STUDY OF WATER HARVESTING POTENTIAL OF MORNA RIVER CATCHMENT 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
Chavan Pallavi Bharatrao

DEPARTMENT OF SOIL AND WATER CONSERVATION ENGINEERING
COLLEGE OF AGRICULTURAL ENGINEERING AND TECHNOLOGY
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DAPOLI- 415 712, DIST. RATNAGIRI, M. S. (INDIA)
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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: Dapoli

Date: / /2013 **(Chavan Pallavi Bharatrao)**

Prof. dilip MAHALE.

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CERTIFICATE

This is to certify that the thesis entitled **“STUDY OF WATER HARVESTING POTENTIAL OF MORNA RIVER CATCHMENT 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 **Ms. Chavan Pallavi Bharatrao** 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.

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Place : Dapoli

Date : / /2013 **(Chavan Pallavi Bharatrao)**

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LIST OF ABBREVIATIONS AND SYMBOLS

Abbreviations		Meanings
%	:	Per cent
<	:	Less than
>	:	Greater than
Agril.	:	Agricultural
AMC	:	Antecedent Moisture Condition
C.A.E.T	:	College of Agricultural Engineering and Technology
CN	:	Curve Number
DEM	:	Digital Elevation Model
Dept.	:	Department
Dr. B.S.K.K.V	:	Doctor Balasaheb Sawant Konkan Krishi Vidyapeeth
E	:	East
e.g.	:	For Example
Eq^n.	:	Equation
ERDAS	:	Earth Resources Data Analysis Systems
ESRI	:	Environmental System Research Institute
et.al	:	And others
Etc	:	Etcetera
Fig.	:	Figure
GIS	:	Geographical information system
Govt.	:	Government
Ha	:	Hectare
HSG	:	Hydrologic Soil Group
i.e	:	That is
ISRO	:	Indian Space Research Organization
J	:	Journal
Km	:	kilo meter
km^2	:	Square kilo meter
LULC	:	Land Use Land Cover

M	:	Million
m	:	Meter
m^3	:	Cubic meter
N	:	North
NARP	:	National Agricultural Research Project
No.	:	Number
SCS	:	Soil Conservation Service
SOI	:	Survey of India
Sq.	:	Square
SRTM	:	Shuttle Radar Topographic Mission
WHS	:	Water Harvesting Structures

ABSTRACT

STUDY OF WATER HARVESTING POTENTIAL OF MORNA RIVER CATCHMENT USING REMOTE SENSING AND GIS

By

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Human population of Indian subcontinent is ever increasing, thereby increasing the demand of water for domestic, agricultural and industrial use. Availability of groundwater varies spatially and temporally depending upon the terrain. The scarcity of water affects the environmental and developmental activities of an area. Construction of small water harvesting structures across streams or in the watersheds is gaining momentum in recent years.

In the present study, potential sites for construction of rainwater harvesting structures and water harvesting potential of the Morna river catchment of Satara District, Maharashtra, India have been identified by using remote sensing and GIS techniques. Various thematic maps such as Land use/Land cover, stream order, slope etc. were prepared using remote sensing application. After that runoff potential and runoff coefficient maps were prepared with the help of combined land use land cover and HSG map in ArcGIS 10 environment, SCS-CN method was adopted to do so. Daily rainfall data was used for determination of runoff coefficient. Runoff coefficient and slope map were then assigned a weightage and each class or unit in these maps were assigned a knowledge based ranking of one to ten depending on its significance in storage and transmittance of groundwater. These rank values were multiplied with layer weightage to form score. Water harvesting potential map was prepared using this score. Suitable zones for the construction of

different water conservation measures in the study area were identified. To do this, suitability criteria was developed according to field situations for slope, soil, drainage network and rainfall. After that, these layers along with geology and drainage were integrated using GIS techniques to derive suitable water harvesting sites. The final map showing different categories of suitability sites for water harvesting structures such as Check dams, percolation ponds, farm ponds, Contour bunding, and Contour trenching have been suggested.

For entire study area, 149 suitable sites for various water harvesting structures were identified. Best suitable sites for check dam construction have been distributed all over the study area, while sites suitable for percolation pond found more towards the north east part of watershed. Sites suitable for contour bunding and trenching were found near to the boundary of watershed. One of the important criteria in selecting sites suitable for farm ponds was that land use should be agriculture with logic that farm ponds are suitable for providing supplementary irrigation to the crops. We have got 28 best suitable sites for check dam, 27 suitable locations for farm pond, 35 for percolation pond, 30 for contour bunding and 29 for contour trenching. Water harvesting potential map was prepared for microwatersheds of study area. Results showed that maximum area comes under high water harvesting potential category.

INTRODUCTION

"When you see clouds gathering,

Prepare to catch rainwater"

Water is a key component in determining the quality of our lives. It is one of the most essential elements for good health. Human population of Indian subcontinent is ever increasing, thereby increasing the demand of water for domestic, agricultural and industrial use. Out of 2.5%, global fresh water only 1% is available for human consumption. According to the World Bank report, India will be in water stress zone by the year 2025 and water scare zone by 2050 (Anonymous, 2013). Hence, there is great necessity of water conservation. In spite of higher average annual rainfall in India (about 120 cm) as compared to the global average (about 99 cm) we face the problem of water scarcity. Most of the rain received on the surface tends to flow away rapidly, leaving very little for the recharge of groundwater. As a result, most parts of India experience scarcity of water even for domestic use. However, if every city, town and village adopts and implements rainwater-harvesting techniques, the water crisis can be tackled easily. Because of water scarcity, Indian Government has declared year 2013 as "Water Conservation Year"

Maharashtra is situated in the western part of India. Total area of Maharashtra is 30.8 Mha out of which 14.4 Mha (47 %) is affected by soil erosion. Average annual rainfall of Maharashtra is 117 cm. Maharashtra has experienced the problem of water scarcity for many years. The worst ever drought that the state of Maharashtra has experienced till date was in year 1972 when almost 5 million people had no work as the crops failed. However, the current drought of 2013 in Maharashtra is set to break all the records. With millions estimated to be affected, lakhs of cattle rendered hungry without fodder. This drought is the worst kind of natural disaster that the state has faced. State's economic survey estimates a fall in agriculture and allied sectors by 2.1% and decrease in food production from 12.7 million tonnes to 10.4 million tonnes in current fiscal year (Anonymous, 2013). Almost 1/5th of Maharashtra is reeling under drought. According to official figures, 15 districts comprising 11,801 villages are declared as drought-affected. There is acute water scarcity in 1,779 villages and 4,709 smaller habitations (Anonymous, 2013). Some of the villages are facing drought for the second consecutive year.

The dams in Maharashtra are in a sad state. It is ironical that the state having largest number of dams in the whole country is currently facing severe droughts. Big dams like Jayakwadi and Ujani are running dry and have to rely on their dead storage for supplying water. According to the state's Groundwater Surveys, 195 of the 1531 watersheds are critically depleted, 73 already 'over exploited'. So it is very essential to make concentrated efforts towards proper scientific planning and execution for water resources development. If this planning gets boost of advance techniques and tools like RS and GIS, it would be faster and most accurate.

Watershed is a hydrological unit and is an ideal unit for management of natural resources like land and water. Rainwater harvesting can be broadly defined as a collection, concentration and recycling of runoff for productive purposes like crop, fodder, pasture or trees production, livestock and domestic water supply. Watershed development calls for a detailed understanding and analysis of various rainfall-runoff data, hydraulic properties of soil, soil moisture, slope, rainfall intensity and lithology.

Remote Sensing and Geographic Information Systems (GIS) techniques are increasingly used for planning, development, and management of natural resources at regional, national, and international level. It is becoming a significant tool in hydrological modeling in view of its capacity to handle large amount of spatial and attribute data. In recent days, an aggregated study of runoff modeling, remote sensing and GIS has gained significance in targeting suitable sites for water harvesting structures (Padmavathy *et al* 1993). Remote sensing and GIS are the advanced tools used for watershed development and management. They also have been applied for the assessment of several water related environmental challenges such as soil erosion, degradation of land by water logging, contamination of ground and surface water, and changes in ecological parameters. The significant factors for the planning and development of a watershed are its physiographical characteristics, drainage, geomorphology, soil, land use/land cover and available water resources. Using RS and GIS, various thematic maps such as land use map, hydrological soil group map, slope map and DEM map can be prepared for selecting suitable site for construction of water harvesting structures (Singh *et.al* 2009). The runoff estimates for different combinations of soil group, land use classes and Antecedent Moisture Content (AMC) can be estimated.

Morna river catchment (i.e. KR-27 watershed) lies in Satara district of Maharashtra state. In this region, irrigated area under cultivation is very less as compared to non-irrigated area.

Therefore, there is need to increase the potential of irrigation by developing water-harvesting structures. This area is facing various problems associated with land and water resources management. As per the All India Soil and Land Use Survey Organization, this watershed is considered under very high priority category. Present watershed contains very less quantity of soil and water conservation structures. As per the strategy under Western Ghats Development Project; it is being proposed for giving treatment and it is suggested that whole watershed should be treated with soil and water conservation measures. In addition, area under irrigation is very less because of the less quantity of water harvesting structures and most of the agriculture is rainfed. Therefore, there is, need to increase the water harvesting potential of this region. Keeping this in mind the study is undertaken with following specific objectives,

1. To identify the water harvesting sites of Morana River catchment using GIS and Remote Sensing.
2. To estimate the water harvesting potential of Morana River catchment by using Remote Sensing and GIS.

II. REVIEW OF LITERATURE

This chapter deals with the work done by various scientists, internationally and nationally on water harvesting site selection and water harvesting potential by Remote Sensing and GIS.

2.1. Water harvesting site selection by using Remote Sensing and GIS:

Vorhauer and James (1996) predicted that GIS is a best tool for siting farm ponds. The specific approach considered in this study is locating potential sites for water harvesting based on topography, land use, soil and slope. The GIS screening produced maps showing the location of suitable pond sites. Based on these maps, the watershed of each site was determined and the potential runoff to the pond was predicted using the Natural Resources Conservation Service Number Method.

Gupta *et al* (1997) estimated water-harvesting potential for a semarid area using GIS and remote sensing. The present study was aimed to develop a water harvesting strategy in the semiarid area of Rajasthan, India using the geographic information system (GIS). The SCS runoff curve number model was applied to derive the annual runoff potential for each basin. The most commonly used structure in the study area is the "check dam" which fulfills the need of the local community and is suitable for the condition of the area.

Murthy *et al* (2003) studied the integration of thematic maps through GIS for Identification of Groundwater Potential Zones. The studies reveal that instead of taking only one characteristic into consideration to identify potential ground water zones, integrating the thematic maps prepared from conventional and remote sensing techniques using GIS yields more and near accurate results.These maps are integrated after assigning weight factors to the identified features in each thematic map depending upon their infiltration capacities and the groundwater potential zones are demarcated.

Durbude and Venkatesha (2004) studied the site suitability analysis for soil and water conservation structures. In this study an integrated approach of remote sensing and GIS techniques was used to identify runoff potential zones and further suitable sites for soil and water conservation structures such as contour bunding/ land levelling, farm ponds, gully plugging, percolation tanks, nala bunds etc for Hire watershed in Koppal district of Karnataka state. The decision rules are formulized for selection of sites for various soil and water conservation structures as per the guidelines given by integrated mission for sustainable development (IMSD, 1995), Indian national committee on hydrology (INCOH) and the criteria given as per the field manual.

Nookaratnam *et al* (2005) carried out the check dam positioning by prioritization of micro watersheds using SYI model and morphometric analysis. Based on this study it is found that a total of 21 micro-watersheds fall under category very high, in which 24 check dams were proposed on 3^{rd}, 4^{th} and 5^{th} order streams.

Ravi Shankar and Mohan (2005) studied a GIS based hydrogeomorphic approach for identification of site-specific artificial-recharge techniques in the Deccan Volcanic Province. In this study, an attempt is made to identify zones favourable for the application and adaptation of site-specific artificial-recharge techniques for augmentation of groundwater through a Geographical Information System (GIS) based hydrogeomorphic approach in the Bhatsa and Kalu river basins of Thane district. The integrated study helps to design a suitable groundwater management plan for a basaltic terrain.

Mohtar *et al* (2006) presented the web based GIS- hydrologic modeling for sitting water harvesting reservoir. In this research, a web based GIS- hydrologic modeling system was designed to implement a spatial Analytical Hierarchy Process (AHP) for selecting the most suitable and practical location for building water harvesting reservoirs.

Narendra and Nageswararao (2006) studied morphometry of Meghadrigedda watershed, Visakhapatnam district, Andhra Pradesh using GIS and Resourcesat data. In this study, GIS tools and image processing techniques are used to identify the morphological features and water resources of the Meghadrigedda watershed. Most of the water tanks of the area have been silted. Twelve recharge pits were located to excavate silted water tanks. To improve the ground water levels, thirteen suitable sites were identified for the construction of check dams in the Meghadrigedda watershed.

Ahemd *et. al* (2007) studied the analytical hierarchical process in conjunction with GIS for identification suitable sites for water harvesting in the Oasis areas. This study aims at identifying suitable sites for water harvesting in the arid zone of Northern Mauritania using Landsat imagery and GIS technology. The combination of different thematic layers; prepared from remote sensing images and ancillary data, such as land cover, geology, slope, drainage, geomorphology and lineament, using weighted overlay technique permit an effective way for monitoring and planning natural resources.

Mbilinyi *et. al* (2007) had given GIS-based decision support system for identifying potential sites for rainwater harvesting. This paper presents a geographic information system (GIS)-based Decision Support System (DSS) that uses remote sensing (RS), limited field survey and GIS to identify potential sites for RWH technologies. Two sites in the Makanya watershed, in Kilimanjaro Region, Tanzania, were used for testing and validation of the DSS. The results indicate that the developed DSS tool can reliably be used to predict potential sites for RWH technologies in semi-arid areas.

Kumar *et.al* (2008) had given delineation of Potential Sites for Water Harvesting Structures using Remote Sensing and GIS in the Bakhar watershed of Mirzapur District, Uttar Pradesh, India. The final map showing different categories of suitability sites for water harvesting structures such as Check dams, Contour bunding, Recharge pits, Wells and Contour trenching have been suggested. Out of total 136 villages of Bakhar watershed 22 villages were found suitable for check dams, 14 for contour bunding, 5 for recharge pits and 12 for contour trenching and rest are found not suitable for any of these water harvesting structure.

Kahinda *et.al* (2008) developed suitability maps for rainwater harvesting in South Africa. In this study, in-field rain water harvesting and ex-field RWH suitability maps are developed based on a combination of physical, ecological and socio-economic factors Model Builder, an extension of ArcView 3.3 that enables a weighted overlay of datasets, is used to create the suitability model, comprising the physical, ecological and vulnerability sub-models from which the physical, the ecological and the vulnerability maps are derived respectively. Results indicate that about 30% is highly suitable for in-field RWH and 25% is highly suitable for ex-field RWH.

Javed (2009) studied the prioritization of sub-watersheds based on morphometric and land use analysis using remote sensing and GIS. Study demonstrates the significant land use changes especially in cultivated lands, open shrub, open forest, water bodies and waste lands since 1989 to 2001. Based upon morphometric and land use/land cover analysis, the sub watersheds have been classified into three categories as high, medium and low in terms of priority for conservation and management of natural resources.

Jothiprakash and Sathe (2009) evaluated rainwater harvesting methods and structures using Analytical Hierarchy Process for a large scale industrial area. The systematic methodology of AHP was applied to identify most appropriate RWH structure to store the required quantity of water with given conditions. As a result of this process "RCC tank" was identified as the most appropriate RWH structure for given requirements and conditions.

Singh *et.al* (2009) studied suitable sites for Water Harvesting Structures in Soankhad Watershed, Punjab using RS&GIS. A case study has been conducted to identify suitable sites for water harvesting structures using RS-GIS. The various Thematic maps such as land use map, hydrological soil group map, slope map and DEM map were prepared for selecting suitable site for construction of water harvesting structures. The water balance study of the Soankhad watershed was also computed with monthly mean temperature and rainfall data using TM model.

Adamat *et al* (2010) developed combination of GIS with multicriteria decision making for siting water-harvesting ponds in Northern Jordan. The selection of best sites for water harvesting schemes is based on certain criteria that take into consideration the socio-economic and the physical characteristics of the targeted area. This research aimed to use both the Weighted Linear Combination and the Boolean techniques within GIS environment to select suitable areas in Northern Jordan for establishing water-harvesting ponds. This resulted in having 25% of the study area (64,184.8 ha) with high potential for constructing water harvesting ponds.

Dutta *et. al* (2010) studied erosion-deposition processes around Majuli Island, Assam using Remote Sensing. The approach have been made to study the erosion-deposition processes with the help of data resource generated from the Survey of India (SOI) toposheets and Indian Remote Sensing (IRS) satellite imagery spanning the period from 1966-1975 to 2008 in a Geographical Information System (GIS) environment. The observation has revealed a dramatic change in reduction of land area of the Majuli Island.

Srivastava *et.al* (2010) studied that planning for watershed development in Badri Gad watershed of Tehari Garhwal district of Uttrakhand. Slope was divided into eight classes I, II, III, IV, V, VI, VII and VIII. They demonstrated that only land suitable for agriculture under the class I to IV was found 11.50% of total area. Remaining area 88.50 % was not suitable for agriculture as per land capability classification. More than 70 % area of the watershed was under steep slope. They suggested continuous contour trenching, staggered trenching for the higher slopes which conserve moisture, recharging the natural resources. They recommended check dam and gabion structure for drainage line treatment.

