation*, Longman Group Limited. 63 -74.

Morgan, R. P. C. 1994. *Soil erosion and conservation*. Slisoe College, Cranfield university, Slisoe.

Musgrave, G. 1947. The quantitative evaluation of factors in water erosion, a first approximation. *Journal of Soil and Water Conservation*, 2(3): 133-138.

Narayana V. V. D. and R. Babu. 1983. Estimation of soil erosion in India. *Journal of Irrigation and Drainage Engineering*, 109(4): 419-433.

Nayak, T. R . and R. K. Jaiswal. 2003. Rainfall-Runoff Modelling using Satellite Data and GIS for Bebas River in Madhya Pradesh. *Journal of the Institution of Engineers(INDIA), Civil Engineering Division*. 84: 47-50.

NBSS and LUP. 1995. *Soils of Maharashtra for Optimising Land Use*. National Bureau Soil Survey Publication 54, Soils of India Series 5.

NRSA.1989. *Manual of Nationwide Land Use Mapping using Satellite Imagery, Part I*, National Remote Sensing Agency, Hyderabad.

Pal, B. and S. Samanta. 2011. Estimation of soil loss using remote sensing and geographic information system techniques (Case study of Kaliaghai River basin, Purba &

Paschim Medinipur District, West Bengal, India). *Indian Journal of Science and Technology*, 4(10): 1202-1207.

Pandey, A. P., V. M . Dabral and B. C. Chowdary 2006. Estimation of runoff for agricultural watershed using SCS curve number and geographic information system. <http://www.gisdevelopment.net>

Panuska, J. C., I. D. Moore and L. A. Kramer .1991. Terrain analysis: integration into the agricultural nonpoint source (AGNPS) pollution model. *Journal of Soil and Water Conservation*. 46(1): 59-64.

Patil, J. P., A. Sarangi, O. P. Singh, A. K. Singh and T. Ahmad. 2008. Development of a GIS Interface for Estimation of Runoff from Watersheds. *Water Resource Management*, 22: 1221–1239.

Pradhan, R., M. P Pradhan, M. K. Ghose, V.S. Agarwal and S. Agarwal. 2010. Estimation of rainfall-runoff Using Remote Sensing and GIS In and around Singtam, East Sikkim. *International Journal of Geomatics and Geosciences*. 1(3): 466-476.

Prasannakumar, V., R. Shiny, N. Geetha, and Vijith, H. 2011. Spatial prediction of soil erosion risk by remote sensing, GIS and RUSLE approach: a case study of Siruvani river Watershed in Attapady valley, Kerala, India. *Environmental Earth Science*, 64(4): 965-972.

Ram Babu, BL. Dhyani and N. Kumar. 2004. Assessment of erodibility status and refined Iso-Erodant Map of India. *Indian Journal of Soil Conservation*, 32(2): 171-177.

Ramakrishnan D., A. Bandyopadhyay and K. N. Kusuma. 2009. SCS-CN and GIS based approach for identifying potential water harvesting sites in the Kali Watershed, Mahi River Basin, India. *Journal of Earth System Science*, 118(4): 355–368.

Rao, K.V., A. K. Bhattacharya and K. Mishra.1996. Runoff estimation by curve number method- case studies. *Journal of Soil and Water Conservation*, 40 :1-7.

Renard, K. G., G. R. Foster, G. A. Weesies and J. P Porter. 1991. RUSLE, Revised Universal Soil Loss Equation. *Journal of Soil and Water Conservation*, 46(1): 30-33.

Renard, K.G., G. R. Foster, G. A. Weesies, D. K. McCool and D.C. Yoder. 1997. Predicting Soil Erosion by Water. A Guide to Conservation Planning with the Revised Universal Soil Loss Equation (RUSLE). USDA Agriculture Handbook No.703.

Richards, J. A. and X. Jia. 2006. Remote Sensing Digital Image Analysis: An Introduction, 4th edn., New York: Springer.

Rojas-Gonzalez, A. M. 2008. Soil erosion calculation using Remote sensing and GIS in Rio Grade De Arecibo watershed, Puerto Rico. *American Society of Photogrametry and Remote Sensing (ASPRS)*. Annual Conference. Portland Oregon.

Romkens M. J. M., S. N. Prasad and J. J. Gerits.1997. Soil erosion models of sealing soils: a phenomenological study. *Soil technology*.11: 31-41.

Sabins, F. F. J. 1987. Remote Sensing Principles and Interpretation, 2nd ed., Remote Sensing Enterprise, Inc., New York.

Saleh, N. M., M. S. AbdulMohsin and S. S. Sammer. 2011. Evaluation of Rainfall-Runoff Relationship of Hemren basin by using Remote Sensing and GIS Techniques. *European Journal of Scientific Research*, 54(2): 224-244.

Samah Al-Jabari., M. A. Sharkh and A. Ziad. 2009. Estimation of runoff for agricultural watershed using SCS curve number and GIS. In: *Thirteenth International Water Technology Conference, IWTC 13 2009*, Hurghada, Egypt.

Sarangi, A., C. A. Madramootoo, P. Enright, S. O. Prasher and R.M. Patel. 2005a. Performance evaluation of ANN and geomorphology-based models for runoff and sediment yield prediction for a Canadian watershed. *Current Science*, 89(12): 2022–2033.

Sarangi, A., A. K. Bhattacharya, A. K. Singh and A. Sambaiha. 2005b. Performance of Geomorphologic Instantaneous Unit Hydrograph (GIUH) model for estimation of surface runoff. In: *International conference on recent advances in water resources development and management*, 23rd to 25th Nov 2005, IIT, Roorkee, Uttaranchal, India. pp 569–581.

Schowengerdt R. A. 1983. Techniques for image processing and classification in remote sensing. Academic Press, Inc., New York.

Sharma, T., P. V. Satya Kiran, T. P. Singh, A.V Trivedi and R. R. Navalgund. 2001. Hydrologic response of a watershed to landuse changes: A remote sensing and GIS approach. *International Journal of Remote Sensing*, 22 (11): 2095-2108.

Sharma, D. and V. Kumar. 2002. Application of SCS model with GIS data base for estimation of runoff in an arid watershed. *Journal of Soil and Water Conservation*, 30 (2): 141-145.

Shahid, S. and M. Almasri. 2010. Application of GIS-based SCS- CN method in West Bank catchments, Palestine. *Water Science and Engineering*, 3(1): 1-13.

Shinde, V., A. Sharma, K. N. Tiwari and M. Singh. 2011. Qualitative determination of soil erosion and prioritization of micro-watersheds using Remote Sensing and GIS. *Journal of Indian Society of Remote Sensing*, 39(2): 181-192.