Weerasinghe *et.al* (2010) developed the Water Harvest and Storage-Location Optimization Model Using GIS and Remote Sensing. They retrieve input data from global data repositories and rescaled to 1km spatial resolution, to obtain a set of manageable input data having adequate level of information. According to the results from testing and validation of the GWAMP they point out that the GWAMP can be used reliably to predict potential sites for rain water harvesting and storage technologies in a given catchment.

Gavade *et al* (2011) revealed the site suitability analysis for surface rainwater harvesting of Madha Tahsil from Solapur District Maharashtra. The present study is carried out by GPS, survey of India toposheets i.e NE 43-7 and NE 43-11, on scale of 1: 250,000, SRTM data for creation of DEM and satellite imagery of LANSAT ETM+ (30m. spatial resolution).

Satya Raj (2011) studied rainwater-harvesting potential of Pallavapuram area of Meerut. Present paper uses a GIS approach to assess total area of catchments available for rainwater harvesting in Pallavapuram area of Meerut and calculate the amount of water, which could be really harvested or used for replenishing groundwater reserves. The different types of catchments included rooftops, roads and open spaces. Finally, the area of catchments was calculated to find the total rainwater harvesting potential of the study area.

Sharma and Singh (2012) identified the potential runoff harvesting sites in a water scarce rural watershed using GIS approach in arid and semi arid regions. The study identifies priority areas for runoff harvesting in the rural watershed with the use of GIS. Output of this study, based on integrated GIS modeling system, is presented using ‘suitability maps’ developed for potential runoff harvesting sites for the rural watershed. It is concluded that providing an accurate spatial representation of the runoff generation potential within a watershed is an important factor in developing a strategic runoff harvesting plan for any watershed.

Elewa *et al* (2012) determined the potential sites for runoff water harvesting using remote sensing and geographic information systems-based modeling in Sinai. The areas of high potential for RWH are occupying only 5.74-12.0% (3,201-6,695 Km^2), whereas the areas of low potential for RWH are existing in 23.64-29.85% (13,185-16,652 Km^2) of the total Sinai’s area. However, most of Sinai’s area 64.35-64.40% (35,923.12-35,896.87 Km^2) is represented by the moderate potentiality class.

2.2. Curve number:

James and Bonta (1997) studied determination of watershed curve number using derived distributions. Curve numbers (CNs) are developed from measured rainfall *(P)* and runoff *(Q)* data, yet there is no standard method for determining CN. The original method of CN determination used maximum annual events. Subsequent development treated measured *P* and *Q* data as frequency distributions. In this paper, derived frequency distributions are evaluated as another method for determining watershed

Perrone and Madramootoo (1998) studied improved curve number selection for runoff Prediction. The three antecedent moisture conditions used in the SCS (Soil Conservation Service) curve number method of surface runoff volume prediction have been shown to be inapplicable in humid regions such as the Ottawa – St. Lawrence Lowlands. The antecedent precipitation index is an alternative indicator of soil moisture. Using a hydrologic database, calibration curves were developed to correlate antecedent precipitation index to the SCS curve number.

Nayak and Jaiswal (2003) studied Rainfall-Runoff Modeling using Satellite data and GIS for Bebas River in Madhya Pradesh. 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 CN 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.

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 needs to be operated under different watershed conditions to ascertain the predictability of the modified CN techniques for runoff estimation from ungauged watersheds.

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 result 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.

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. GIS is utilised as a tool to store, analyse and integrate spatial and attribute information pertaining to runoff, slope, drainage and fracture. Using the overlay and decision tree concepts in GIS, potential water harvesting sites are identified. In all, the accuracy of the site selection at implementation level varies from 80–100%.

Samah *et al.* (2009) studied watershed having a geographical area of 1.87 km^2 and the average annual rainfall was around 500 mm. The study showed that the average annual runoff depth for the area (Wadi Su'd watershed) was 36.3 mm, and the average volume of runoff from the same watershed was 67840.2 m^3/year. The amount of runoff represents 7.3 % 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. The approach could be applied in other Palestinian watersheds for planning of various conservation measures.

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 result indicated that combination of remote sensing and SCS model makes the runoff estimate more accurate and fast.

Laura *et al.* (2011) studied Soil Conservation Service Curve Number Method for Surface Runoff Estimation Using GIS Technique. The objective of this study was to estimate the surface runoff in Rosia Poieni mining area, using the Soil Conservation Service Curve Number (SCS-CN) method. Geographic Information Systems were applied as tools to store, analyze and manage spatial information. ArcCN-Runoff tool, an extension of ESRI ArcGIS software, was used for the study. Based on the soil and land use data, curve numbers and runoff maps were produced.

Pandey *et al.* (2011) 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 mansoon season of the year 1993 which was approximately 35.52 % of the total rainfall.

III. MATERIALS AND METHODS

In this chapter, a brief description of the study area, data used and the methodology adopted for selecting suitable water harvesting sites and estimation of water harvesting potential, in the study area using remote sensing and GIS techniques, are presented.

3.1 Study area:

Morna River catchment was selected as study area for the present research. Morna is tributary of Koyna River, which is one of the major tributaries of river Krishna. It originates from Atoli of Patan tehsil. This catchment lies in Satara district of Maharashtra state in western India. The area extends between 17º24' to 17º50' N Latitude and 73º46' to 74º0' E Longitudes. It is about 120 km away from Satara to its west. This area comes under Sub-montane Zone. Government of Maharashtra has coded this watershed as KR-27. In case of KR-27, 'KR' stands for river Krishna according to standard format for coding of watershed. The total area of watershed is 13,254.13 ha. In this watershed, area under agriculture is about 4946.23 ha. Majority of area is covered under II, III, IV, VI and VII land capability classes. This area is situated at an altitude of 582 m above mean sea level. Length of Morna River is 27.971 km. Location map of study area is shown in fig. 3.1.

Average daily temperature in this zone is about 27 ºC and May is hottest month. Average annual rainfall was about 1300 mm. The soil is laterite having dark reddish to yellowish red color. Sand, Silt and Clay proportion was 40:30:50. The textural class is clay-to-clay loam. Soil moisture varies from 6 to 8% and pH value lies between 4 to 5.8. There is one medium irrigation project in this area at Ambeghar. The catchment area under this project is 55.94 sq. km. Cropping pattern of the watershed was dominated by Cereals. Paddy and Millets are major Kharif crops. Entire watershed is divided into 22 micro-watersheds. Area covered under various cropping pattern is shown in Table 3.1.

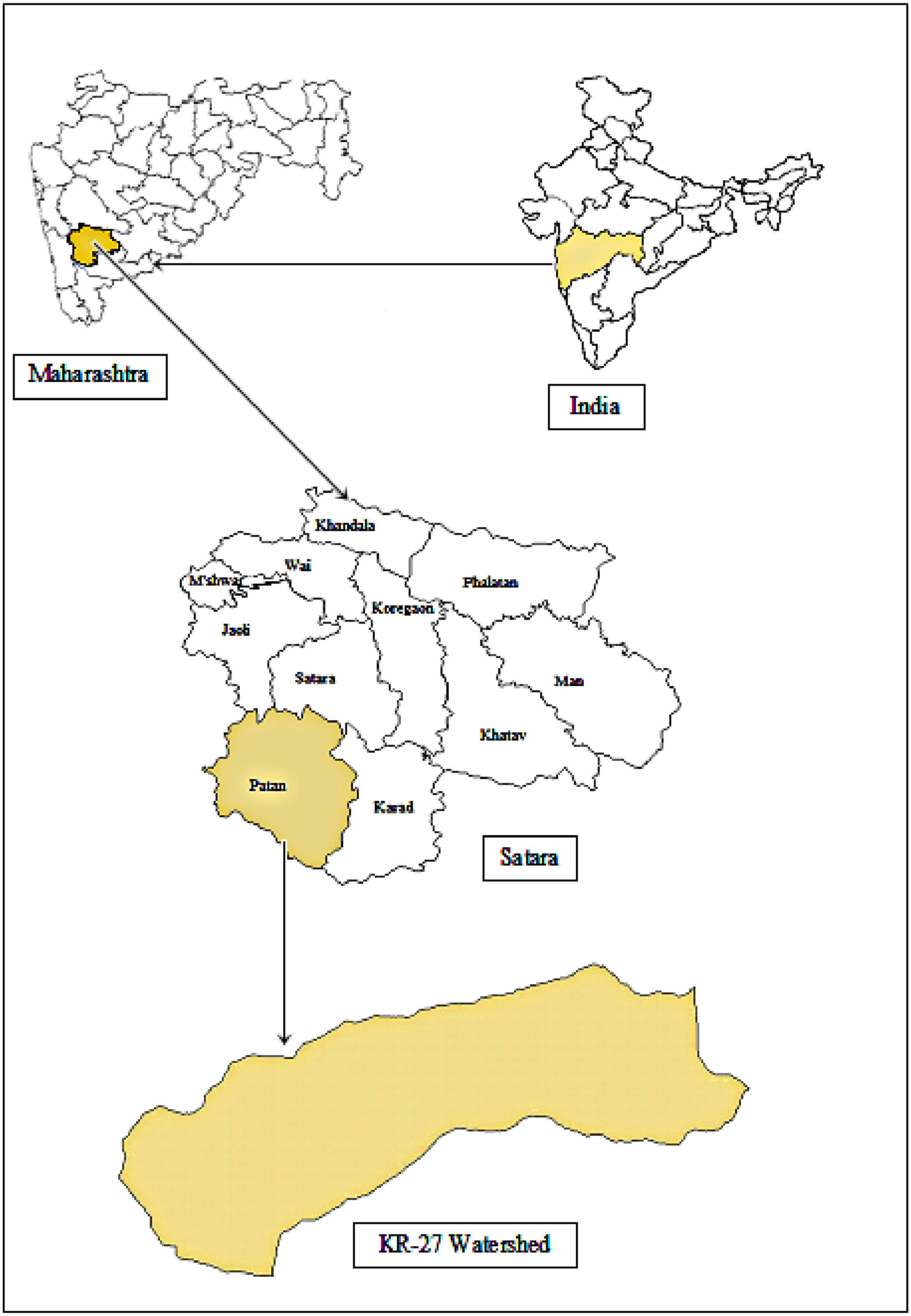

Fig. 3.1 Location map of study area

Table 3.1 Area of KR-27 watershed under various crops

Sr. No.	Land use	Area (ha)
1.	Kharif	3096.48
2.	Kharif (Sugarcane)	496
3.	Kharif+Rabi (Double cropped)	793.96
4.	Rabi	170.91
5.	Gullied land	1.28

3.2 Data Collection and Pre-processing:

As per the requirements of study, variety of data was collected from various sources. This section describes the data used for selecting suitable sites for water conservation measures and water harvesting potential.

1. Daily rainfall data of five stations in the study area was used to prepare rainfall map. It was collected from the Hydrological Data Users Group Nasik, Maharashtra and Tehsil office Patan, district Satara.
2. Digital Elevation Model (DEM) of the study area was used to generate slope map, which is downloaded from (http://bhuvan-noeda.nrsc.gov.in).
3. Satellite images captured on 30 November 2009 having spatial resolution of 24 m were downloaded and used for land use land cover determination. It was also downloaded from (http://bhuvan-noeda.nrsc.gov.in).
4. Soil depth map of the study area was collected from GIS unit Cell, Commissionorate of Agriculture, Pune. It was used for the determination of HSG map.
5. Toposheets of study area were obtained from GIS unit cell, Commissionorate of Agriculture, Pune, which was used for the boundary map preparation.

3.2.1 Software and System

Arcs-GIS 10.2, ERDAS-Imagine 9.1 and MS-Office suit were used for data creation, data analysis and output generation. Arc-GIS 10.2 is advanced tool used for mapping, geographic analysis, spatial analysis, hydrology, overlay analysis, data editing etc. ERDAS-Imagine 9.1 software used for satellite image processing. MS-Office was used for documentation analysis purpose.

3.3 Methodology:

Various interpretation techniques and methodologies were adopted to prepare thematic maps for this study. This section deals with detailed description of the methodology adopted for fulfillment of objectives.

3.3.1 Watershed delineation

Watershed is a hydrological unit from which runoff resulting from precipitation flows past a single point into a large stream, river, lake or pond. It is an ideal unit for management of natural resources like land and water. Watershed delineation plays an important role in watershed management. Arc-GIS 10.2 was used for the purpose of watershed delineation using Survey of India toposheets (1:50,000 scale). Toposheets provide information related to the location, drainage network and contours. 47 G/15, 47 G/11 and 47 G/16 numbered toposheets were used for watershed delineation.

3.3.2 SCS Curve Number Method

The runoff estimates for different combinations of soil group, land use classes and Antecedent Moisture Condition (AMC) were estimated by following the procedure of 'SCS-CN method'. The Curve Number method was used with daily measured rainfall data. The relationship excludes time as an explicit variable. For drainage basins where no runoff has been measured, the Curve Number method can be used to estimate the depth of direct runoff from the rainfall depth, given an index describing runoff response characteristics. It is widely used because of its flexibility and simplicity. This method is based on the potential maximum retention (S) of the watershed, which is determined by wetness of the watershed i.e. the Antecedent Moisture Condition and physical characteristics of the watershed.

The Soil Conservation Service (Soil Conservation Service 1964; 1972) for conditions prevailing in the United States originally developed the Curve Number Method. Since then, it has been adapted to conditions in other parts of the world. This method is based on the water balance equation of the rainfall in a known interval of time, which is given as

$$P = Ia + F + Q \quad \text{… (3.1)}$$

Where,

P = total precipitation, I_a = initial abstraction, F = Cumulative infiltration, Q = direct surface runoff

There are two more concepts, which are also used with the above equation. These are described in following points,

i) The ratio of actual amount of direct runoff (Q) to maximum potential runoff (P- I_a) is equal to the ratio of actual infiltration (F) to the potential maximum retention (or infiltration), S. This proportionality concept can be schematically thus,

$$\frac{Q}{P - Ia} = \frac{F}{S} \quad \text{… (3.2)}$$

ii) The second concept is that the amount of initial abstraction (I_a) is some fraction of the potential maximum retention (S) thus,

$$Ia = \lambda S \quad \text{… (3.3)}$$

Combining equqations (3.1) and (3.2), and using (3.1) we get, (For $P>\lambda S$)

$$Q = \frac{(P - \lambda S)^2}{P + (1-\lambda)S} \quad \text{… (3.4)}$$

The initial abstraction rate is normally set to a constant value (I_a=0.2S) in order for S to be the only parameter of the method. The retention capacity (S) of the watershed can be predicted in terms of a dimensionless parameter curve number (CN) and given by,

$$S = \frac{25400}{CN} - 254 \qquad \ldots (3.5)$$

CN has a range of $100 \geq CN \geq 0$. A CN = 100 represents a condition of zero potential retention and CN = 0 represents an infinitely abstracting catchment with S = ∞. There are some advantages of SCS CN method which are as follows,

i) It is a simple, predictable and stable conceptual method for estimation of direct runoff depth based on storm rainfall depth, supported by empirical data.

ii) It depends upon only one parameter i.e Curve Number

This CN depends upon,

i) Soil type
ii) Antecedent Moisture Content
iii) Land use/land cover

3.3.2.1 Soil Type

In the determination of CN, the Hydrological Soil Classification is adopted. In this classification system, four major characteristics of soil namely, effective depth (depth of soil readily penetrated by plant roots), average clay content in the whole profile depth, infiltration and permeability are considered. Soil properties greatly influence the amount of runoff. For hydrologic analysis of watershed, the hydrologic properties of soil or a group of soils are essential factors (Suresh R. 1996). In the SCS-CN method, these properties are represented by a hydrological parameter such as the minimum 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) are there by included. Following is a brief description of four classes,

3.3.2.2 Antecedent Moisture Condition

Antecedent Moisture Condition (AMC) is defined as the wetness index of soil. It refers to the moisture content present in the soil at the beginning of the rainfall runoff event under consideration. There are three levels of AMC are recognized by SCS as follows,

i) **AMC I:** This includes the lowest runoff potential, because the soils are dry enough for satisfactory cultivation to take place.

ii) **AMC II:** Average condition regarding runoff potential.

iii) **AMC III:** This includes highest runoff potential of the soil, which is practically happened, when areas of watershed are saturated from antecedent rains.

AMC is determined on the basis of five days antecedent rainfall amounts. To determine the appropriate CN value, various tables can be used. Firstly, there are tables relating the value of CN to land use or cover, to treatment or practice, to hydrological condition, and to hydrological soil group. Together, these four categories are called the Hydrological Soil-Cover Complex. The relationship between the CN value and the various Hydrological Soil-Cover Complexes is usually given for average conditions, i.e. Antecedent Soil Moisture Condition Class II. Secondly, there is a conversion table for the CN value because these CN values are applied to AMC II condition i.e., for average conditions only. If the runoff for AMC I or II is to be estimated, the antecedent moisture conditions can be determined by using following the criteria given in the following table,

Table 3.2 Rainfall limits for estimating Antecedent Moisture Conditions

Antecedent Moisture Condition	**5 days total antecedent rainfall, cm**	
	Dormant season	**Growing season**
I	Less than 1.25	Less than 3.5
II	1.25 to 2.75	3.5 to 5.25
III	Over 2.75	Over 5.25

In order to obtain the curve number for AMC-I and AMC-III, the following formulae were used. (Subramanya, 2008)

$$CN_{I} = \frac{CN_{II}}{2.281 - 0.01281CN_{II}} \quad \text{… (3.6)}$$

$$CN_{III} = \frac{CN_{II}}{0.427 - 0.00573CN_{II}} \quad \text{… (3.7)}$$

3.3.2.3 Land use/Land cover

Land use/Land cover is one of the most important thematic inputs in any study as it provides the present status of land utilization and its pattern. The change in 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 various uses which are carried out on land, whereas land cover refers to natural vegetation, water bodies, rock/soil, artificial cover and others resulting due to land transformations. Land use encompasses several aspects of man's relationship to the environment e.g. activity, ownership and land quality. Land use/Land cover map was derived from satellite images captured on 30 November 2009 having spatial resolution of 24 m. Interpretation of multi-season satellite data had been carried out to generate the land use land cover map of study area. Thematic mapping of the different land use/ land cover classes was achieved through unsupervised classification. ERDAS-imagine 9.1 is image processing software which can be used for pre-processing of satellite data.