Shiferaw. A. 2011. Estimating soil loss rates for soil conservation planning in the borena woreda of South wollo highlands, Ethiopia. *Journal of Sustainable Development in Africa*. 13(3): 87-106.

Stone, R. P. and D. Hilborn. 2000. Universal Soil Loss Equation(USLE). Ontario Ministry of Agricultural and Food original factsheet.

<http://www.gov.on.ca/OMAFRA/english/engineer/facts/00-001.htm>

Sundar Kumar, P., M. J. Ratna Kanth Babu, T. V. Praveen and V. Venkata kumar. 2010. Analysis of the Runoff for Watershed Using SCS-CN Method and Geographic Information Systems. *International Journal of Engineering Science and Technology*. 2(8): 3947-3654.

Tian, Y. C., Y. M. Zhou, B. F. Wu and W. F. Zhou. 2009. Risk assessment of water soil erosion in upper basin of Miyun Reservoir, Beijing, China. *Environmental Geology*, 57: 937–942.

Tou, J. T. and R. C. Gonzalez.1974. *Pattern recognition Principles*. Reading, Massachusetts Addison-Wesley Publishing Company.

UNEP. 1997. *World atlas of desertification*. 2nd edition, Arnold London.

USDA-SCS. 1972. Sediment sources, yields and delivery ratios. National engineering handbook. Section 3 Sedimentation. Engineering.

USDA. 1985. *Soil Conservation Service*. National Engineering Handbook, USA.

Van der Knijff, J. M., RJA. Jones and L. Montanarella.2000. Soil erosion risk assessment in Europe EUR 19044 EN. *Office for Official Publications of the European Communities*, Luxembourg, pp 34.

Walling, D. E. 1983. The sediment delivery problem. *Journal of Hydrology*, 65: 209-237.

Weber, M. R. and G. A. Dunno. 2001. Riparian vegetation mapping and image processing techniques Hopi Indian Reservation, Arizona. *Photogrammetric Engineering and Remote sensing*, 67(2): 179-186.

Williams, J. R. 1975. Sediment routing for agricultural watersheds. *Water Resource Bulletin*, 11: 965-974.

Wischmeier, W. H. and D. D. Smith. 1958. Rainfall energy and its relationship to soil loss. *Trans. AGU39(Q)* : 285-291.

Wischmeier, W. H. 1959. A rainfall erosion index for a universal soil loss equation. *Soil Sci. Soc. Am. Proc.* 23: 246- 249.

Wischmeier, W. H. and D. D. Smith. 1965. Predicting rainfall erosion losses from cropland east of the Rocky Mountains. Guide for selection of practices from soil and water conservation. U.S. Department of Agriculture handbook No. 537.

Wischmeier, W. H. 1971. A soil erodibility nomograph for farmland and construction sites. *Journal of Soil and Water Conservation*, 26: 189–193.

Wischmeier, W. H. and D. D. Smith. 1978. *Predicting Rainfall Erosion Losses-* a guide to conservation planning. Agriculture Handbook no. 537, United States Department of Agriculture Science and Education Administration, Washington. pp.163.

Yue-Qing, X., S. Xiao-Mei, K. Xiang-Bin, P. Jian and C. Yun-Long. 2008. Adapting the RUSLE and GIS to model soil erosion risk in a mountains karst watershed, Guizhou Province, China. *Environ Monit Assess*, 141: 275–286.

Zade, M. R., S. S. Ray, S. Dutta and S. Panigrahy. 2005. Analysis of runoff pattern for all major basins of India derived using remote sensing data. *Current Science*, 88(8): 1301-1305.

Zhou, P., O. Luukkanen, T. Tokola and J. Nieminen. 2008. Effect of vegetation cover on soil erosion in a mountainous watershed. *Catena*, 75(3): 319–325.

VII. APPENDICES

APPENDIX-I

Table I: Rainfall data of Asthi Tahsil from 1998 to 2005

Year	Annual Rainfall (mm)
1998	958.6
1999	979.4
2000	938.9
2001	635.6
2002	783.8
2003	620.9
2004	1026.6
2005	406.5
Average	744

APPENDIX-II

Monthly Rainfall (mm) and Antecedent moisture condition(AMC) of Asthi Tahsil for the year 2005

Table II : 1. Rainfall (mm) and AMC for January to December

Date	Rainfall	Sum of 5 days rainfall (mm)	AMC
01-Jan-05	0	0	I
02-Jan-05	0	0	I
03-Jan-05	0	0	I
04-Jan-05	0	0	I
05-Jan-05	0	0	I
06-Jan-05	0	0	I
07-Jan-05	0	0	I
08-Jan-05	0	0	I
09-Jan-05	0	0	I
10-Jan-05	0	0	I
11-Jan-05	0	0	I
12-Jan-05	0	0	I
13-Jan-05	0	0	I
14-Jan-05	0	0	I
15-Jan-05	0	0	I
16-Jan-05	0	0	I
17-Jan-05	0	0	I
18-Jan-05	0	0	I
19-Jan-05	0	0	I
20-Jan-05	0	0	I
21-Jan-05	0	0	I
22-Jan-05	0	0	I
23-Jan-05	0	0	I
24-Jan-05	0	0	I
25-Jan-05	0	0	I
26-Jan-05	0	0	I
27-Jan-05	0	0	I
28-Jan-05	0	0	I
29-Jan-05	0	0	I
30-Jan-05	0	0	I
31-Jan-05	4.6	4.6	I

Date	Rainfall	Sum of 5 days rainfall (mm)	AMC
01-Feb-05	0	4.6	I
02-Feb-05	0	4.6	I
03-Feb-05	0	4.6	I
04-Feb-05	0	4.6	I
05-Feb-05	0	0	I
06-Feb-05	0	0	I
07-Feb-05	0	0	I
08-Feb-05	0	0	I
09-Feb-05	0	0	I
10-Feb-05	0	0	I
11-Feb-05	0	0	I
12-Feb-05	0	0	I
13-Feb-05	0	0	I
14-Feb-05	0	0	I
15-Feb-05	0	0	I
16-Feb-05	0	0	I
17-Feb-05	0	0	I
18-Feb-05	0	0	I
19-Feb-05	0	0	I
20-Feb-05	0	0	I
21-Feb-05	0	0	I
22-Feb-05	0	0	I
23-Feb-05	0	0	I
24-Feb-05	0	0	I
25-Feb-05	0	0	I
26-Feb-05	0	0	I
27-Feb-05	0	0	I
28-Feb-05	0	0	I