3.3.3 Preparation of various Thematic Maps:

3.3.3.1. Rainfall Map

Daily rainfall data of five raingauge stations from study area was used to create rainfall maps by using ArcGIS software. The Thiessen polygon technique was used to calculate mean areal rainfall in the study area. The formula for the calculation of mean areal rainfall by Thiessen polygon method is as follows (Subramanya, 2008)

$$P = \sum_{i=1}^{M} P_i \, W_i \quad \text{… (3.8)}$$

Where,

P = Mean areal rainfall,

P_i = Rainfall at station i,

W_i = weightage assigned to station i, and

M = Total number of stations.

3.3.3.2 Hydrologic Soil Group Map

Soil map of the study area was reclassified into the four hydrologic soil groups on the basis of soil texture and infiltration characteristics. Thus, the soils of the area were classified into four hydrologic soil groups: Group A, Group B, Group C, Group D. After that final HSG map of the study area was prepared using Arc GIS software.

3.3.3.3 Land use land cover Map

Land use refers to human activities and various uses, which are carried on land. Land cover refers to vegetation, water bodies, rocks/soil, artificial cover and others resulting due to transformations. Land use/land cover map of the study area was prepared using cloud-free data of Cartosat 1, which was downloaded from (http://bhuvan-noeda.nrsc.gov.in). Digital image processing software ERDAS Imagine 9.1 was used for preprocessing.

3.3.3.4 Slope Map

The topographic slope of area has its own importance in affecting the runoff, recharge and movement of surface water and it is one of the important parameters for developmental activities. The slope map of the study area was developed from the Digital Elevation Model (DEM) acquired from the (http://bhuvan-noeda.nrsc.gov.in). The digital elevation model (DEM) is the continuous representation of elevation values over a topographic surface by regular array of z-values, referenced to a common datum. 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. This method uses irregularly arranged data to fit into regular grid by resampling technique. Prior to this, the DEM was filled for topographic features of land surface. Slope map of the study area was prepared by using ArcGIS software. The slope map was one of the major criteria in the generation of water conservation structures suitability map.

3.3.3.5 Stream order Map

Stream order map of the study area was delineated using the SOI toposheets of the study area and updated using satellite data. The Strahler's stream ordering system was adopted for stream ordering (Singh, 1992). The Stream order map was also used for selecting sites for water conservation structures. Fig.3.2 gives step by step procedure adopted for generating steam order map.

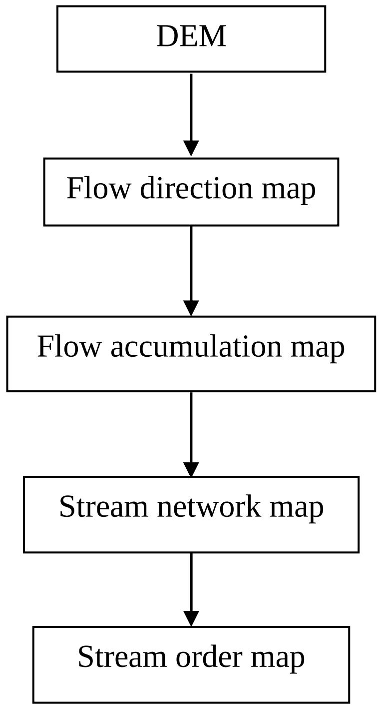

Fig. 3.2. Flowchart for the generation of stream order map

3.3.4 Generation of SCS-CN Map

Thematic layers of land use/land cover and hydrologic soil group were overlaid and a composite layer was generated using ArcGIS 10.2 software. Each land use/land cover class was assigned a suitable curve number on the basis of hydrologic soil groups with the help of the standard table provided by SCS, United States Department of Agriculture (USDA) (Singh, 1992; Subramanya, 2008). After the determination of curve numbers for AMC I, II and III, potential maximum retention (S) for each AMC was estimated using equation. (3.5). The AMC was determined by considering previous five days rainfall amount and using standard guidelines. Given the spatially distributed values of CN and S, runoff potential for each polygon of the CN

… ng ArcGIS software.

… n of …

Runoff coefficient is a dimensionless value that indicates the fraction of rainfall that generates runoff. Its value varies from 0.05 for sandy soils to 0.95 for concrete surfaces (Singh, 1992). Runoff coefficient … was g… runoff map and rainfall map in the GIS environment. Thus, a runoff coefficient map of the study area was prepared.

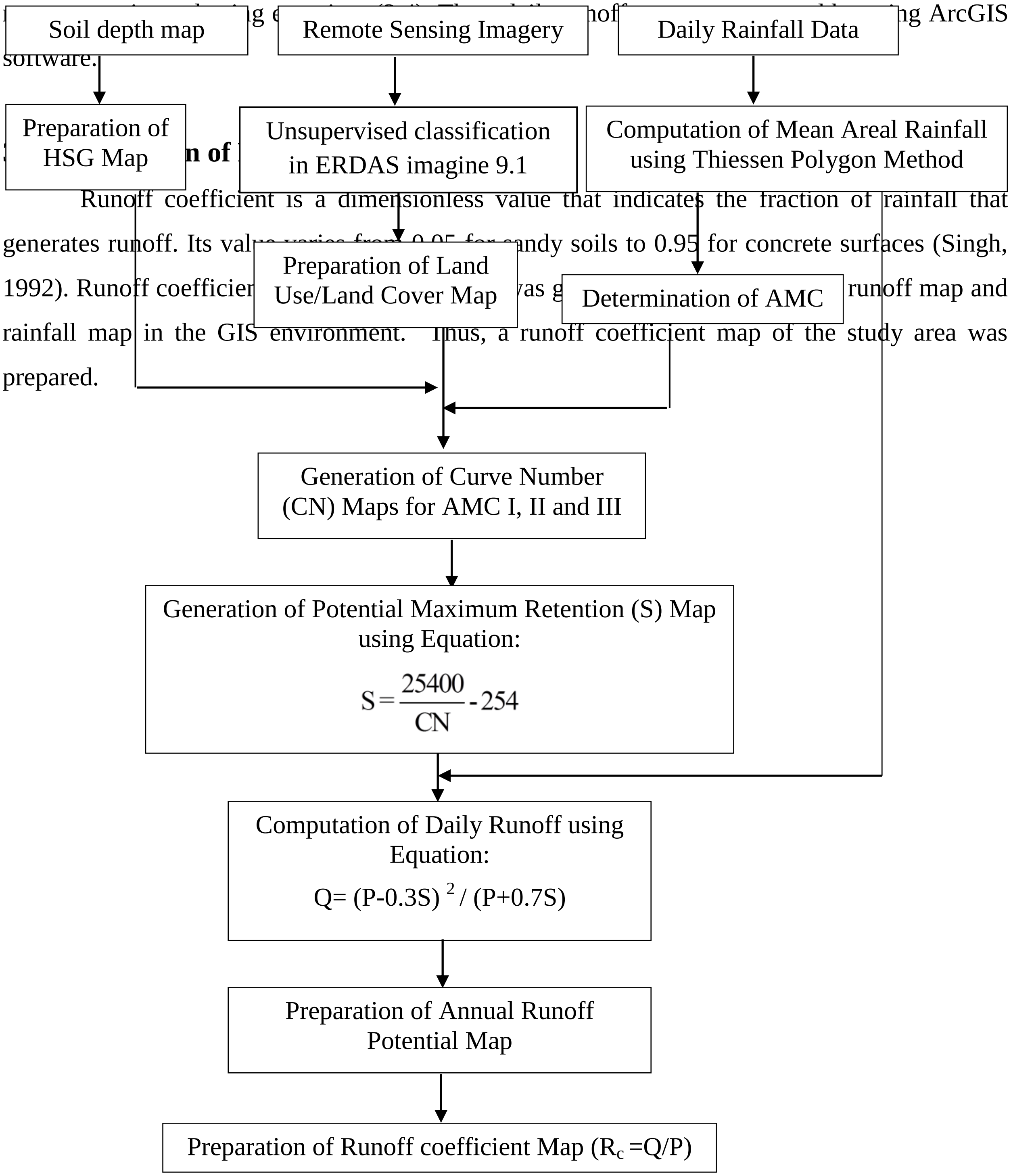

Fig. 3.3. Flowchart for the generation of runoff coefficient map.

3.3.6 Generation of Water Conservation Potential Map

In this study, GIS techniques were used to develop a water conservation potential map of the study area. Thematic layers of runoff coefficient and slope were used to delineate runoff potential zones in the study area. The weights were assigned to thematic layers and ranks on 1-10 scale were assigned to features of thematic layers. The ranks were assigned based on standard references (Kumar *et al*., 2008). The more significant features have been assigned higher ranks. This means that the most significant feature gets a rank of 10 (out of 10). Thereafter, the score was calculated by multiplication of rank and weights are assigned to each parameter, which affects site selection suitability.

Finally, to delineate water conservation potential zones, thematic layers along with their score were integrated using ArcGIS 10 software. The total score of different polygons in the integrated layer were computed in the GIS environment using the weighted sum overlay method as follows,

$$WCPI = RC_w RC_r + SL_w SL_r \quad \dots (3.8)$$

Where,

WCPI = water conservation potential index,
RC = runoff coefficient and SL = slope.

The subscripts w and r refer to the weight of a theme and the rank of individual features of a theme, respectively. WCPI is a dimensionless indicator that is helpful in identifying probable water conservation potential zones in the area.

3.3.7 Identification of Sites Suitable for Water Conservation

Structures

3.3.7.1 Suitability Criteria

In this study, the sites for construction of water conservation measures (check dam, farm pond, percolation pond, bunding, and trenching) have been identified. Suitability criteria are decided in this section. These criteria were decided on the basis of various factors such as permeability of soil, slope, runoff coefficient, stream order .

3.3.7.1.1 Check dam

Check dams are small rock or concrete dams constructed across the river or depression to check the flow and allow it for infiltration. It also replenishes the aquifer below the bed. This system includes various benefits such as less loss of water due to evaporation than the surface water reservoirs, fewer problems of siltation and cheaper construction.

3.3.7.1.2 Farm pond

Farm ponds are small tank or reservoir like constructions, which are constructed for storing surface runoff, generated from the catchment area. The farm ponds are water-harvesting structures used for various purposes such as supply of water for irrigation, cattle feed, fish production etc. In addition, they play important role of storage of monsoon water, which is used for various purposes according to need.

3.3.7.1.3 Percolation pond

Percolation pond is a small water storage structure constructed across water body to harvest the runoff from the catchment and impound for a longer time thereby recharging ground water storage in zone of influence of pond. Such ponds are very useful in harvesting the unutilized balance of the surface flow during the period of availability and conserving it in the underground reservoirs. It should be constructed across the natural stream or watercourse. It should be constructed in the upstream. Percolation ponds are abundant in Maharashtra, Gujarat and Tamilnadu.

3.3.7.1.4 Contour bunding

Contour bunding is the most widely practiced soil and water conservation measures for mild slopes (1-6%) and low rainfall (<600) area. Contour bunds are very effective in light so and in low rainfall conditions. The main objective of contour bunding is to reduce the length of slope for checking soil erosion and to impound water and permit more infiltration of runoff for increasing soil moisture. The bunds on contour break the length of slope before rill formation takes place. It has been reported that in western part of India, contour bunds have helped to save about 25 to 162 tones/ha of soil from erosion.

3.3.7.1.5 Contour trenching

Contour trenching implies excavating trenches along the contour or along a uniform level across the slope of land. Bunds are constructed downstream along the trenches with the material excavated out of them. These trenches break the slope lengths reduce the velocity of runoff and retard its scouring action. The rainwater retained in the trenches percolate slowly in the soil profile and finally increases ground water recharge. It is very effective and low cost moisture conservation techniques particularly in rainfed area and hilly region. Size of trenches is generally varies 0.30×0.30×15 m to 0.50×0.50×15 m and spacing is kept 3 to 5 m. Construction of contour trenches is always started from the ridge and progressively extended towards the valley. The top soil should be placed on the upstream side where as boulders and gravels are staked on the lower side to act as toe to the soil bank.

Above structures are suggested as water conservation measures for the study area. Suitability criteria are needed to be deciding for these structures. This criterion is useful in case of proper location of conservation measures. To achieve this goal, we have assumed Table 3.4 and Table 3.5 as site suitability criteria for each water conservation measures. Criteria mentioned in Table 3.4 gives suitable locations as specific points whereas a criterion in Table 3.5 gives suitable location as specific area to develop respective water conservation measures.

Table 3.3. Suitability criteria for different point wise water conservation structures

Sr. No	Water conservation Structures	Slope (%)	Permeability of soil	Runoff coefficient	Stream order
1.	Farm pond	0-5	low	Medium/high	1
2.	Check dam	< 15	low	Medium/high	1-4
3.	Percolation pond	<10	high	low	1-4

Table 3.4. Suitability criteria for different area wise water conservation structures

Sr. No	Water conservation Structures	Slope (%)	Annual Rainfall (mm)	Suitable area
1.	Contour bunding	<10	<800	Medium textured soil
2.	Contour trenching	10-33	<1200	Light soil

3.4 Delineation of Water Conservation Sites

For the selection of suitable sites for water conservation structures, thematic layers of land use/land cover, slope, soil, and drainage network were integrated in ArcGIS software and zones suitable for different water conservation structures were identified using the suitability criteria (Table 3.3 and Table 3.4). The specified suitability criteria were applied to fields in the attribute table of integrated map and different polygons with suitability criteria for a particular structure were selected and assigned with a structure code. Thus, polygons were selected for all the structures and corresponding structure codes were assigned. A flowchart showing the procedures followed for the identification of a water conservation map of the study area is shown in Fig 3.4.

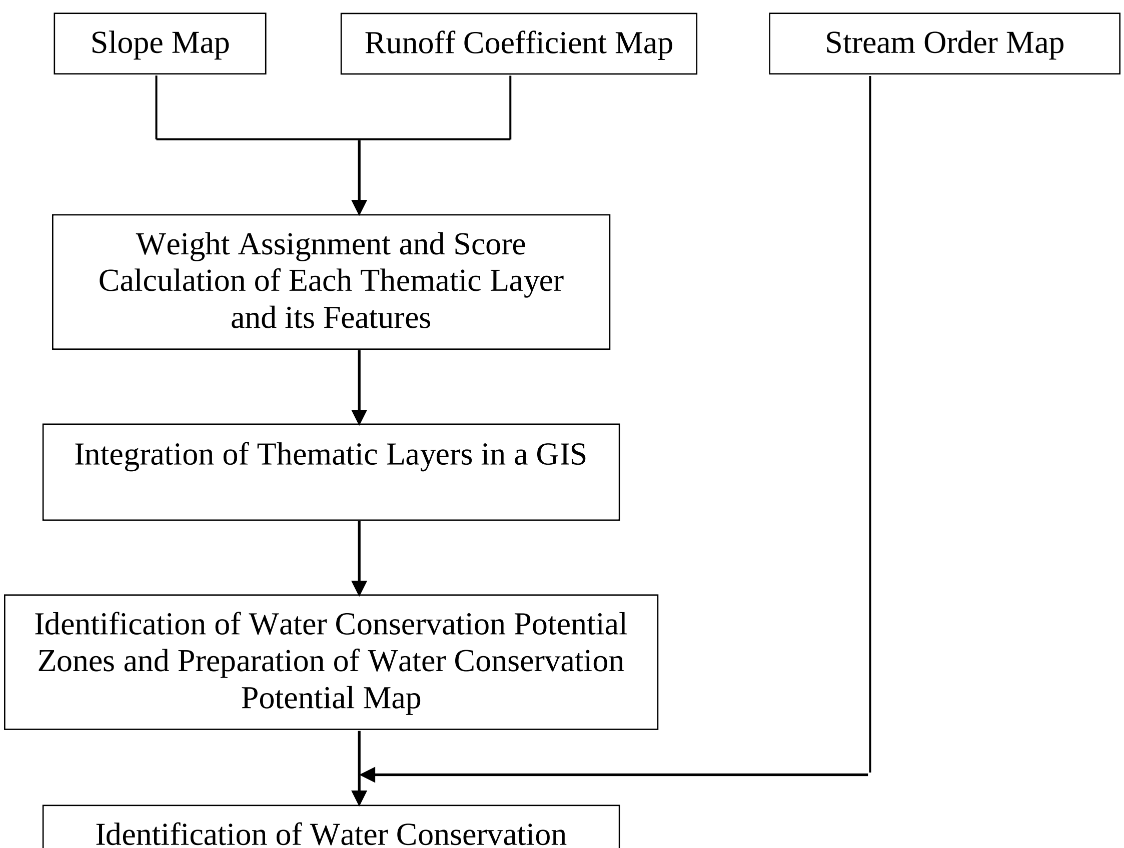

Fig 3.4 Flowchart showing the procedure of identification of WHS in study area.