Date	Rainfall	Sum of 5 days rainfall(mm)	AMC
01-Mar-05	0	0	I
02-Mar-05	0	0	I
03-Mar-05	0	0	I
04-Mar-05	0	0	I
05-Mar-05	0	0	I
06-Mar-05	0	0	I
07-Mar-05	0	0	I
08-Mar-05	0	0	I
09-Mar-05	0	0	I
10-Mar-05	0	0	I
11-Mar-05	0	0	I
12-Mar-05	0	0	I
13-Mar-05	0	0	I
14-Mar-05	0	0	I
15-Mar-05	0	0	I
16-Mar-05	0	0	I
17-Mar-05	0	0	I
18-Mar-05	0	0	I
19-Mar-05	0	0	I
20-Mar-05	0	0	I
21-Mar-05	0	0	I
22-Mar-05	0	0	I
23-Mar-05	0	0	I
24-Mar-05	0	0	I
25-Mar-05	0	0	I
26-Mar-05	0	0	I
27-Mar-05	0	0	I
28-Mar-05	0	0	I
29-Mar-05	0	0	I
30-Mar-05	0	0	I
31-Mar-05	0	0	I

Date	Rainfall	Sum of 5 days rainfall(mm)	AMC
01-Apr-05	0	0	I
02-Apr-05	0	0	I
03-Apr-05	0	0	I
04-Apr-05	0	0	I
05-Apr-05	0	0	I
06-Apr-05	0	0	I
07-Apr-05	0	0	I
08-Apr-05	0	0	I
09-Apr-05	0	0	I
10-Apr-05	0	0	I
11-Apr-05	0	0	I
12-Apr-05	0	0	I
13-Apr-05	0	0	I
14-Apr-05	0	0	I
15-Apr-05	0	0	I
16-Apr-05	0	0	I
17-Apr-05	0	0	I
18-Apr-05	0	0	I
19-Apr-05	0	0	I
20-Apr-05	0	0	I
21-Apr-05	0	0	I
22-Apr-05	0	0	I
23-Apr-05	0	0	I
24-Apr-05	0	0	I
25-Apr-05	0	0	I
26-Apr-05	0	0	I
27-Apr-05	0	0	I
28-Apr-05	0	0	I
29-Apr-05	0	0	I
30-Apr-05	0	0	I

Date	Rainfall	Sum of 5 days rainfall (mm)	AMC
01-May-05	0	0	I
02-May-05	0	0	I
03-May-05	0	0	I
04-May-05	0	0	I
05-May-05	0	0	I
06-May-05	0	0	I
07-May-05	0	0	I
08-May-05	0	0	I
09-May-05	0	0	I
10-May-05	0	0	I
11-May-05	0	0	I
12-May-05	0	0	I
13-May-05	0	0	I
14-May-05	0	0	I
15-May-05	0	0	I
16-May-05	0	0	I
17-May-05	0	0	I
18-May-05	0	0	I
19-May-05	0	0	I
20-May-05	0	0	I
21-May-05	0	0	I
22-May-05	0	0	I
23-May-05	0	0	I
24-May-05	0	0	I
25-May-05	0	0	I
26-May-05	0	0	I
27-May-05	0	0	I
28-May-05	0	0	I
29-May-05	0	0	I
30-May-05	0	0	I
31-May-05	0	0	I

Date	Rainfall	Sum of 5 days rainfall (mm)	AMC
01-Jun-05	0	0	I
02-Jun-05	0	0	I
03-Jun-05	0	0	I
04-Jun-05	0	0	I
05-Jun-05	0	0	I
06-Jun-05	0	0	I
07-Jun-05	0	0	I
08-Jun-05	0	0	I
09-Jun-05	0	0	I
10-Jun-05	4.5	4.5	I
11-Jun-05	0	4.5	I
12-Jun-05	0	4.5	I
13-Jun-05	0	4.5	I
14-Jun-05	0	4.5	I
15-Jun-05	0	0	I
16-Jun-05	0	0	I
17-Jun-05	0	0	I
18-Jun-05	0	0	I
19-Jun-05	0	0	I
20-Jun-05	0	0	I
21-Jun-05	0	0	I
22-Jun-05	0	0	I
23-Jun-05	0	0	I
24-Jun-05	0	0	I
25-Jun-05	0	0	I
26-Jun-05	0	0	I
27-Jun-05	0	0	I
28-Jun-05	0	0	I
29-Jun-05	0	0	I
30-Jun-05	0	0	I

Date	Rainfall	Sum of 5 days rainfall (mm)	AMC
01-Jul-05	2	2	I
02-Jul-05	5	7	I
03-Jul-05	0	7	I
04-Jul-05	0	7	I
05-Jul-05	2	9	I
06-Jul-05	0	7	I
07-Jul-05	0	2	I
08-Jul-05	0	2	I
09-Jul-05	0	2	I
10-Jul-05	11	11	I
11-Jul-05	11	22	I
12-Jul-05	0	22	I
13-Jul-05	0	22	I
14-Jul-05	0	22	I
15-Jul-05	0	11	I
16-Jul-05	23	23	I
17-Jul-05	29	52	II
18-Jul-05	6	58	III
19-Jul-05	0	58	III
20-Jul-05	26	84	III
21-Jul-05	0	61	III
22-Jul-05	0	32	I
23-Jul-05	5	31	I
24-Jul-05	0	31	I
25-Jul-05	8.4	13.4	I
26-Jul-05	18	31.4	I
27-Jul-05	22	53.4	III
28-Jul-05	8.2	56.6	III
29-Jul-05	8	64.6	III
30-Jul-05	3	59.2	III
31-Jul-05	0	41.2	II

Date	Rainfall	Sum of 5 days rainfall (mm)	AMC
01-Aug-05	20	39.2	II
02-Aug-05	7	38	II
03-Aug-05	0	30	I
04-Aug-05	0	27	I
05-Aug-05	0	27	I
06-Aug-05	4	11	I
07-Aug-05	0	4	I
08-Aug-05	0	4	I
09-Aug-05	0	4	I
10-Aug-05	0	4	I
11-Aug-05	0	0	I
12-Aug-05	0	0	I
13-Aug-05	0	0	I
14-Aug-05	0	0	I
15-Aug-05	0	0	I
16-Aug-05	0	0	I
17-Aug-05	2	2	I
18-Aug-05	0	2	I
19-Aug-05	0	2	I
20-Aug-05	0	2	I
21-Aug-05	0	2	I
22-Aug-05	0	0	I
23-Aug-05	0	0	I
24-Aug-05	0	0	I
25-Aug-05	0	0	I
26-Aug-05	0	0	I
27-Aug-05	0	0	I
28-Aug-05	0	0	I
29-Aug-05	0	0	I
30-Aug-05	0	0	I
31-Aug-05	5	5	I