3.5 Water Harvesting Potential

The total amount of water that is received in the form of rainfall over an area is called as the rainwater endowment of that area. Out of this, the amount that can be effectively harvested is called as the water harvesting potential (Sharma 2010). Among the several factors that influence the rainwater harvesting potential of a site, Climatic condition (i.e. Rainfall quantity and Rainfall pattern) and the catchment characteristics are considered most important factors affecting rainwater Potential. Rainwater harvesting also depends on the area of catchments, which directly accounts for rain collected. Thus greater the area, greater is the amount of water collected. The quality of water that gets collected from the catchment also depends on the location of the catchment (Satya Raj, 2011). Formula for calculating water-harvesting potential is given as follows,

Water Harvesting Potential = Catchment Area (m^2) X Amount of rainfall (mm) X Runoff Coefficient

Here Runoff coefficient for any catchment is the ratio of the volume of water that runs off a surface to the volume of rainfall that falls on the surface. Runoff coefficient accounts for losses due to spillage, leakage, infiltration, catchment surface wetting and evaporation, which will all contribute to reducing the amount of runoff. Runoff coefficient varies from 0.5 to 1.0. Table 3.5 shows values of runoff coefficient with respect to types of surface areas,

Table 3.5. Values of Runoff Coefficient for different catchments

Sr. No.	Type of Area	Value of Runoff Coefficient		
		0-5% slope	5-10% slope	10-30% slope
1.	Cultivated areas			
	• Open sandy Loam	0.30	0.40	0.52
	• Clay and Silt Loam	0.50	0.60	0.72
	• Tight Clay	0.60	0.70	0.82
2.	Pastures			
	• Open sandy Loam	0.10	0.16	0.22
	• Clay and Silt Loam	0.30	0.36	0.42
	• Tight Clay	0.40	0.55	0.60

3.	Forested land • Open sandy Loam • Clay and Silt Loam • Tight Clay	0.10 0.30 0.40	0.25 0.35 0.50	0.30 0.50 0.60
4.	Urban areas	0.55	0.65	-

(Irrigation Engineering & Hydraulic Structure, by Garg, S.K.)

3.5.1 Types of catchments-

Rainwater Harvesting is of three types depending on the types of catchments. Catchments can be in the form of rooftops, roads or open spaces like forests, cultivated areas (Satya Raj, 2011) Various types of Catchments are discussed in following points,

6. 3.5.1 Surface runoff collection from open surface into pans/ponds-

7. The potential of RWH and storage in small ponds and pans refers to collection of runoff from open surfaces, such as roads, home compounds, hillsides, open pasturelands and may also include runoff from watercourses and gullies. Therefore, this intervention could be implemented almost anywhere, as long as local site conditions are permit. For the GIS mapping, only areas with steep slopes (>8%) and areas with very were removed (Khaka *et. al.* 2006). Runoff harvesting into ponds depends also on soil type and geology, especially to avoid seepage problems.

8. 3.5.2 In-situ water harvesting-

9. In-situ RWH refers to all activities in which rainwater is harvested and stored within the soil profile for crop production. It may include open sky RWH systems such as terraces, pitting methods and bunding. Since water is stored in the soil, the main criterion for mapping is that the area may be in need to soil moisture replenishment, at some point within the year. By removing protected areas and areas with saline soils, it was assumed that the rest of the land had agricultural potential and therefore eligible for In-situ RWH (Khaka *et. al.* 2006).

IV. RESULTS AND DISCUSSIONS

This chapter deals with determination of water harvesting sites and water harvesting potential of Morna river catchment by using Remote Sensing and GIS. The results and discussion of various thematic maps prepared from remote sensing data, water conservation potential zoning and site selection for different water conservation structures are presented in this chapter. The results were analyzed for whole study area, to answer the water resources conservation potential on these areas. The findings are discussed below.

4.1 Thematic Layers

4.1.1 Land Use/Land Cover

The land use and land cover characteristics of the study area and its parts are discussed using land use/land cover (LU/LC) maps and the statistics generated on this aspect. The LU/LC in the study area was classified in to six classes: (i) water bodies (ii) Fallow land (iii) Dense forest (iv) Cultivated area (v) Open forest and (vi) settlement the statistics are given in Table 4.1.

Table 4.1 Spatial coverage of land use/land cover classes of study area

Sr. No.	Land Use/Land Cover Class	Area (ha)
1.	Water bodies	191.8656
2.	Fallow land	2455.8912
3.	Dense forest	2762.4960
4.	Cultivated area	4946.2272
5.	Open forest	1618.3296
6.	Settlement	1279.2960
	Total	**13254.172**

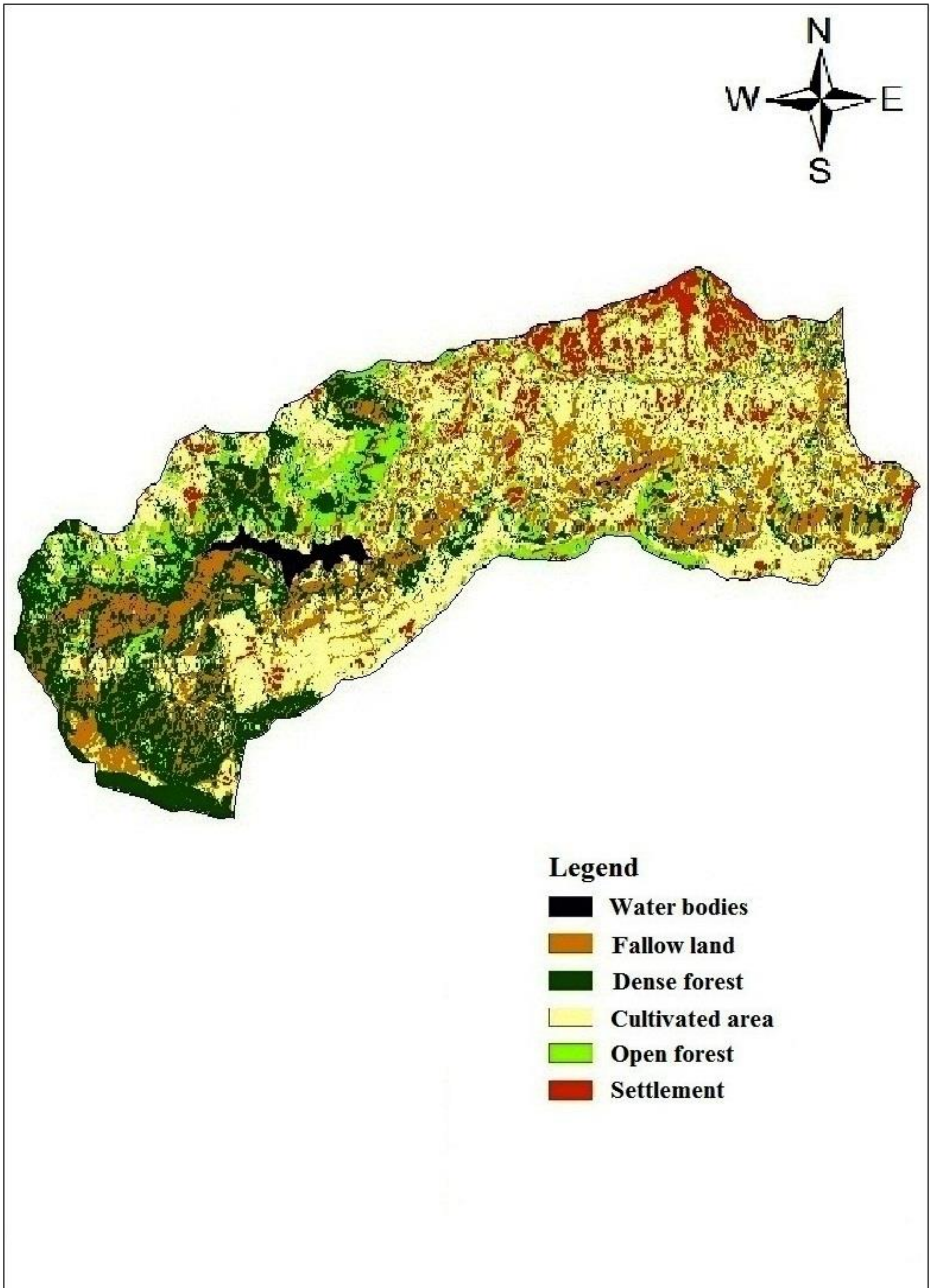

Fig. 4.1. Land Use/Land Cover map of study area

Analysis of Land Use/Land Cover pattern of study area showed that, the major portion of KR-27 watershed was covered by cultivated area 4946.2271 ha (37.31%) Next dominant class is dense forest, which covers about 20.84% of total area. Further classes according to their majority are, fallow land 2455.8912 ha (18.52%), open forest 1618.3296 ha (12.2%), settlement both together covers about 1279.2960 ha (9.65%) and water bodies occupy about 191.86 ha (1.44%) of total area. Following pie chart shows percent occupation of various land use land cover categories.

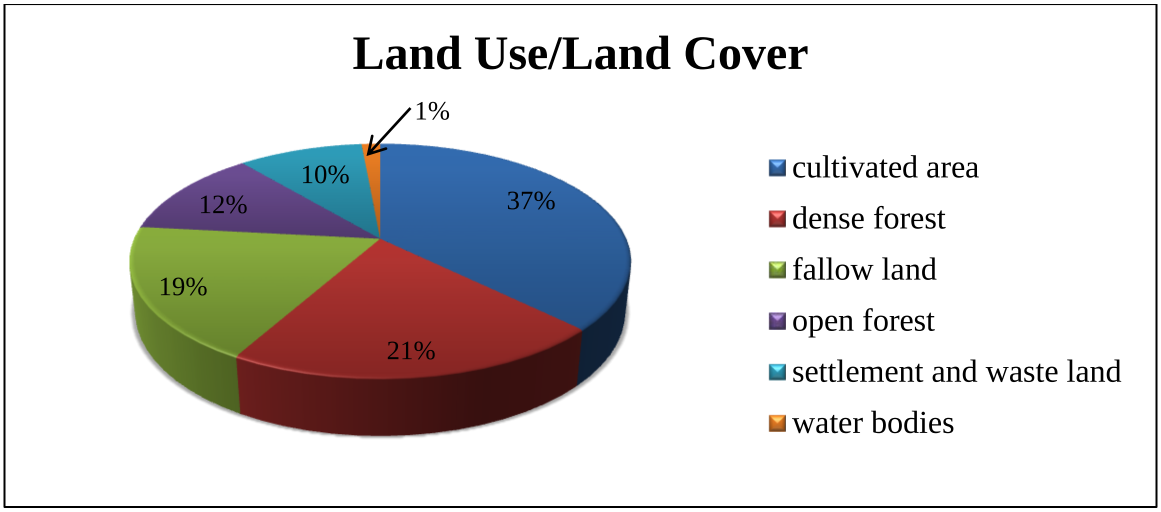

Fig. 4.2 Percent Contribution of LU/LC in study area

4.1.2 Hydrologic Soil Group map

Soil characteristics of the study area are discussed here. The thematic layer of soil is shown in Fig.4.3 for the entire study area. The soil is laterite having dark reddish to yellowish red color. Sand: Silt: Clay proportion is 40:30:50. The textural class is clay to clay loam. Soil depth map shows that maximum area was covered by moderately deep soil. Shallow soil contributes relatively less area. Hydrologic Soil Group map for study area was prepared in GIS environment. The spatial distribution of hydrologic soil groups in the entire study area is shown in Fig. 4.3. HSG B and D were major soil groups found in KR-27 watershed. Maximum area of this watershed comes under HSG B (91.125%), while only 8.87% of entire study area was contributed under HSG D.

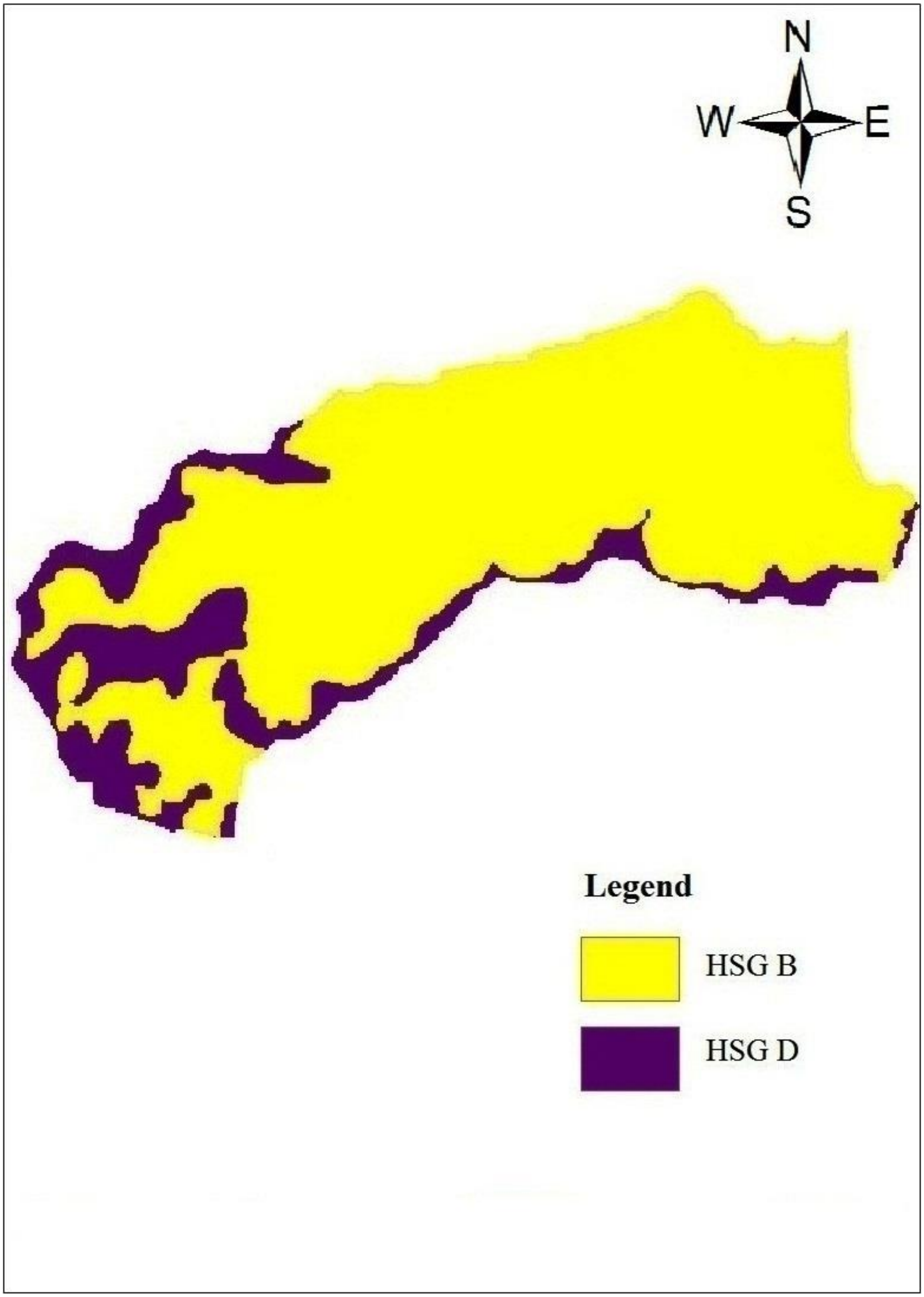

Fig. 4.3. Hydrologic Soil Group map of study area

HSG B mainly consists of moderately deep to deep soils however HSG D consists of shallow soils. HSG B covers almost all eastern and middle part of this watershed.

Table 4.2 Spatial distribution of Hydrologic Soil Groups in study area

Sr. No	Soil Group	Area (ha)	Area (%)
1.	HSG B	12,077.8259	91.125
2.	HSG D	1175.6413	8.87

4.1.3 Digital Elevation Model of study area

Digital Elevation model (DEM) is a simple, regularly spaced grid of elevation points. A DEM can be represented as a raster or as a vector based Triangular Irregular Network (TIN). DEM is most common basis for digitally produced relief maps in GIS environment. DEM can be obtained by field survey or from satellite imagery. Fig. 4.4 shows the DEM (Digital Elevation Model) of study area and it was downloaded from http://bhuvan-noeda.nrsc.gov.in. This DEM was obtained from Cartosat1. It shows lowest elevation of 490 m and highest elevation of 1031 m. It was used to generate the slope map of study area. Slope map was generated in GIS environment.

4.1.4 Slope Map

Slope map of study area is shown in Fig. 4.5. Study area shows variation of slope. Higher slopes were concentrated in middle part of watershed, whereas lower slopes were seen in southwest part. 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). Slope map was divided into 6 classes as (i) ‘nearly level’ (0-3%), (ii) ‘gentle’ (3-5%), (iii) ‘moderately gentle’ (5-10%), (iv) ‘steep’ (10-15%), (v) ‘moderately steep’ (15-20%), and (vi) ‘very steep’ (>20%). Majority of area was under moderately gentle class (4049 ha).