Date	Rainfall	Sum of 5 days rainfall (mm)	AMC
01-Sep-05	6	11	I
02-Sep-05	0	11	I
03-Sep-05	7	18	I
04-Sep-05	25	43	II
05-Sep-05	2	40	II
06-Sep-05	0	34	I
07-Sep-05	0	34	I
08-Sep-05	0	27	I
09-Sep-05	26	28	I
10-Sep-05	9.5	35.5	II
11-Sep-05	0	35.5	II
12-Sep-05	0	35.5	II
13-Sep-05	0	35.5	II
14-Sep-05	0	9.5	I
15-Sep-05	0	0	I
16-Sep-05	0	0	I
17-Sep-05	0	0	I
18-Sep-05	0	0	I
19-Sep-05	0	0	I
20-Sep-05	0	0	I
21-Sep-05	15	15	I
22-Sep-05	13	28	I
23-Sep-05	0	28	I
24-Sep-05	0	28	I
25-Sep-05	0	28	I
26-Sep-05	0	13	I
27-Sep-05	8.3	8.3	I
28-Sep-05	0	8.3	I
29-Sep-05	0	8.3	I
30-Sep-05	0	8.3	I

Date	Rainfall	Sum of 5 days rainfall (mm)	AMC
01-Oct-05	0	8.3	I
02-Oct-05	0	0	I
03-Oct-05	0	0	I
04-Oct-05	0	0	I
05-Oct-05	0	0	I
06-Oct-05	0	0	I
07-Oct-05	0	0	I
08-Oct-05	0	0	I
09-Oct-05	0	0	I
10-Oct-05	0	0	I
11-Oct-05	0	0	I
12-Oct-05	0	0	I
13-Oct-05	0	0	I
14-Oct-05	0	0	I
15-Oct-05	0	0	I
16-Oct-05	10	10	I
17-Oct-05	50	60	III
18-Oct-05	0	60	III
19-Oct-05	0	60	III
20-Oct-05	0	60	III
21-Oct-05	0	50	II
22-Oct-05	0	0	I
23-Oct-05	0	0	I
24-Oct-05	0	0	I
25-Oct-05	0	0	I
26-Oct-05	0	0	I
27-Oct-05	0	0	I
28-Oct-05	0	0	I
29-Oct-05	0	0	I
30-Oct-05	0	0	I
31-Oct-05	0	0	I

Date	Rainfall	Sum of 5 days rainfall (mm)	AMC
01-Nov-05	0	0	I
02-Nov-05	0	0	I
03-Nov-05	0	0	I
04-Nov-05	0	0	I
05-Nov-05	0	0	I
06-Nov-05	0	0	I
07-Nov-05	0	0	I
08-Nov-05	0	0	I
09-Nov-05	0	0	I
10-Nov-05	0	0	I
11-Nov-05	0	0	I
12-Nov-05	0	0	I
13-Nov-05	0	0	I
14-Nov-05	0	0	I
15-Nov-05	0	0	I
16-Nov-05	0	0	I
17-Nov-05	0	0	I
18-Nov-05	0	0	I
19-Nov-05	0	0	I
20-Nov-05	0	0	I
21-Nov-05	0	0	I
22-Nov-05	0	0	I
23-Nov-05	0	0	I
24-Nov-05	0	0	I
25-Nov-05	0	0	I
26-Nov-05	0	0	I
27-Nov-05	0	0	I
28-Nov-05	0	0	I
29-Nov-05	0	0	I
30-Nov-05	0	0	I

Date	Rainfall	Sum of 5 days rainfall (mm)	AMC
01-Dec-05	0	0	I
02-Dec-05	0	0	I
03-Dec-05	0	0	I
04-Dec-05	0	0	I
05-Dec-05	0	0	I
06-Dec-05	0	0	I
07-Dec-05	0	0	I
08-Dec-05	0	0	I
09-Dec-05	0	0	I
10-Dec-05	0	0	I
11-Dec-05	0	0	I
12-Dec-05	0	0	I
13-Dec-05	0	0	I
14-Dec-05	0	0	I
15-Dec-05	0	0	I
16-Dec-05	0	0	I
17-Dec-05	0	0	I
18-Dec-05	0	0	I
19-Dec-05	0	0	I
20-Dec-05	0	0	I
21-Dec-05	0	0	I
22-Dec-05	0	0	I
23-Dec-05	0	0	I
24-Dec-05	0	0	I
25-Dec-05	0	0	I
26-Dec-05	0	0	I
27-Dec-05	0	0	I
28-Dec-05	0	0	I
29-Dec-05	0	0	I
30-Dec-05	0	0	I
31-Dec-05	0	0	I

APPENDIX-III

Table III : Runoff curve numbers for hydrologic soil cover complexes (for AMC II and $I_a = 0.2S$)

Land use cover	Treatment	Hydrologic condition	Hydrologic soil group			
			A	B	C	D
Fallow	Straight row	-	77	86	91	94
Row Crops	Straight row	Poor	72	81	88	91
	Straight row	Good	67	78	85	89
	Contoured	Poor	70	79	84	88
	Contoured	Good	65	75	82	86
	Contoured and terraced	Poor	66	74	80	82
	Contoured and terraced	Good	62	71	78	81
Small grain	Straight row	Poor	65	76	84	88
	Straight row	Good	63	75	83	87
	Contoured	Poor	63	74	82	85
	Contoured	Good	63	74	82	85
	Contoured and terraced	Poor	61	72	79	82
	Contoured and terraced	Good	59	70	78	81
Close seeded legumes	Straight row	Poor	66	77	85	89
	Straight row	Good	58	72	81	85
Legumes or rotation	Contoured	Poor	64	75	83	85
	Contoured	Good	55	69	78	83
Meadow	Contoured and terraced	Poor	63	73	80	83
	Contoured and terraced	Good	51	67	76	80
Pasture or range	-	Poor	68	79	86	89
		Fair	49	69	79	84
		Good	39	61	74	80
	Contoured	Poor	47	67	81	88
	Contoured	Fair	25	59	75	83
	Contoured	Good	6	35	70	79
Meadow		Good	30	58	71	78
Woodland	-	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)	-	-	77	84	90	92

(Source: Soil Conservation Service, 1972)

APPENDIX-IV

Table IV: Micro-watershed wise mean CN

M.W.	Slope (α) m/m	Mean CN	$323.79+1563\alpha$ $/\alpha+323.52$	$(323.79+1563$ α $/\alpha+323.52)^*$ Mean CN	$CNI=$ $4.2*CNII$ $/10-(0.058*CNII)$	$CNIII=$ $23*CNII$ $/10+(0.13*CNII)$
				Slope corrected CN	AMC I	AMC III
1	0.17	87	1.01	88	75	94
2	0.09	88	1.00	88	75	94
3	0.15	86	1.00	87	73	94
4	0.15	86	1.00	87	73	94
5	0.03	87	1.00	87	73	94
6	0.09	90	1.00	90	80	96
7	0.09	87	1.00	87	74	94
8	0.04	88	1.00	88	76	94
9	0.10	90	1.00	90	80	96
10	0.02	90	1.00	89	78	95
11	0.06	90	1.00	90	79	95
12	0.04	89	1.00	88	76	95
13	0.14	89	1.00	90	78	95
14	0.07	90	1.00	90	79	95
15	0.17	93	1.01	94	86	97

APPENDIX-V

Table V: Micro-watershed wise mean CN for different AMC Conditions

Micro-watersheds in SA - 13 Watershed	Mean CN for Different AMC Conditions		
	AMC - I	AMC - II	AMC - III
1	75	87	94
2	75	88	94
3	73	86	94
4	73	86	94
5	73	87	94
6	80	90	95
7	74	87	94
8	76	88	94
9	80	90	95
10	78	90	95
11	79	90	95
12	76	89	95
13	78	89	95
14	79	90	95
15	86	93	97

APPENDIX-VI

Runoff generated from sub watersheds of SA-13 Watershed based on rainfall data of Asthi Tahsil

Month	January			June		
M.W.	Rainfall	Runoff	% Runoff	Rainfall	Runoff	% Runoff
1	4.6	0	0	4.5	0	0
2	4.6	0	0	4.5	0	0
3	4.6	0	0	4.5	0	0
4	4.6	0	0	4.5	0	0
5	4.6	0	0	4.5	0	0
6	4.6	0	0	4.5	0	0
7	4.6	0	0	4.5	0	0
8	4.6	0	0	4.5	0	0
9	4.6	0	0	4.5	0	0
10	4.6	0	0	4.5	0	0
11	4.6	0	0	4.5	0	0
12	4.6	0	0	4.5	0	0
13	4.6	0	0	4.5	0	0
14	4.6	0	0	4.5	0	0
15	4.6	0	0	4.5	0	0

Month	July			August		
M.W.	Rainfall	Runoff	% Runoff	Rainfall	Runoff	% Runoff
1	187.60	40.06	21.35	38.00	3.58	9.43
2	187.60	40.06	21.35	38.00	3.58	9.43
3	187.60	37.10	19.78	38.00	3.06	8.05
4	187.60	37.10	19.78	38.00	3.06	8.05
5	187.60	37.10	19.78	38.00	3.06	8.05
6	187.60	46.96	25.03	38.00	4.90	12.90
7	187.60	37.10	19.78	38.00	3.06	8.05
8	187.60	40.06	21.35	38.00	3.58	9.43
9	187.60	46.96	25.03	38.00	4.90	12.90
10	187.60	43.33	23.09	38.00	4.19	11.02
11	187.60	46.96	25.03	38.00	4.90	12.90
12	187.60	40.06	21.35	38.00	3.58	9.43
13	187.60	46.96	25.03	38.00	4.90	12.90
14	187.60	46.96	25.03	38.00	4.90	12.90
15	187.60	67.06	35.75	38.00	9.22	24.27

Month	September			October		
M.W.	Rainfall	Runoff	% Runoff	Rainfall	Runoff	% Runoff
1	120.80	7.59	6.29	60	37.82	63.03
2	120.80	7.59	6.29	60	37.82	63.03
3	120.80	6.35	5.26	60	36.80	61.33
4	120.80	6.35	5.26	60	36.80	61.33
5	120.80	6.35	5.26	60	36.80	61.33
6	120.80	10.83	8.97	60	39.85	66.42
7	120.80	6.35	5.26	60	36.80	61.33
8	120.80	7.59	6.29	60	37.82	63.03
9	120.80	10.83	8.97	60	39.85	66.42
10	120.80	9.07	7.51	60	38.83	64.72
11	120.80	10.83	8.97	60	39.85	66.42
12	120.80	7.59	6.29	60	37.82	63.03
13	120.80	10.83	8.97	60	39.85	66.42
14	120.80	10.83	8.97	60	39.85	66.42
15	120.80	23.23	19.23	60	43.94	73.23

APPENDIX-VII

Area wise various factors required for Soil erodibility factor

Village Code	Area(ha)	Texture	St	% Sand	% Silt	% Clay	Pt	% OM	HSG-Group	
Pardi-0135	8.87	Gravelly clay loam	1	40	24	36	2	1	D	0
Pardi-0135	1.41	Gravelly clay loam	1	40	24	36	2	1	D	0
Bogpimpalgaon-0212	21.06	Clayey	4	18	23	59	5	0	C	0
Sirpur-0128	13.64	Clayey	4	14	24	62	6	1	D	0
Bramhanvadi-0184	15.26	Gravelly clay	1	32	23	45	5	1	D	0
Shendi-0233	792.68	Gravelly clay	1	8	31	61	6	0	D	0
Pardi-0135	6.30	Gravelly clay loam	1	40	24	36	2	1	D	0
Dalimb-0214	88.48	Clayey	4	18	23	59	5	1	C	0
Pardi-0135	25.50	Gravelly clay loam	1	40	24	36	2	1	D	0
Malewadi-0225	671.03	Clayey	4	32	22	46	5	1	C	0
Dalimb-0214	53.19	Clayey	4	18	23	59	5	1	C	0
Daregaon-0185	42.73	Gravelly clay loam	1	44	21	35	2	1	B	0
Ujjani-0234	576.89	Clayey	4	16	26	58	5	1	B	0
Sirpur-0128	1.40	Clayey	4	14	24	62	6	1	D	0
Bramhanvadi-0184	215.71	Gravelly clay	1	32	23	45	5	1	D	0
Malewadi-0225	8.59	Clayey	4	32	22	46	5	1	C	0
Malewadi-0225	248.13	Clayey	4	32	22	46	5	1	C	0
Habitation Mask-9898	4.73	Habitation Mask	0	0	0	0	0	0	-	
Malewadi-0225	33.12	Clayey	4	32	22	46	5	1	C	0
Dalimb-0214	2.50	Clayey	4	18	23	59	5	1	C	0
Daregaon-0185	229.83	Gravelly clay loam	1	44	21	35	2	1	B	0
Sirpur-0128	41.53	Clayey	4	14	24	62	6	1	D	0
Dalimb-0214	30.32	Clayey	4	18	23	59	5	1	C	0
Malewadi-0225	1.67	Clayey	4	32	22	46	5	1	C	0
Dalimb-0214	75.38	Clayey	4	18	23	59	5	1	C	0
Ujjani-0234	210.05	Clayey	4	16	26	58	5	1	B	0
Dalimb-0214	28.90	Clayey	4	18	23	59	5	1	C	0
Malewadi-0225	214.65	Clayey	4	32	22	46	5	1	C	0
Habitation Mask-9898	15.41	Habitation Mask	-	0	0	0	0	0	-	
Sirpur-0128	26.56	Clayey	4	14	24	62	6	1	D	0
Dalimb-0214	6.68	Clayey	4	18	23	59	5	1	C	0
Dalimb-0214	102.98	Clayey	4	18	23	59	5	1	C	0