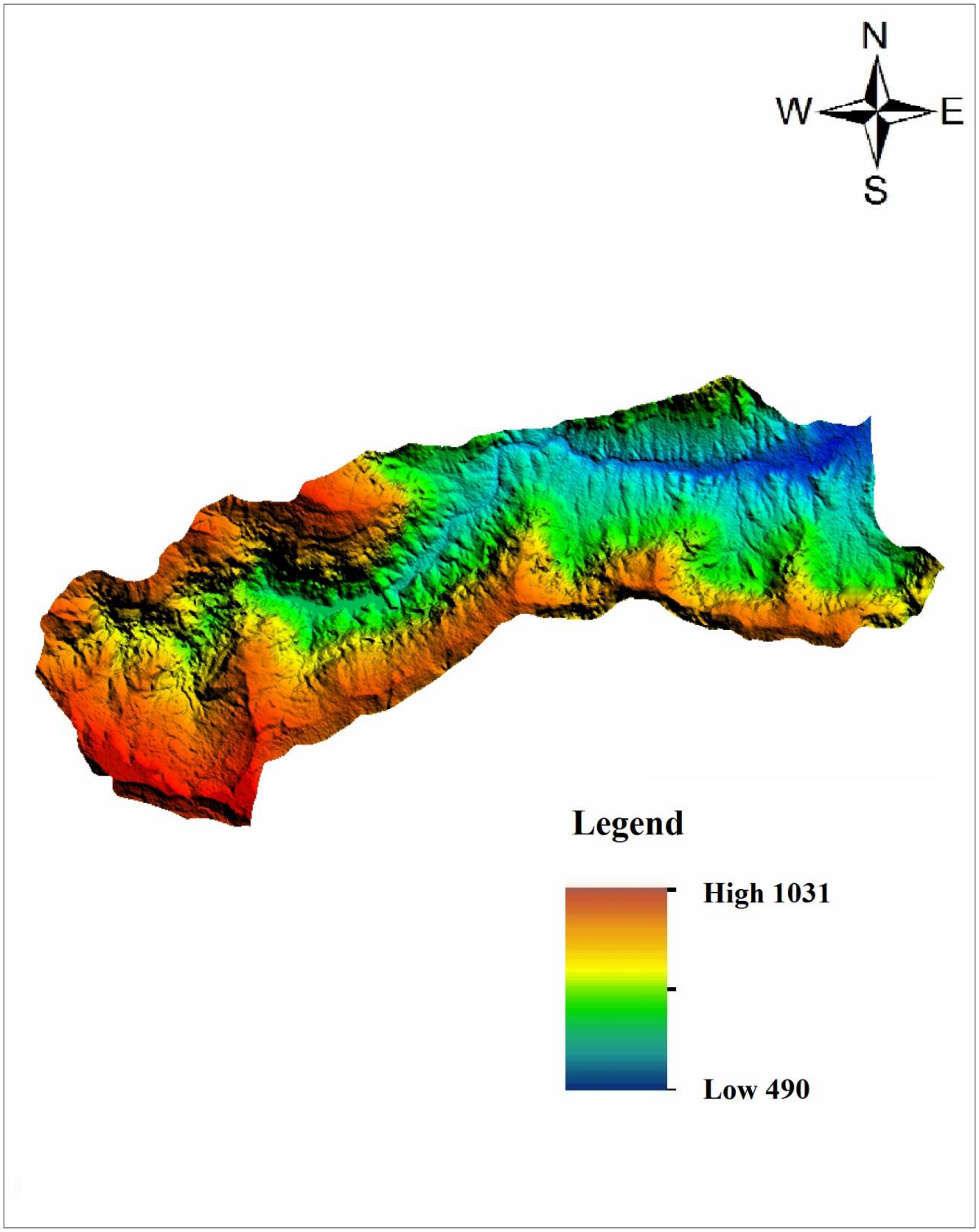

Fig. 4.4 Digital Elevation Model of study area

Next major class is very steep; about 23.78 % area was covered under this class. In case of nearly level class area covered was only 6.50 %. Gentle class covers 8.23 % of total area. Steep class contributes about 19.85 %. Spatial distribution of various slope classes is given in Table 4.3.

Table 4.3 Spatial distribution of slope classes in study area

Sr. No.	Slope (%)	Area (ha)	Area (%)
1.	0-3	891	6.50
2.	3-5	1128	8.23
3.	5-10	4049	29.55
4.	10-15	2720	19.85
5.	15-20	1654	12.07
6.	>20	3258	23.78

4.1.5 Drainage Map

Drainage network map of the study area was developed by utilizing DEM and presented in Fig.4.18 with statistics in Table 4.4. It shows that the study area has five order drainage networks. Drainage in the study area is mostly taken care by the first order streams having maximum drainage length of 262.323 km (68.49% of total length of drainage). The second and third order streams have also considerable drainage length, 66.535 km (17.37 %) and 21.59 km (5.63 %), respectively. The fourth order stream contributes to drainage with a length of 4.547 km, which accounts for 1.187 % of the total drainage length. Morna river is a fifth order stream in the study area. Length of the fifth order stream in the study area is 27.971 km (7.303%)

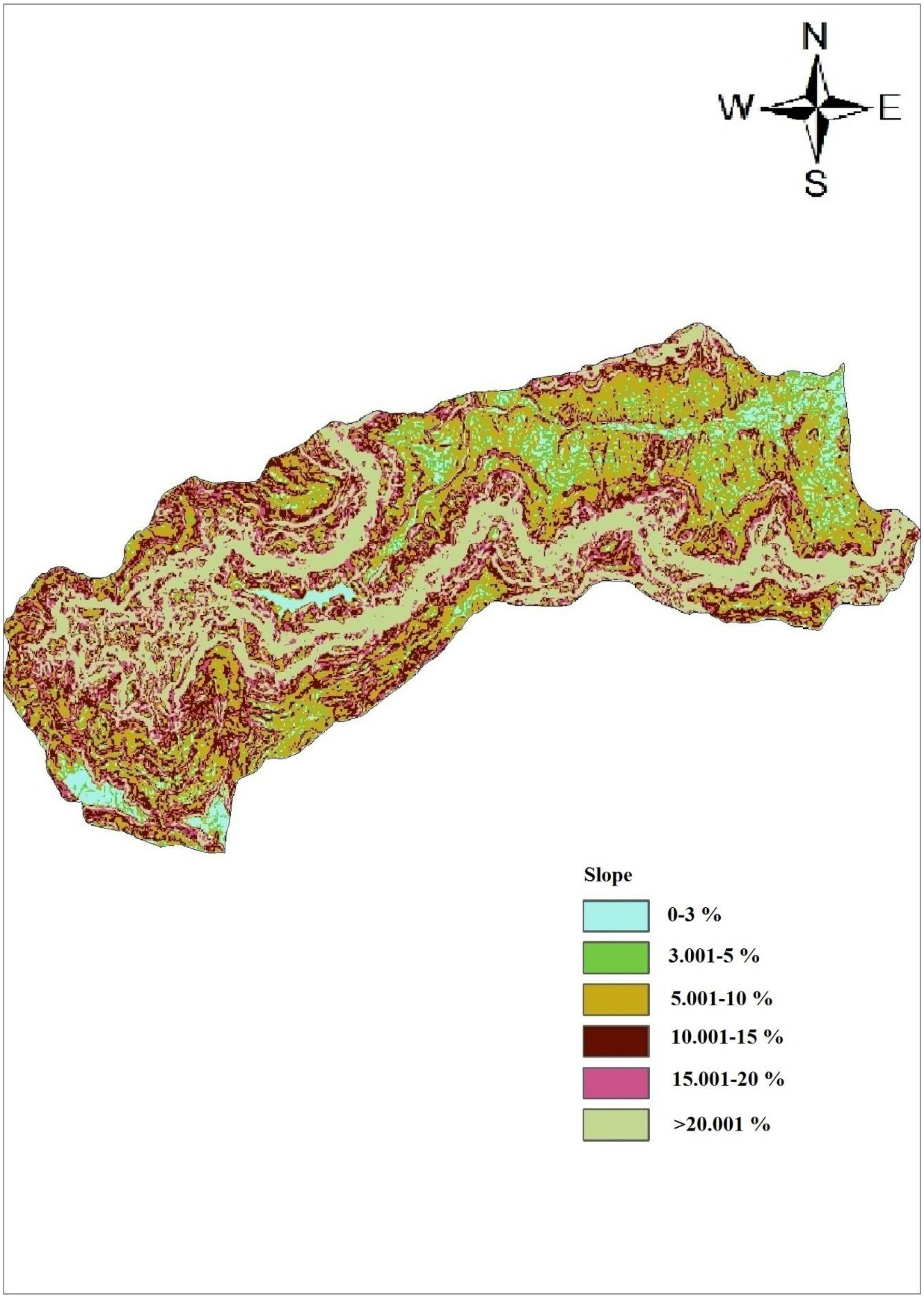

Fig. 4.5. Slope Map of study area

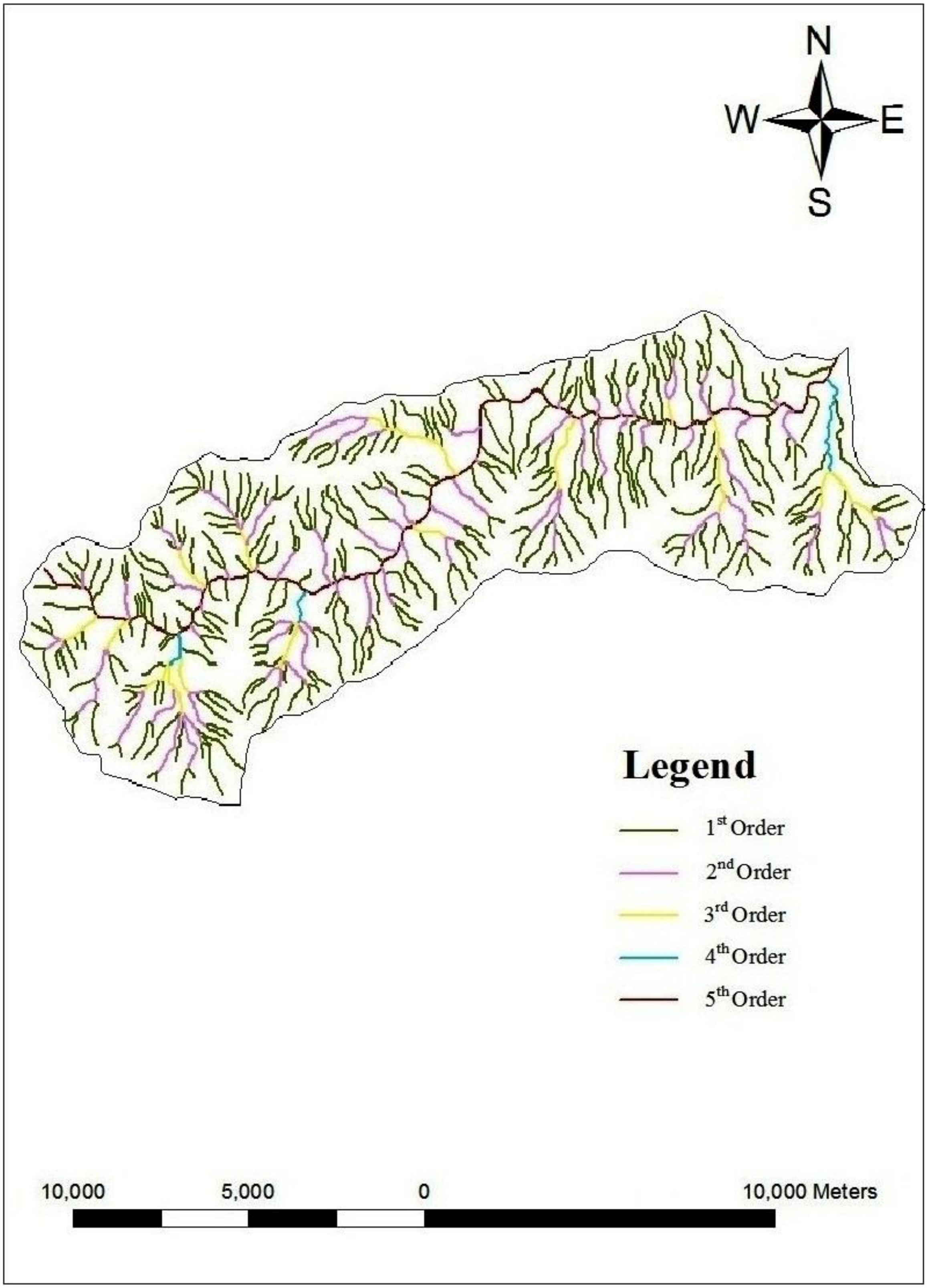

Fig. 4.6 Drainage Map of study area

Table 4.4 Spatial distribution of various stream orders in study area

Sr. No	Stream network	Total length(km)
1.	1 Order	262.323
2.	2 Order	66.535
3.	3 Order	21.59
4.	4 Order	4.547
5.	5 Order	27.971

4.1.6 Thiessen Polygon

Thiessen polygon method has been used to estimate the average rainfall over the study area using the rainfall information collected from five stations shown in Fig. 4.5. It is evident from the map that most of the study area was under the influence of Gokul tarf Patan raingauge station which covers an area of 3327.13 ha (25% of total area). Next major influencing raingauge station was Gureghar, area under this station was 2565.03 ha (19.35% of total area). Area under Belwade (Kh) raingauge station was 2547.712 ha covering 19.22 % of total area. Results showed that area under above two raingauge stations was more or less same. Marali station has covered area of 1268.2381 ha which was 9.56 % of total area. Least area was covered by Davari station; it is about 682.95 ha (5.15%). Area under various raingauge stations is shown in Table 4.4.

Table 4.5 Area under various raingauge stations

Sr. No	Raingauge Station	Area (ha)
1.	Gokul tarf Patan	3327.13
2.	Gureghar	2565.03
3.	Belwade (Kh)	2547.712
4.	Marali	1268.23
5.	Davari	682.95

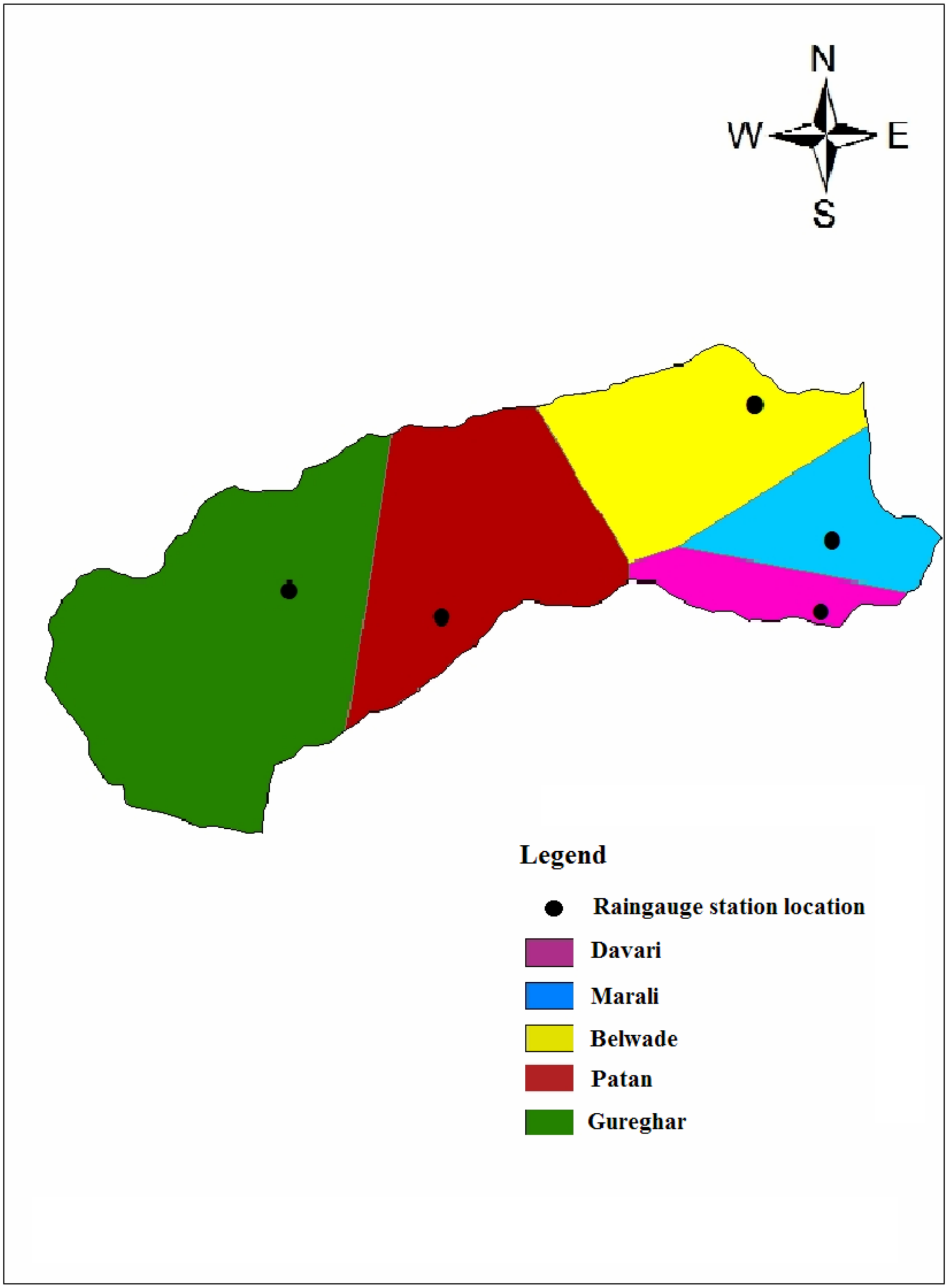

Fig 4.7. Theissen polygon map of study area

4.1.7 Combined Land use / land cover and HSG map

After the generation of Land use land cover map and HSG map, combined LULC and HSG was prepared in GIS environment. It helps to generate the Runoff coefficient map. In study area major combination was of cultivated area +HSG B class. Percent area under this combination was 33.99 % and minimum combination was of waterbody + HSG D class and it was 0.12 %. Percent area under remaining combinations of LULC and HSG is given in Table 4.5

Table 4.6 Percent area under combined LULC and HSG

Sr. No	LULC class	% area under soil group	
		HSG B	HSG D
1.	Cultivated area	33.99	3.309
2.	Dense forest	18.99	1.84
3.	Fallow land	16.87	1.64
4.	Open forest	11.84	1.15
5.	Settlement	8.79	0.85
6.	Water bodies	1.31	0.12

4.1.8 Runoff Potential Map

Runoff potential map was developed for the study area using thematic layers to extract inputs for SCS Curve number method and presented in Fig. 4.6. It can be seen based on the annual runoff generated in the study area during year 2009, the study area was classified into five groups (i) 'very high'(>801 mm) (ii) 'high'(601-800 mm), (iii) 'moderate'(400-601 mm), (vi) 'poor' (201-400 mm) and (vii) very poor' (<200 mm) as shown in Fig.4.6. It is clear from figure that maximum area was covered by moderate runoff potential class. Table 4.7 gives spatial distribution of various runoff potential classes.

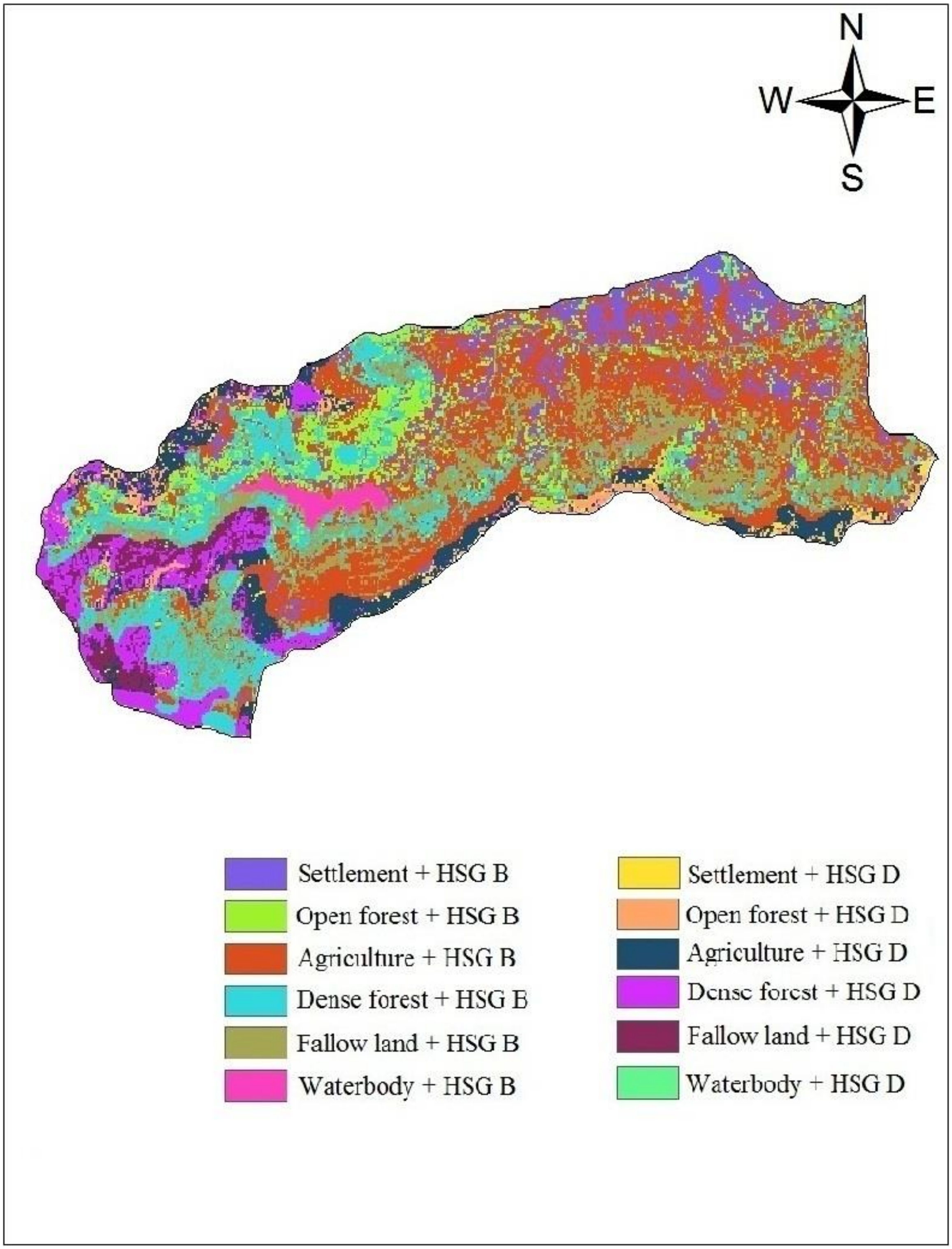

Fig. 4.8 Combined LU/LC and HSG map of study area

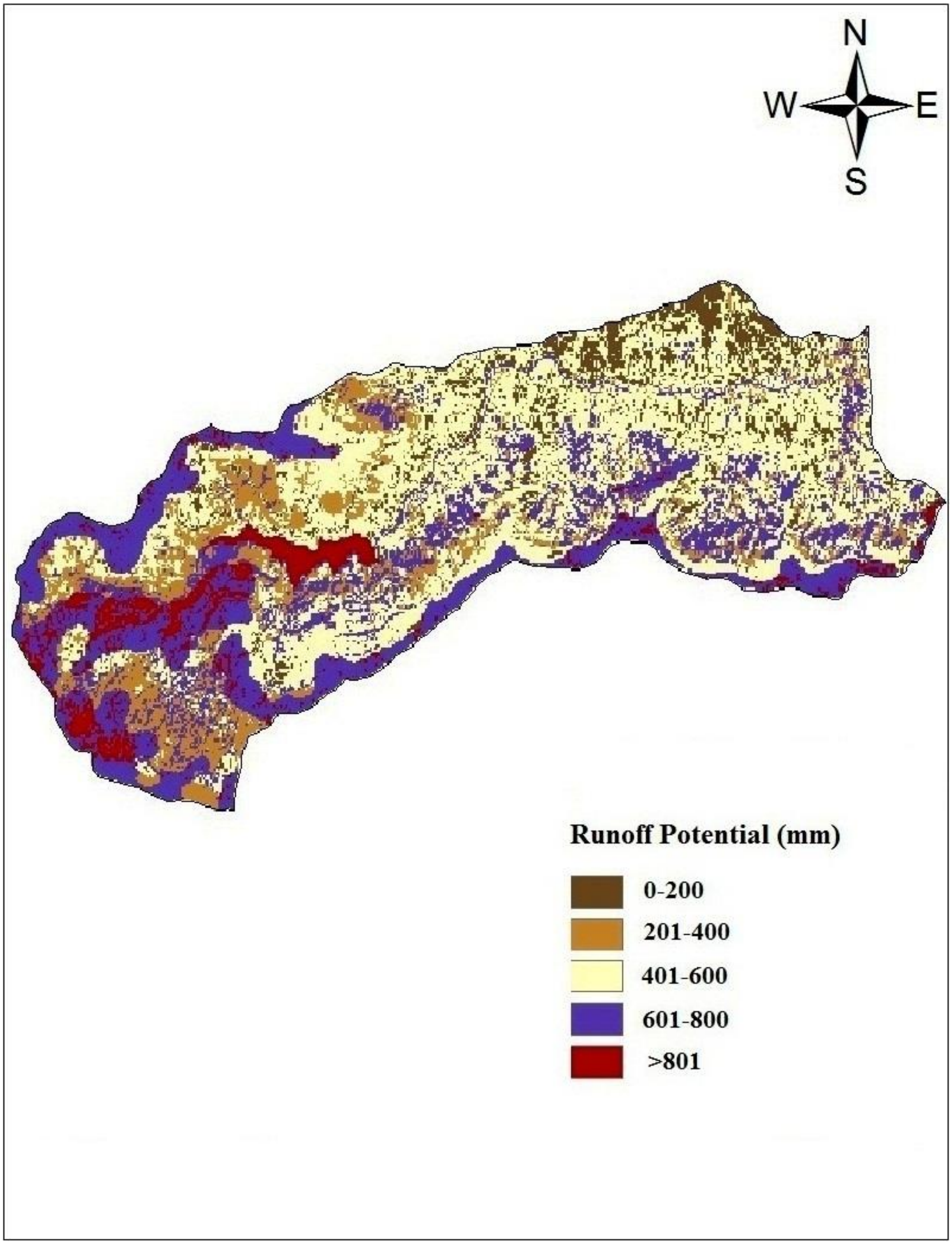

Fig. 4.9 Runoff Potential map of study area

Table 4.7 Spatial coverage of runoff potential classes over study area

Sr. No	Runoff potential (mm)	Area (ha)	Area (%)
1.	0-200	1174.8	8.78
2.	201-400	1958.64	14.65
3.	401-600	5491.92	41.07
4.	601-800	3938.16	29.45
5.	>801	805.44	6.02

4.1.8 Runoff Coefficient Map

Runoff coefficient map for the study area were developed for the year 2009 and is shown in Fig 4.20. Based on the spatial distribution of runoff coefficient values, the study area was divided into six classes, (i) 'high runoff coefficient' (>0.561-1.00), (ii) 'moderate runoff coefficient' (0.41-0.56), (iii) 'low runoff coefficient' (0.121-0.40), (iv) 'very low runoff coefficient' (<0.12). It is apparent from figure that most of the study area comes under 'low runoff coefficient' coefficient category. The zones of 'low' runoff coefficient are spread in the entire part of the study area. The area having 'high' runoff coefficient is 805.44 ha (6.02%). The figure also shows that 'very low' runoff coefficient zone does not exist for this year 2091. Spatial coverage of runoff coefficient classes of study area is summarized in Table 4.8

Table 4.8 Spatial coverage of runoff coefficient classes over study area

Sr. No	Runoff Coefficient	Area (ha)	Area (%)
1.	0-0.12	-	-
2.	0.121-0.40	8625.36	64.51
3.	0.401-0.56	3938.16	29.45
4.	0.561-1.00	805.44	6.02

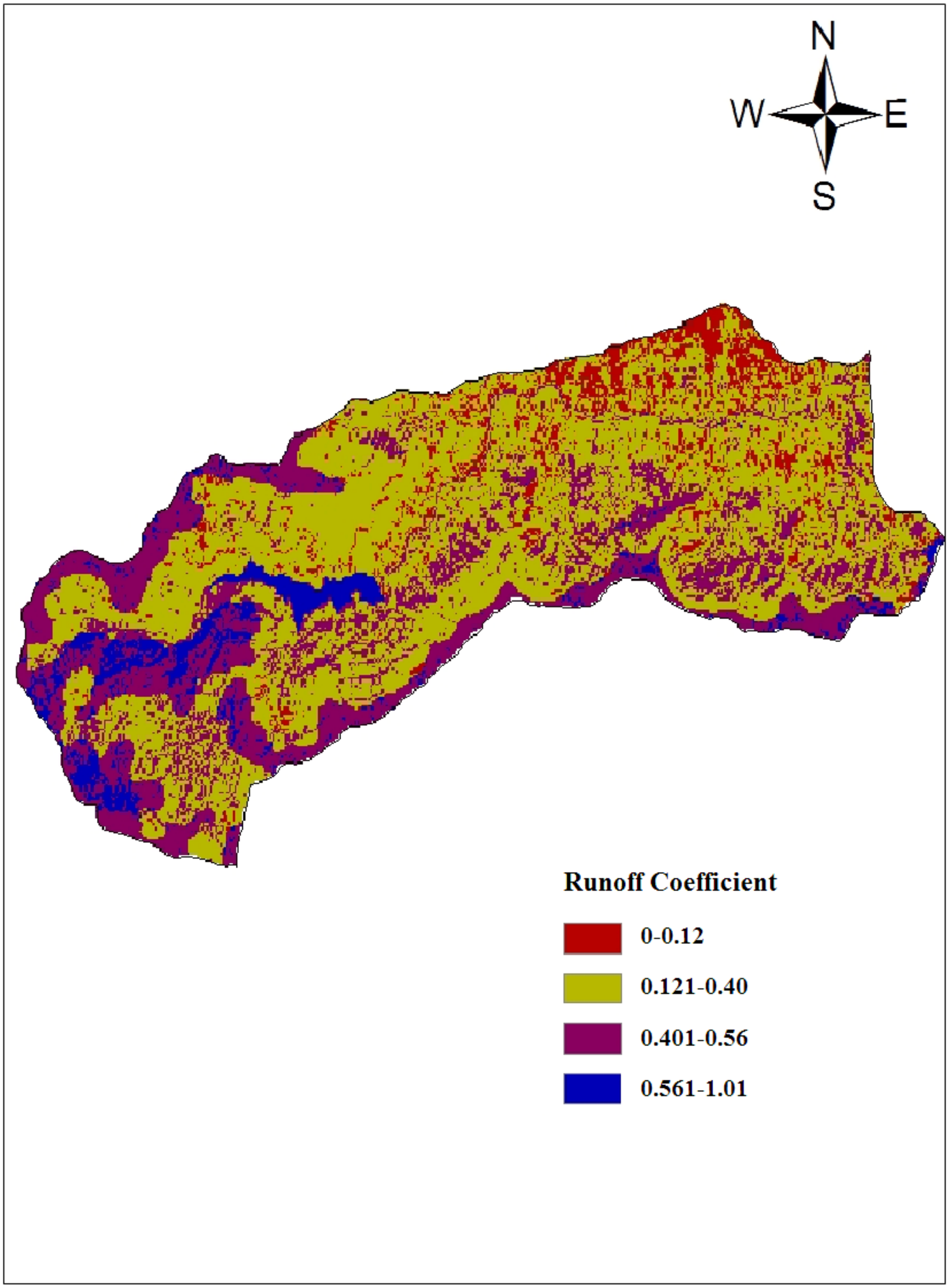

Fig. 4.10 Runoff Coefficient map of study area

4.2 Weights of Thematic Layers and Ranks for their Features

Next task done was of assigning weights and ranks for thematic layers. The weights were assigned to thematic layers and ranks on 1-10 scale were assigned to features of thematic layers. The more significant features have been assigned higher ranks. Thereafter, the score was calculated by multiplication of rank and weight's assigned to each parameter which affects the site selection suitability. The values of weight's and ranks for various water harvesting structures are given in Table 4.9 and Table 4.10 respectively.

Table 4.9 Weights and ranks assigned to thematic layers to Check dam and Farm pond (Group 1)

Thematic layer	Feature Class	Weight	Ranks
Runoff Coefficient	0.56-1 (Very High)	60	10
	0.40-0.56 (High)		8
	0.12-0.40 (Moderate)		6
	0- 0.12 (Low)		4
Slope	0-3%(Nearly level)	40	1
	3-5% (Gentle)		3
	5-10% (Moderately gentle)		6
	10-15%(Steep)		8
	15-20% (Very steep)		10

Table 4.10 Weights and ranks assigned to thematic layers to Contour bunding, Contour Trenching and Percolation pond (Group 2)

Thematic Layer	Feature Class	Weight	Ranks
Runoff Coefficient	0.56-1 (Very High)	60	4
	0.40-0.56 (High)		6
	0.12-0.40 (Moderate)		8
	0- 0.12 (Low)		10
Slope	0-3% (Nearly level)	40	10
	3-5% (Gentle)		8
	5-10% (Moderately gentle)		6
	10-15%(Steep)		4
	15-20% (Very steep)		2

The total score of different polygons in the integrated layer were computed in the GIS environment using the weighted sum overlay method as follows:

$$WCPI = RC_w RC_r + SL_w SL_r$$

Where,

WCPI = water conservation potential index,

RC = runoff coefficient

SL = slope.

The subscripts *w* and *r* refer to the weight of a theme and the rank of individual features of a theme, respectively. WCPI is a dimensionless indicator that is helpful in identifying probable water conservation potential zones in the area.

4.3 Water Conservation Potential Maps

Water conservation potential map was prepared for two different groups. After integrating the thematic layers (runoff coefficient and slope), a water conservation potential map of the study area was prepared. Based on the WCPI values (280-1000) obtained, the study area was divided into three distinct classes (zones) for Group 1 as (i) ‘Excellent’ (WCPI = 920-1000), (ii) ‘good’ (WCPI = 760-920) and (iii) ‘poor’ (WCPI = 280-760) water conservation potential and for Group 2 into (i) ‘Excellent’ (WCPI = 680-1000), (ii) ‘good’ (WCPI = 520-680), (iii) ‘moderate’ (320-520) and (iv) ‘poor’(WCPI = 0-320)

4.3.1 Water Conservation Potential Map for Check dam and Farm pond

‘Excellent’ water harvesting potential zone covers about 3962.64 ha area. Water conservation potential Map for Group 1 had 5407.2 ha (40.25%) area under ‘good’ potential category. ‘Poor’ water conservation potential area was about 4062.96 ha (30.24 %). It is clear that maximum study area was covered under ‘Good’ water harvesting potential zone. The spatial coverage of water harvesting potential zone for group 1 is given in Table 4.11.

Table 4.11 Spatial coverage of water harvesting potential zones for Group 1

Sr. No	Water Harvesting Potential Zones	Score	Area (ha)	Area (%)
1.	Excellent	920-1000	3962.64	29.49
2.	Good	760-920	5407.2	40.25
3.	Poor	280-760	4062.96	30.24

4.3.2 Water Conservation Potential Map for Contour bunding, Contour Trenching and Percolation pond

In case of Group 2 maximum study area was covered by ‘Moderate’ class. It was about 40.25 % of total area. ‘Excellent’ water conservation potential zone covers about 410.64 ha area. It was 3.05 % of total area. Water conservation potential map for Group 2 has 3652.32 ha (27.18%) area of ‘good’ potential. ‘Poor’ water harvesting potential area was about 3962.64 ha (29.49 %). The spatial coverage of water harvesting potential zone for group 2 is given in Table 4.12.