Dhamangaon-0129	25.18	Clayey	4	18	23	59	5	0	C	0
Sirpur-0128	7.50	Clayey	4	14	24	62	6	1	D	0
Habitation Mask-9898	1.57	Habitation Mask	0	0	0	0	0	0	-	
Habitation Mask-9898	2.05	Habitation Mask	0	0	0	0	0	0	-	
Dhamangaon-0129	45.88	Clayey	4	18	23	59	5	0	C	0
Malewadi-0225	390.80	Clayey	4	32	22	46	5	1	C	0
Habitation Mask-9898	5.41	Habitation Mask	0	0	0	0	0	0	-	
Malewadi-0225	23.58	Clayey	4	32	22	46	5	1	C	0
Habitation Mask-9898	1.59	Habitation Mask	0	0	0	0	0	0	-	
Sirpur-0128	94.73	Clayey	4	14	24	62	6	1	D	0
Dhamangaon-0129	54.10	Clayey	4	18	23	59	5	0	C	0
Dalimb-0214	48.64	Clayey	4	18	23	59	5	1	C	0
Waterbody Mask-9999	602.31	Waterbody Mask	0	0	0	0	0	0	-	
Bogpimpalgaon-0212	170.17	Clayey	4	18	23	59	5	0	C	0
Habitation Mask-9898	3.74	Habitation Mask	0	0	0	0	0	0	-	
Dhamangaon-0129	91.07	Clayey	4	18	23	59	5	0	C	0
Dalimb-0214	3.24	Clayey	4	18	23	59	5	1	C	0
Linga-0238	264.03	Clayey	4	29	24	47	5	0	D	0
Dalimb-0214	270.25	Clayey	4	18	23	59	5	1	C	0
Dalimb-0214	58.87	Clayey	4	18	23	59	5	1	C	0
Linga-0238	17.47	Clayey	4	29	24	47	5	0	D	0
Malewadi-0225	41.48	Clayey	4	32	22	46	5	1	C	0
Dalimb-0214	135.66	Clayey	4	18	23	59	5	1	C	0
Dhamangaon-0129	553.97	Clayey	4	18	23	59	5	0	C	0
Linga-0238	351.11	Clayey	4	29	24	47	5	0	D	0
Habitation Mask-9898	4.32	Habitation Mask	0	0	0	0	0	0	-	
Matauda-0229	17.84	Gravelly clay	1	12	28	60	5	0	D	0
Malewadi-0225	36.55	Clayey	4	32	22	46	5	1	C	0
Dalimb-0214	98.80	Clayey	4	18	23	59	5	1	C	0
Dalimb-0214	142.31	Clayey	4	18	23	59	5	1	C	0
Habitation Mask-9898	8.73	Habitation Mask	0	0	0	0	0	0	-	
Malewadi-0225	129.96	Clayey	4	32	22	46	5	1	C	0
Dalimb-0214	274.37	Clayey	4	18	23	59	5	1	C	0
Malewadi-0225	190.14	Clayey	4	32	22	46	5	1	C	0
Matauda-0229	21.89	Gravelly clay	1	12	28	60	5	0	D	0
Malewadi-0225	1081.39	Clayey	4	32	22	46	5	1	C	0
Dalimb-0214	104.93	Clayey	4	18	23	59	5	1	C	0
Matauda-0229	41.39	Gravelly clay	1	12	28	60	5	0	D	0
Malewadi-0225	17.15	Clayey	4	32	22	46	5	1	C	0
Sirpur-0128	8.69	Clayey	4	14	24	62	6	1	D	0

Sirpur-0128	9.90	Clayey	4	14	24	62	6	1	D	0
Dalimb-0214	96.22	Clayey	4	18	23	59	5	1	C	0
Ujjani-0234	77.53	Clayey	4	16	26	58	5	1	B	0
Habitation Mask-9898	5.01	Habitation Mask	0	0	0	0	0	0	-	
Waterbody Mask-9999	5.64	Waterbody Mask	0	0	0	0	0	0	-	
Malewadi-0225	0.63	Clayey	4	32	22	46	5	1	C	0
Malewadi-0225	5.74	Clayey	4	32	22	46	5	1	C	0
Malewadi-0225	1.58	Clayey	4	32	22	46	5	1	C	0
Dhamangaon-0129	150.93	Clayey	4	18	23	59	5	0	C	0
Habitation Mask-9898	2.73	Habitation Mask	0	0	0	0	0	0	-	
Linga-0238	11.01	Clayey	4	29	24	47	5	0	D	0
Dhamangaon-0129	81.28	Clayey	4	18	23	59	5	0	C	0
Malewadi-0225	1.81	Clayey	4	32	22	46	5	1	C	0
Dalimb-0214	445.60	Clayey	4	18	23	59	5	1	C	0
Linga-0238	83.39	Clayey	4	29	24	47	5	0	D	0
Habitation Mask-9898	7.17	Habitation Mask	0	0	0	0	0	0	-	
Malewadi-0225	36.72	Clayey	4	32	22	46	5	1	C	0
Dalimb-0214	51.33	Clayey	4	18	23	59	5	1	C	0
Dalimb-0214	11.06	Clayey	4	18	23	59	5	1	C	0
Dalimb-0214	14.31	Clayey	4	18	23	59	5	1	C	0
Malewadi-0225	465.08	Clayey	4	32	22	46	5	1	C	0
Matauda-0229	31.38	Gravelly clay	1	12	28	60	5	0	D	0
Habitation Mask-9898	2.01	Habitation Mask	0	0	0	0	0	0	-	
Dalimb-0214	16.73	Clayey	4	18	23	59	5	1	C	0
Dalimb-0214	20.22	Clayey	4	18	23	59	5	1	C	0
Ujjani-0234	365.65	Clayey	4	16	26	58	5	1	B	0
Malewadi-0225	5.29	Clayey	4	32	22	46	5	1	C	0
Dhamangaon-0129	16.17	Clayey	4	18	23	59	5	0	C	0
Dalimb-0214	9.85	Clayey	4	18	23	59	5	1	C	0
Habitation Mask-9898	5.95	Habitation Mask	0	0	0	0	0	0	-	
Dalimb-0214	142.42	Clayey	4	18	23	59	5	1	C	0
Daregaon-0185	52.46	Gravelly clay loam	1	44	21	35	2	1	B	0
Malewadi-0225	7.87	Clayey	4	32	22	46	5	1	C	0
Dhamangaon-0129	62.13	Clayey	4	18	23	59	5	0	C	0
Dalimb-0214	3.46	Clayey	4	18	23	59	5	1	C	0
Dalimb-0214	12.05	Clayey	4	18	23	59	5	1	C	0
Dalimb-0214	65.90	Clayey	4	18	23	59	5	1	C	0
Matauda-0229	20.87	Gravelly clay	1	12	28	60	5	0	D	0
Habitation Mask-9898	6.28	Habitation Mask	0	0	0	0	0	0	-	
Dalimb-0214	13.01	Clayey	4	18	23	59	5	1	C	0

Dhamangaon-0129	407.37	Clayey	4	18	23	59	5	0	C	0
Malewadi-0225	42.54	Clayey	4	32	22	46	5	1	C	0
Malewadi-0225	2.21	Clayey	4	32	22	46	5	1	C	0
Habitation Mask-9898	4.93	Habitation Mask	0	0	0	0	0	0	-	
Habitation Mask-9898	3.76	Habitation Mask	0	0	0	0	0	0	-	
Linga-0238	15.62	Clayey	4	29	24	47	5	0	D	0
Dhamangaon-0129	72.05	Clayey	4	18	23	59	5	0	C	0
Ujjani-0234	30.46	Clayey	4	16	26	58	5	1	B	0
Dalimb-0214	33.00	Clayey	4	18	23	59	5	1	C	0
Habitation Mask-9898	2.54	Habitation Mask	0	0	0	0	0	0	-	
Malewadi-0225	76.33	Clayey	4	32	22	46	5	1	C	0
Kansur-0221	16.77	Clayey	4	7	29	64	6	0	D	0
Ujjani-0234	215.71	Clayey	4	16	26	58	5	1	B	0
Habitation Mask-9898	19.53	Habitation Mask	0	0	0	0	0	0	-	
Dalimb-0214	61.42	Clayey	4	18	23	59	5	1	C	0
Malewadi-0225	30.21	Clayey	4	32	22	46	5	1	C	0
Malewadi-0225	95.68	Clayey	4	32	22	46	5	1	C	0
Sirpur-0128	43.57	Clayey	4	14	24	62	6	1	D	0
Jalkot-0218	90.34	Sandy clay loam	4	64	16	20	2	0	D	
Dalimb-0214	51.90	Clayey	4	18	23	59	5	1	C	0
Sirpur-0128	83.96	Clayey	4	14	24	62	6	1	D	0
Malewadi-0225	93.76	Clayey	4	32	22	46	5	1	C	0
Dalimb-0214	10.07	Clayey	4	18	23	59	5	1	C	0
Jalkot-0218	11.82	Sandy clay loam	1	64	16	20	2	0	D	
Habitation Mask-9898	12.95	Habitation Mask	0	0	0	0	0	0	-	
Dhamangaon-0129	203.54	Clayey	4	18	23	59	5	0	C	0
Dalimb-0214	28.28	Clayey	4	18	23	59	5	1	C	0
Malewadi-0225	4.70	Clayey	4	32	22	46	5	1	C	0
Linga-0238	90.61	Clayey	4	29	24	47	5	0	D	0
Waterbody Mask-9999	5.52	Waterbody Mask	0	0	0	0	0	0	-	
Jalkot-0218	0.89	Sandy clay loam	1	64	16	20	2	0	D	
Dalimb-0214	23.89	Clayey	4	18	23	59	5	1	C	0
Habitation Mask-9898	3.48	Habitation Mask	0	0	0	0	0	0	-	
Habitation Mask-9898	2.87	Habitation Mask	0	0	0	0	0	0	-	
Dalimb-0214	15.94	Clayey	4	18	23	59	5	1	C	0
Matauda-0229	20.32	Gravelly clay	1	12	28	60	5	0	D	0
Dalimb-0214	248.08	Clayey	4	18	23	59	5	1	C	0
Dalimb-0214	108.92	Clayey	4	18	23	59	5	1	C	0
Malewadi-0225	5.06	Clayey	4	32	22	46	5	1	C	0
Malewadi-0225	43.87	Clayey	4	32	22	46	5	1	C	0