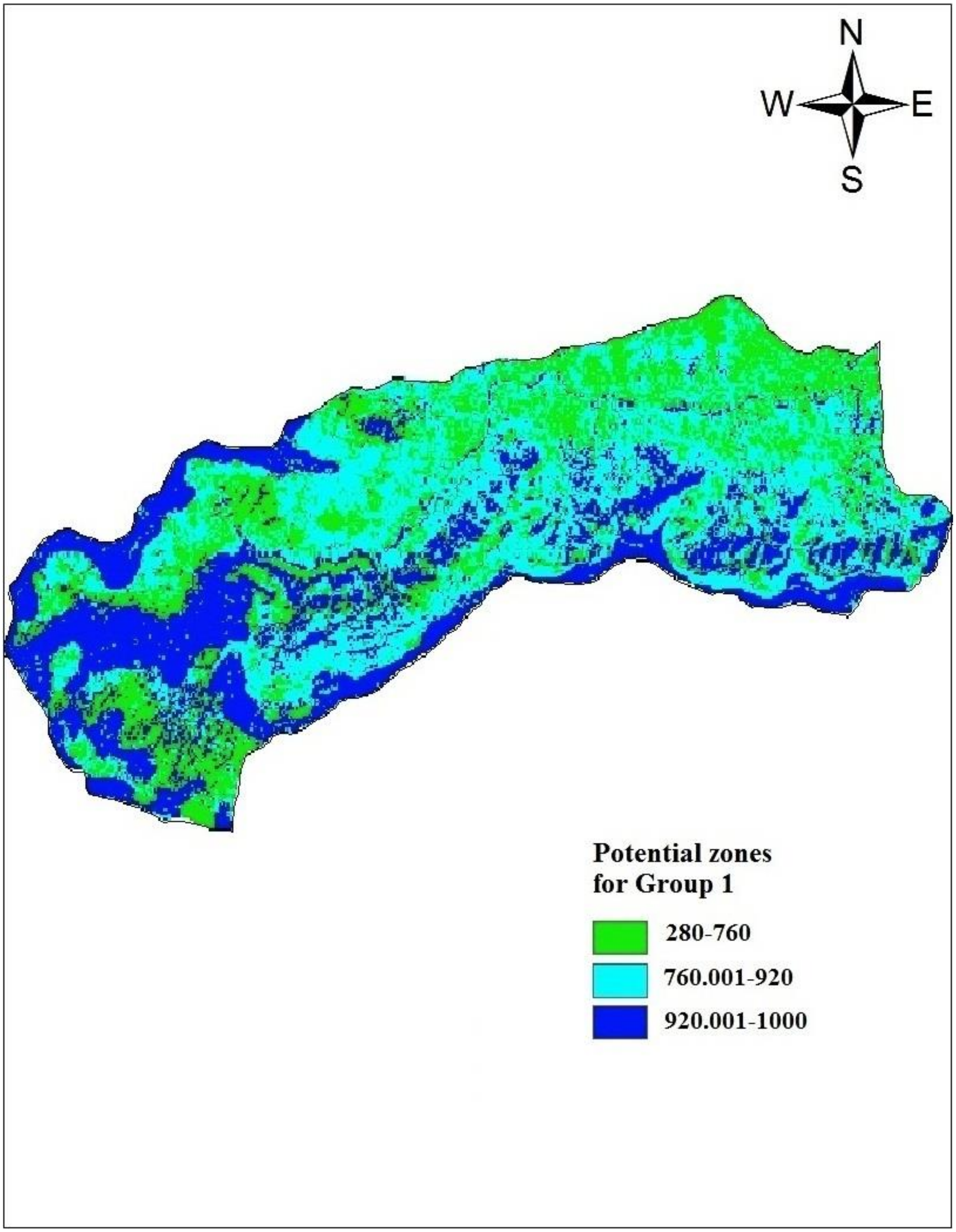

Fig. 4.11 Water harvesting potential for Group 1

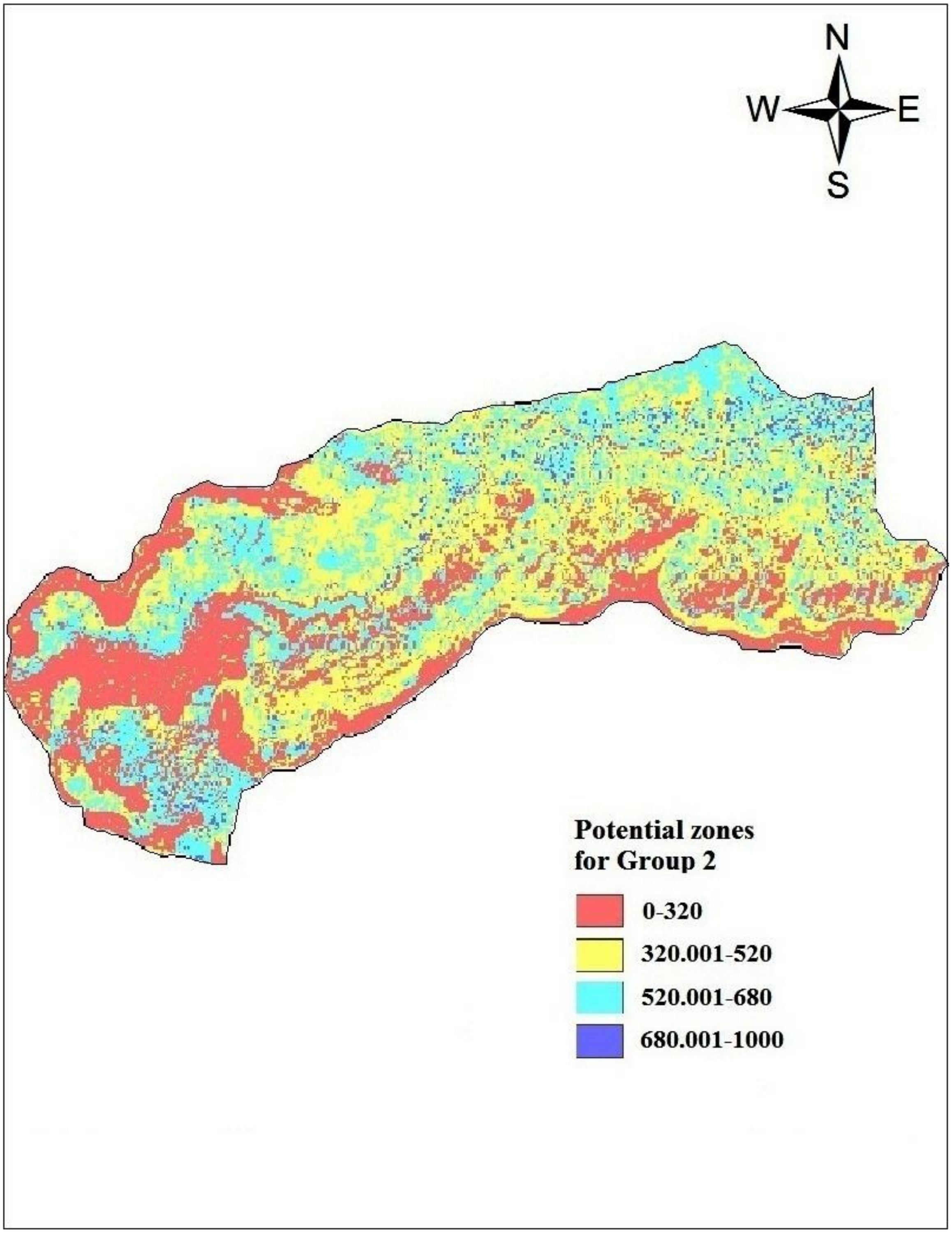

Fig. 4.12 Water harvesting potential map for Group 2

Table 4.12 Spatial coverage of water harvesting potential zones for Group 2

Sr. No	Water Harvesting Potential Zones	Score	Area (ha)	Area (%)
1.	Excellent	680-1000	410.64	3.05
2.	Good	520-680	3652.32	27.18
3.	Moderate	320-520	5407.20	40.25
4.	Poor	0-320	3962.64	29.49

4.4 Suitability criteria used for Water Conservation Measures

Suitable zones/sites for the construction of different water conservation measures in the study area were identified on the basis of land use/land cover, soil, slope and drainage network criteria. The modified suitability criteria used for the selection of zones/sites are given in Table 4.10.

Table 4.13. Suitability criteria used for identifying zones for various WHS

Sr. No	Water harvesting structures	Site suitability criteria			
		Land slope (%)	Soil texture	Stream order	Rainfall (mm)
1.	Check Dam	<15	Fine	1-4	>500
2.	Farm Pond	<5	Fine	1-4	500-1200
3.	Percolation pond	<10	Light	1-4	<500
4.	Contour bunding	<10	Light/medium	-	>500
5.	Contour trenching	10-25	Light	-	>1000

4.5 Best suitable sites selected for various WHS

In this section best suitable sites have been selected for various water harvesting structures namely check dam, farm pond, percolation pond, contour bunding and contour trenching according to the suitability criteria given in Table 4.13. One of the important criteria in selecting sites suitable for farm ponds was that land use should be agriculture with logic that farm ponds are suitable for providing supplementary irrigation to the crops. Moreover, the drainage network map and soil map was imposed on the water conservation potential zone map and best sites were identified for allocating surface water harvesting structures. Fig. 4.13 shows the best suitable sites selected for developing these structures within natural watershed boundary.

For entire study area, we have got 149 sites suitable for various water harvesting structures. Best suitable sites for check dam construction have been distributed over the study area, while sites suitable for percolation pond found more towards the north east part of watershed. Sites suitable for contour bunding and trenching were found near to the boundary of watershed. Table 4.14 gives total number of various WHS in whole study area.

Table 4.14. Total number of various WHS in entire study area

Sr. No.	Water Conservation Structures	Total number
1.	Check Dam	28
2.	Farm Pond	27
3.	Percolation Pond	35
4.	Contour Bunding	30
5.	Contour Trenching	29

4.6 Water harvesting potential

Water harvesting potential accounts for the amount of rainfall that can be effectively harvested. Water harvesting potential map was obtained for 22 micro- watersheds of study area. It was divided into 5 classes namely very low, low, moderate, high and very high. Runoff coefficient used for calculating the water harvesting potential was 0.5. Area under various classes is discussed in Table 4.15. Fig. 4.10 shows water harvesting potential map

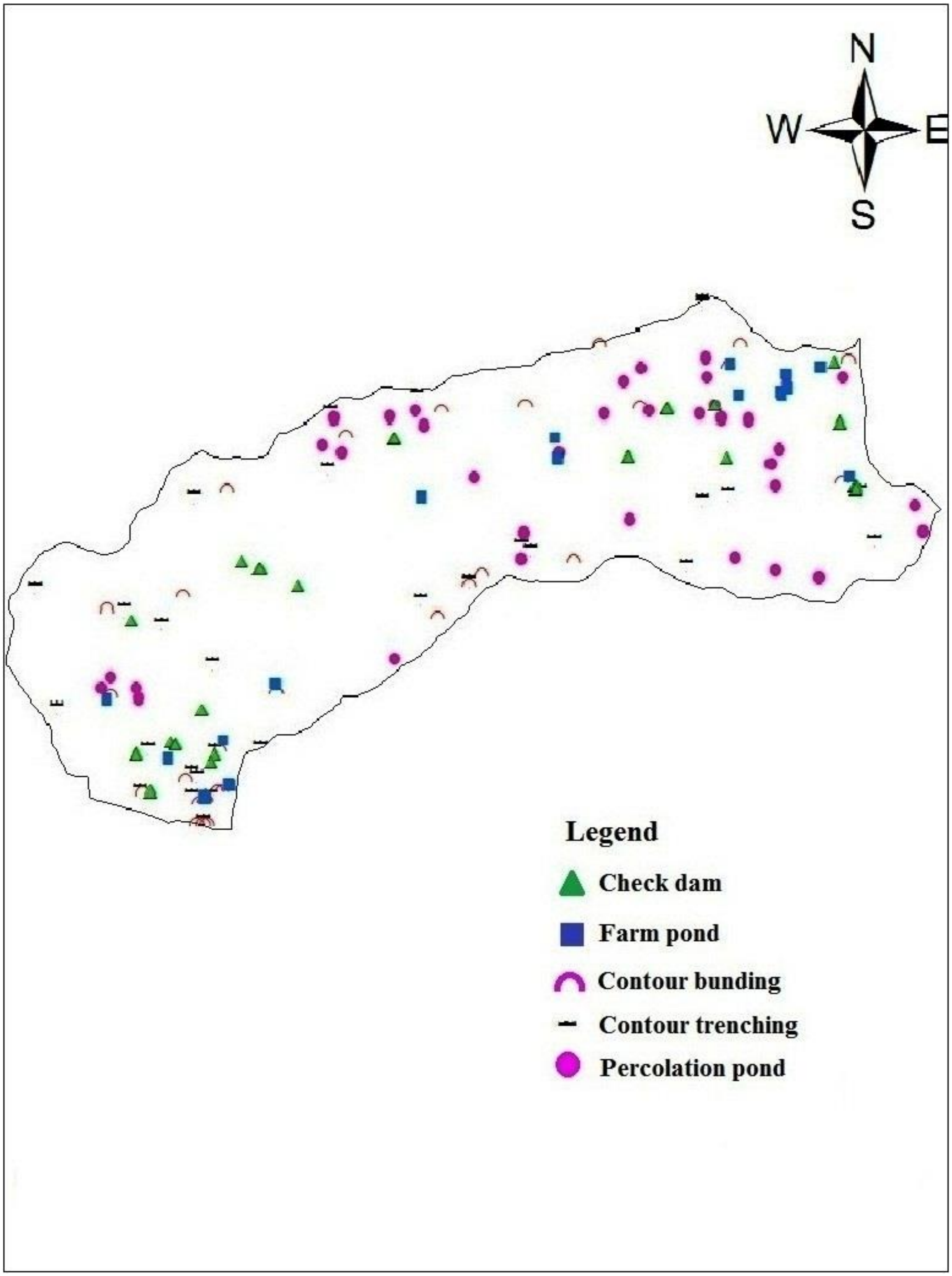

Fig 4.13. Best suitable sites for various Water Harvesting Structures

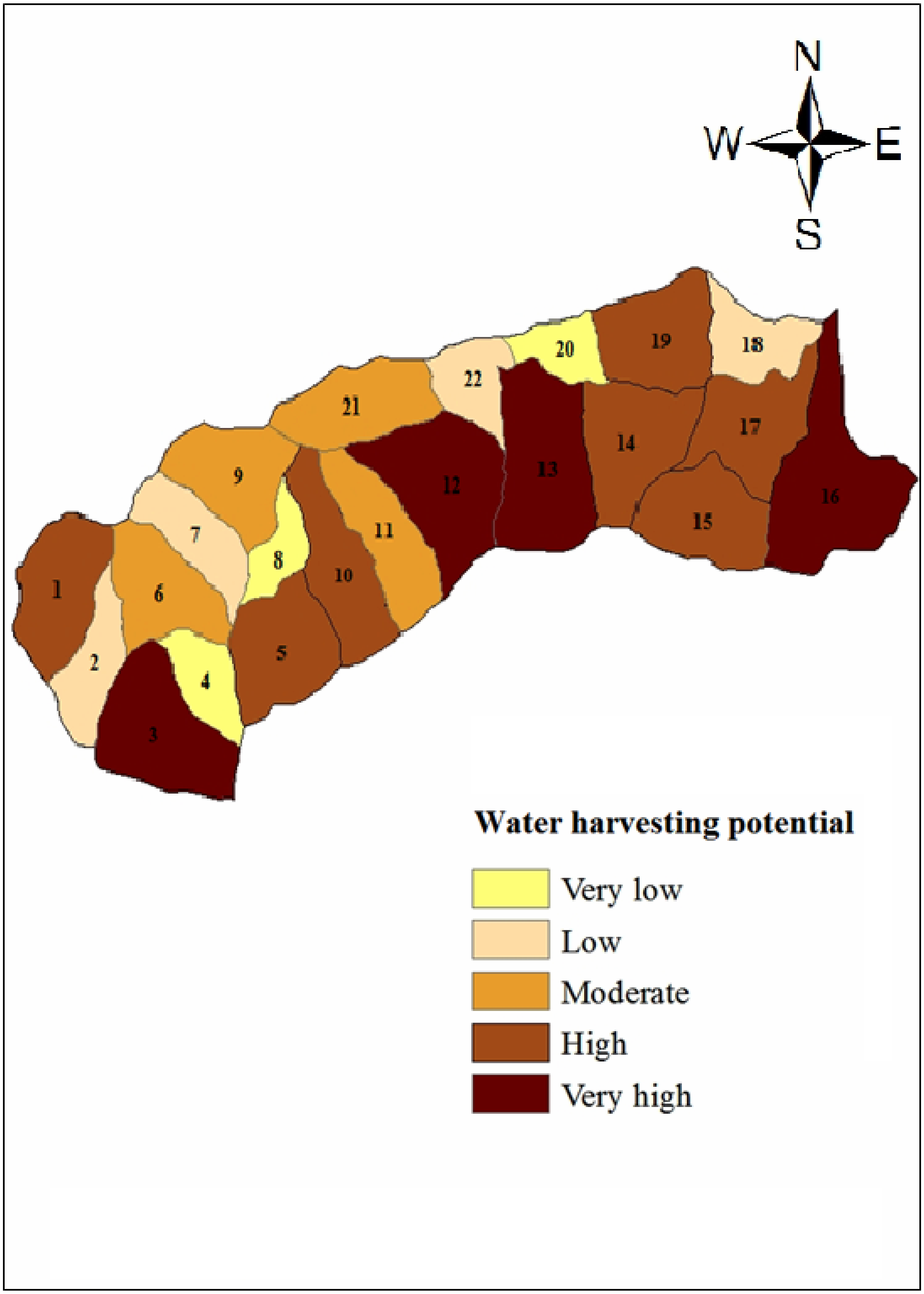

Fig 4.14 Water harvesting potential map

Results showed that the 35.05% (4832.53 ha) was covered by high water harvesting potential class. Next class was of very high category which contributes about 3901.15 ha area (28.29%). Only 6.26% area was under very low water harvesting potential class

Table 4.15 Percent area under different water harvesting potential classes

Sr. No	Water harvesting potential class	Area (ha)	Area (%)
1.	Very low	863.2040	6.26
2.	Low	1672.12	12.12
3.	Moderate	2517.21	18.25
4.	High	4832.53	35.05
5.	Very high	3901.15	28.29

V. SUMMARY AND CONCLUSIONS

Water is one of the most vital requirements for economic and social development. Water harvesting structures play important role in conservation of precious natural resources like, soil and water, which are depleting day by day at alarming rate. Appropriate structures are needed to avoid excessive runoff, for flood control in lower catchments, improving soil moisture availability and to increase the water table in the watershed.