Matauda-0229	12.29	Gravelly clay	1	12	28	60	5	0	D	0
Habitation Mask-9898	2.52	Habitation Mask	0	0	0	0	0	0	-	
Habitation Mask-9898	3.10	Habitation Mask	0	0	0	0	0	0	-	
Malewadi-0225	424.09	Clayey	4	32	22	46	5	1	C	0
Malewadi-0225	42.10	Clayey	4	32	22	46	5	1	C	0
Dalimb-0214	17.60	Clayey	4	18	23	59	5	1	C	0
Dalimb-0214	54.66	Clayey	4	18	23	59	5	1	C	0
Malewadi-0225	34.37	Clayey	4	32	22	46	5	1	C	0
Matauda-0229	12.12	Gravelly clay	1	12	28	60	5	0	D	0
Matauda-0229	6.68	Gravelly clay	1	12	28	60	5	0	D	0
Dalimb-0214	64.42	Clayey	4	18	23	59	5	1	C	0
Habitation Mask-9898	2.25	Habitation Mask	0	0	0	0	0	0	-	
Dhamangaon-0129	18.23	Clayey	4	18	23	59	5	0	C	0
Linga-0238	30.44	Clayey	4	29	24	47	5	0	D	0
Habitation Mask-9898	3.92	Habitation Mask	0	0	0	0	0	0	-	
Malewadi-0225	65.07	Clayey	4	32	22	46	5	1	C	0
Dhamangaon-0129	336.67	Clayey	4	18	23	59	5	0	C	0
Dalimb-0214	4.83	Clayey	4	18	23	59	5	1	C	0
Dhamangaon-0129	97.70	Clayey	4	18	23	59	5	0	C	0
Dhamangaon-0129	27.11	Clayey	4	18	23	59	5	0	C	0
Dalimb-0214	1.74	Clayey	4	18	23	59	5	1	C	0
Dhamangaon-0129	70.69	Clayey	4	18	23	59	5	0	C	0
Habitation Mask-9898	1.60	Habitation Mask	0	0	0	0	0	0	-	
Dalimb-0214	43.54	Clayey	4	18	23	59	5	1	C	0
Habitation Mask-9898	2.40	Habitation Mask	0	0	0	0	0	0	-	
Malewadi-0225	13.60	Clayey	4	32	22	46	5	1	C	0
Linga-0238	321.83	Clayey	4	29	24	47	5	0	D	0
Matauda-0229	53.16	Gravelly clay	1	12	28	60	5	0	D	0
Dhamangaon-0129	52.27	Clayey	4	18	23	59	5	0	C	0
Dalimb-0214	16.73	Clayey	4	18	23	59	5	1	C	0
Matauda-0229	27.34	Gravelly clay	1	12	28	60	5	0	D	0
Dalimb-0214	151.11	Clayey	4	18	23	59	5	1	C	0
Dalimb-0214	5.55	Clayey	4	18	23	59	5	1	C	0
Dalimb-0214	33.49	Clayey	4	18	23	59	5	1	C	0
Dhamangaon-0129	212.55	Clayey	4	18	23	59	5	0	C	0
Malewadi-0225	1.54	Clayey	4	32	22	46	5	1	C	0
Habitation Mask-9898	2.41	Habitation Mask	0	0	0	0	0	0	-	
Malewadi-0225	1243.84	Clayey	4	32	22	46	5	1	C	0
Bogpimpalgaon-0212	39.55	Clayey	4	18	23	59	5	0	C	0
Dalimb-0214	28.91	Clayey	4	18	23	59	5	1	C	0

Habitation Mask-9898	5.64	Habitation Mask	0	0	0	0	0	0	-	
Linga-0238	165.07	Clayey	4	29	24	47	5	0	D	0
Habitation Mask-9898	3.80	Habitation Mask	0	0	0	0	0	0	-	
Malewadi-0225	26.34	Clayey	4	32	22	46	5	1	C	0
Dhamangaon-0129	140.35	Clayey	4	18	23	59	5	0	C	0
Dhamangaon-0129	51.43	Clayey	4	18	23	59	5	0	C	0
Habitation Mask-9898	2.55	Habitation Mask	0	0	0	0	0	0	-	
Dalimb-0214	1.92	Clayey	4	18	23	59	5	1	C	0
Dalimb-0214	8.07	Clayey	4	18	23	59	5	1	C	0
Ujjani-0234	84.18	Clayey	4	16	26	58	5	1	B	0
Dhamangaon-0129	285.67	Clayey	4	18	23	59	5	0	C	0
Habitation Mask-9898	4.00	Habitation Mask	0	0	0	0	0	0	-	
Dhamangaon-0129	1.69	Clayey	4	18	23	59	5	0	C	0
Dhamangaon-0129	12.95	Clayey	4	18	23	59	5	0	C	0
Bogpimpalgaon-0212	154.44	Clayey	4	18	23	59	5	0	C	0
Dhamangaon-0129	105.80	Clayey	4	18	23	59	5	0	C	0
Habitation Mask-9898	12.57	Habitation Mask	0	0	0	0	0	0	-	
Linga-0238	2.57	Clayey	4	29	24	47	5	0	D	0
Dalimb-0214	52.58	Clayey	4	18	23	59	5	1	C	0
Dhamangaon-0129	37.31	Clayey	4	18	23	59	5	0	C	0
Dalimb-0214	206.45	Clayey	4	18	23	59	5	1	C	0
Dalimb-0214	105.06	Clayey	4	18	23	59	5	1	C	0
Malewadi-0225	1.05	Clayey	4	32	22	46	5	1	C	0
Habitation Mask-9898	7.15	Habitation Mask	0	0	0	0	0	0	-	
Bogpimpalgaon-0212	20.23	Clayey	4	18	23	59	5	0	C	0
Dhamangaon-0129	22.93	Clayey	4	18	23	59	5	0	C	0
Bogpimpalgaon-0212	8.28	Clayey	4	18	23	59	5	0	C	0
Dalimb-0214	53.75	Clayey	4	18	23	59	5	1	C	0
Sirpur-0128	60.91	Clayey	4	14	24	62	6	1	D	0
Bogpimpalgaon-0212	24.43	Clayey	4	18	23	59	5	0	C	0
Waterbody Mask-9999	3.56	Waterbody Mask	0	0	0	0	0	0	-	
Dalimb-0214	33.88	Clayey	4	18	23	59	5	1	C	0
Dalimb-0214	7.26	Clayey	4	18	23	59	5	1	C	0
Habitation Mask-9898	4.92	Habitation Mask	0	0	0	0	0	0	-	
Dalimb-0214	65.19	Clayey	4	18	23	59	5	1	C	0
Linga-0238	41.17	Clayey	4	29	24	47	5	0	D	0
Waterbody Mask-9999	25.07	Waterbody Mask	0	0	0	0	0	0	-	
Bogpimpalgaon-0212	30.22	Clayey	4	18	23	59	5	0	C	0
Waterbody Mask-9999	0.55	Waterbody Mask	0	0	0	0	0	0	-	
Waterbody Mask-9999	1.96	Waterbody Mask	0	0	0	0	0	0	-	

Dalimb-0214	0.73	Clayey	4	18	23	59	5	1	C	0
Waterbody Mask-9999	1.32	Waterbody Mask	0	0	0	0	0	0	-	0
Waterbody Mask-9999	2.32	Waterbody Mask	0	0	0	0	0	0	-	0
Linga-0238	522.18	Clayey	4	29	24	47	5	0	D	0
Dalimb-0214	319.96	Clayey	4	18	23	59	5	1	C	0
Bogpimpalgaon-0212	10.44	Clayey	4	18	23	59	5	0	C	0
Dhamangaon-0129	916.76	Clayey	4	18	23	59	5	0	C	0
Dalimb-0214	42.47	Clayey	4	18	23	59	5	1	C	0
Total Area	21300.00									