Study showed that Remote sensing data and GIS based approach in evaluation of drainage morphometric parameters and their influence on landforms, soils and eroded land characteristics at river basin level is more appropriate than conventional methods. Interpretation of multi-spectral satellite sensor data is of great help in analysis of drainage parameters and delineation of distinct geological and landform units. The spatial variation in soil depth is associated with type of landform, morphometry and slopes in a toposequence. Therefore, present study was carried out to decide the specific locations of water harvesting structures and water harvesting potential of Morna river catchment using remote sensing and GIS tool.

Morna river catchment (KR-27) extends between 17º24’ to 17º50’ N Latitude and 73º46’ to 74º0’ E Longitudes. This catchment lies in Satara district of Maharashtra state. This catchment is situated at an altitude of 582 m above mean sea level. The total area of watershed is 13,254.13 ha. Various thematic maps were prepared under this study for fulfillment of objectives. First task performed during this study was delineation of watershed. After that Land use / land cover map was prepared using satellite imagery and ERDAS imagine 9.1 in GIS environment. Land use/land cover has been classified into 6 classes as water bodies, fallow land dense forest, cultivated area, open forest and settlement. Maximum area was cultivated. Total geographical area covered under this class has been found to be 4946.22 ha. Next theme prepared was of Hydrologic Soil Group. It was also prepared by using GIS tools. It showed that Hydrologic Soil Group B is dominant soil group in study area covering 12,077.82 ha area.

Slope map of study area was prepared by using Digital Elevation Model (DEM), which was downloaded from (http://bhuvan-noeda.nrsc.gov.in). Slope map was prepared in GIS environment. It was divided into six classes namely nearly level, gentle, moderately gentle, steep, moderately steep and very steep. Majority of area (4049 ha) was under moderately gentle class. Drainage characteristics plays important role in case of identification of suitable sites of various water harvesting structures. It showed that maximum drainage was mostly taken by the first order stream having maximum drainage length of 262.32 km. The second and third order streams have drainage length, 66.53 km (17.37 %) and 21.59 km (5.63 %), respectively. The fourth order stream contributes with a length of 4.547 km. Length of the fifth order stream in the study area is 27.97 km (7.303%). Thiessen polygon method has been used to estimate the average rainfall over the study area using the rainfall information collected from five stations. After that land use/land cover and HSG maps were combined. Cultivated area with HSG B class had been covered the maximum area of 33.9 %

Runoff is one of the important hydrologic variables used in most of the water resources applications. The Soil Conservation Service-Curve Number (SCS-CN) method was adopted for the estimation of surface runoff using multispectral remote sensing data, curve number approach and normal rainfall data. It may be inferred that estimation of runoff by SCS - CN method integrated with GIS can be used in watershed management effectively. Runoff potential map was developed for the study area using thematic layers to extract inputs for SCS Curve number method. The study area was classified into five groups 'very high' (>801 mm), 'high' (601-800 mm), 'moderate' (400-601 mm), 'poor' (201-400 mm) and very poor' (<200 mm). Maximum area of 5491.92 ha was under moderate runoff potential class. The runoff coefficient map was also prepared using combined land use/land cover map and rainfall map. Whole study area was divided into six runoff coefficient classes namely 'high runoff coefficient' (>0.561-1.00), 'moderate runoff coefficient' (0.41-0.56), 'low runoff coefficient' (0.121-0.40), very low runoff coefficient' (<0.12). None area was under very low runoff coeeficient class while maximum area was under low runoff coefficient class i.e 8625.36 ha. Weights and ranks were then assigned to thematic layers of runoff coefficient and slope. The score was calculated by multiplication of rank and weight's assigned to each parameter which affects the site selection suitability.

The use of GIS and Remote Sensing approach improved the accuracy level for locating suitable areas for water harvesting. The major benefit is that the GIS approach for locating suitable sites for water harvesting helps to reduce the extent of the area to be investigated for effective runoff harvesting, by identifying specific areas that are potential sites for water harvesting, and which can then be verified in the field.

The salient conclusions drawn from the present study are as follows:

- The region had scope for various WHS as percolation pond, check dams, farm ponds, contour bunding and contour trenching.
- Major portion i.e. 4946.22 ha area was under cultivated group during year 2009.

- Runoff potential of study area was moderate.
- Low runoff coefficient class (0.121-0.40) was predominant class in study area.
- In all 149 suitable sites were selected for various Water Harvesting Structures.
- Total number of check dam locations selected was 28; farm pond 27, percolation pond 35, contour bunding 30 and that of contour trenching were 29.
- Water conservation potential for Check dam and Farm pond shows maximum area was under poor zone.
- Water conservation potential for Contour bunding, Contour trenching and Percolation pond shows that maximum area was under moderate zone.
- This study will help in the proper management of the study area according to hydrological characteristics.

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VII. APPENDICES

APPENDIX I

Average annual rainfall (mm) of five rain gauge stations

Station / Year	Belwade (kh)	Davari	Gureghar	Marali	Patan
2002	1098.90	1195.70	3068.20	977.30	1246.20
2003	1172.30	1108.80	3201.00	563.50	986.69
2004	1597.10	2137.60	4491.40	928.50	1592.60
2005	2626.50	3314.20	7029.00	2322.10	3289.10
2006	2324.90	3184.80	6568.60	2547.00	2890.00
2007	2213.60	2001.80	5536.10	1431.00	2207.00
2008	1662.80	2079.30	3398.60	815.00	1378.00
2009	1554.10	2145.80	3221.00	1121.00	1319.00
Average	**1781.27**	**2146**	**4564.23**	**1338.17**	**1863.57**

APPENDIX II

Daily rainfall (mm) and AMC for January to December 2009

Date	Rainfall (mm)	Sum of 5 Days rainfall (mm)	AMC
01-01-2009	0.0	0.0	I
02-01-2009	0.0	0.0	I
03-01-2009	0.0	0.0	I
04-01-2009	0.0	0.0	I
05-01-2009	0.0	0.0	I
06-01-2009	0.0	0.0	I
07-01-2009	0.0	0.0	I
08-01-2009	0.0	0.0	I
09-01-2009	0.0	0.0	I
10-01-2009	0.0	0.0	I
11-01-2009	0.0	0.0	I
12-01-2009	0.0	0.0	I
13-01-2009	0.0	0.0	I
14-01-2009	0.0	0.0	I
15-01-2009	0.0	0.0	I
16-01-2009	0.0	0.0	I
17-01-2009	0.0	0.0	I
18-01-2009	0.0	0.0	I
19-01-2009	0.0	0.0	I
20-01-2009	0.0	0.0	I
21-01-2009	0.0	0.0	I
22-01-2009	0.0	0.0	I
23-01-2009	0.0	0.0	I
24-01-2009	0.0	0.0	I

25-01-2009	0.0	0.0	I
26-01-2009	0.0	0.0	I
27-01-2009	0.0	0.0	I
Date	**Rainfall (mm)**	**Sum of 5 Days rainfall (mm)**	**AMC**
28-01-2009	0.0	0.0	I
29-01-2009	0.0	0.0	I
30-01-2009	0.0	0.0	I
31-01-2009	0.0	0.0	I
01-02-2009	0.0	0.0	I
02-02-2009	0.0	0.0	I
03-02-2009	0.0	0.0	I
04-02-2009	0.0	0.0	I
05-02-2009	0.0	0.0	I
06-02-2009	0.0	0.0	I
07-02-2009	0.0	0.0	I
08-02-2009	0.0	0.0	I
09-02-2009	0.0	0.0	I
10-02-2009	0.0	0.0	I
11-02-2009	0.0	0.0	I
12-02-2009	0.0	0.0	I
13-02-2009	0.0	0.0	I
14-02-2009	0.0	0.0	I
15-02-2009	0.0	0.0	I
16-02-2009	0.0	0.0	I
17-02-2009	0.0	0.0	I
18-02-2009	0.0	0.0	I
19-02-2009	0.0	0.0	I
20-02-2009	0.0	0.0	I
21-02-2009	0.0	0.0	I

22-02-2009	0.0	0.0	I
23-02-2009	0.0	0.0	I
24-02-2009	0.0	0.0	I
25-02-2009	0.0	0.0	I
26-02-2009	0.0	0.0	I
Date	**Rainfall (mm)**	**Sum of 5 Days rainfall (mm)**	**AMC**
27-02-2009	0.0	0.0	I
28-02-2009	0.0	0.0	I
01-03-2009	0.0	0.0	I
02-03-2009	0.0	0.0	I
03-03-2009	0.0	0.0	I
04-03-2009	0.0	0.0	I
05-03-2009	0.0	0.0	I
06-03-2009	0.0	0.0	I
07-03-2009	0.0	0.0	I
08-03-2009	0.0	0.0	I
09-03-2009	0.0	0.0	I
10-03-2009	0.0	0.0	I
11-03-2009	0.0	0.0	I
12-03-2009	0.0	0.0	I
13-03-2009	0.0	0.0	I
14-03-2009	0.0	0.0	I
15-03-2009	0.0	0.0	I
16-03-2009	0.0	0.0	I
17-03-2009	0.0	0.0	I
18-03-2009	0.0	0.0	I
19-03-2009	0.0	0.0	I
20-03-2009	0.0	0.0	I
21-03-2009	0.0	0.0	I

22-03-2009	0.0	0.0	I
23-03-2009	0.0	0.0	I
24-03-2009	0.0	0.0	I
25-03-2009	0.0	0.0	I
26-03-2009	0.0	0.0	I
27-03-2009	0.0	0.0	I
28-03-2009	0.0	0.0	I
Date	**Rainfall (mm)**	**Sum of 5 Days rainfall (mm)**	**AMC**
29-03-2009	0.0	0.0	I
30-03-2009	0.0	0.0	I
31-03-2009	0.0	0.0	I
01-04-2009	0.0	0.0	I
02-04-2009	0.0	0.0	I
03-04-2009	0.0	0.0	I
04-04-2009	0.0	0.0	I
05-04-2009	0.0	0.0	I
06-04-2009	0.0	0.0	I
07-04-2009	0.0	0.0	I
08-04-2009	0.0	0.0	I
09-04-2009	0.0	0.0	I
10-04-2009	0.0	0.0	I
11-04-2009	0.0	0.0	I
12-04-2009	0.0	0.0	I
13-04-2009	0.0	0.0	I
14-04-2009	0.0	0.0	I
15-04-2009	0.0	0.0	I
16-04-2009	0.0	0.0	I
17-04-2009	0.0	0.0	I
18-04-2009	0.0	0.0	I

19-04-2009	0.0	0.0	I
20-04-2009	0.0	0.0	I
21-04-2009	0.0	0.0	I
22-04-2009	0.0	0.0	I
23-04-2009	0.0	0.0	I
24-04-2009	0.0	0.0	I
25-04-2009	0.0	0.0	I
26-04-2009	0.0	0.0	I
27-04-2009	0.0	0.0	I
Date	**Rainfall (mm)**	**Sum of 5 Days rainfall (mm)**	**AMC**
28-04-2009	0.0	0.0	I
29-04-2009	0.0	0.0	I
30-04-2009	0.0	0.0	I
01-05-2009	0.0	0.0	I
02-05-2009	0.0	0.0	I
03-05-2009	0.0	0.0	I
04-05-2009	0.0	0.0	I
05-05-2009	0.0	0.0	I
06-05-2009	0.0	0.0	I
07-05-2009	0.0	0.0	I
08-05-2009	0.0	0.0	I
09-05-2009	0.0	0.0	I
10-05-2009	0.0	0.0	I
11-05-2009	0.0	0.0	I
12-05-2009	0.0	0.0	I
13-05-2009	0.0	0.0	I
14-05-2009	0.0	0.0	I
15-05-2009	0.0	0.0	I
16-05-2009	0.0	0.0	I

17-05-2009	0.0	0.0	I
18-05-2009	0.0	0.0	I
19-05-2009	0.0	0.0	I
20-05-2009	0.0	0.0	I
21-05-2009	0.0	0.0	I
22-05-2009	0.0	0.0	I
23-05-2009	0.0	0.0	I
24-05-2009	0.0	0.0	I
25-05-2009	0.0	0.0	I
26-05-2009	0.0	0.0	I
27-05-2009	0.0	0.0	I
Date	**Rainfall (mm)**	**Sum of 5 Days rainfall (mm)**	**AMC**
28-05-2009	0.0	0.0	I
29-05-2009	0.0	0.0	I
30-05-2009	0.0	0.0	I
31-05-2009	0.0	0.0	I
01-06-2009	0.0	0.0	I
02-06-2009	0.0	0.0	I
03-06-2009	0.0	0.0	I
04-06-2009	0.0	0.0	I
05-06-2009	0.0	0.0	I
06-06-2009	0.0	0.0	I
07-06-2009	16.0	0.0	I
08-06-2009	0.0	16.0	II
09-06-2009	0.0	16.0	II
10-06-2009	0.0	16.0	II
11-06-2009	0.0	16.0	II
12-06-2009	0.0	16.0	II
13-06-2009	0.0	0.0	I

14-06-2009	0.0	0.0	I
15-06-2009	0.0	0.0	I
16-06-2009	0.0	0.0	I
17-06-2009	0.0	0.0	I
18-06-2009	0.0	0.0	I
19-06-2009	5.0	0.0	I
20-06-2009	8.0	5.0	I
21-06-2009	0.0	13.0	II
22-06-2009	0.0	13.0	II
23-06-2009	0.0	13.0	II
24-06-2009	4.0	13.0	II
25-06-2009	1.0	12.0	I
26-06-2009	2.0	5.0	I
Date	**Rainfall (mm)**	**Sum of 5 Days rainfall (mm)**	**AMC**
27-06-2009	0.0	7.0	I
28-06-2009	1.0	7.0	I
29-06-2009	0.0	8.0	I
30-06-2009	1.0	4.0	I
01-07-2009	1.0	4.0	I
02-07-2009	8.0	3.0	I
03-07-2009	56.0	11.0	I
04-07-2009	23.0	66.0	III
05-07-2009	3.0	89.0	III
06-07-2009	0.0	91.0	III
07-07-2009	31.0	90.0	III
08-07-2009	23.0	113.0	III
09-07-2009	25.0	80.0	III
10-07-2009	8.0	82.0	III
11-07-2009	14.0	87.0	III

12-07-2009	17.0	101.0	III
13-07-2009	6.0	87.0	III
14-07-2009	28.0	70.0	III
15-07-2009	117.0	73.0	III
16-07-2009	60.0	182.0	III
17-07-2009	43.0	228.0	III
18-07-2009	28.0	254.0	III
19-07-2009	10.0	276.0	III
20-07-2009	10.0	258.0	III
21-07-2009	10.0	151.0	III
22-07-2009	69.0	101.0	III
23-07-2009	68.0	127.0	III
24-07-2009	30.0	167.0	III
25-07-2009	27.0	187.0	III
26-07-2009	28.0	204.0	III
Date	**Rainfall (mm)**	**Sum of 5 Days rainfall (mm)**	**AMC**
27-07-2009	19.0	222.0	III
28-07-2009	12.0	172.0	III
29-07-2009	15.0	116.0	III
30-07-2009	2.0	101.0	III
31-07-2009	1.0	76.0	III
01-08-2009	0.0	49.0	III
02-08-2009	4.0	30.0	III
03-08-2009	0.0	22.0	II
04-08-2009	1.0	7.0	I
05-08-2009	4.0	6.0	I
06-08-2009	7.0	9.0	I
07-08-2009	6.0	16.0	II
08-08-2009	5.0	18.0	II

09-08-2009	3.0	23.0	II
10-08-2009	2.0	25.0	II
11-08-2009	5.0	23.0	II
12-08-2009	5.0	21.0	II
13-08-2009	1.0	20.0	II
14-08-2009	0.0	16.0	II
15-08-2009	0.0	13.0	II
16-08-2009	0.0	11.0	I
17-08-2009	0.0	6.0	I
18-08-2009	4.0	1.0	I
19-08-2009	43.0	4.0	I
20-08-2009	1.0	47.0	III
21-08-2009	13.0	48.0	III
22-08-2009	4.0	61.0	III
23-08-2009	0.0	65.0	III
24-08-2009	8.0	61.0	III
25-08-2009	39.0	26.0	II
Date	**Rainfall (mm)**	**Sum of 5 Days rainfall (mm)**	**AMC**
26-08-2009	0.0	64.0	III
27-08-2009	5.0	51.0	III
28-08-2009	1.0	52.0	III
29-08-2009	4.0	53.0	III
30-08-2009	16.0	49.0	III
31-08-2009	2.0	26.0	II
01-09-2009	1.0	28.0	III
02-09-2009	2.0	24.0	II
03-09-2009	0.0	25.0	II
04-09-2009	15.0	21.0	II
05-09-2009	7.0	20.0	II

06-09-2009	6.0	25.0	II
07-09-2009	0.0	30.0	III
08-09-2009	0.0	28.0	III
09-09-2009	0.0	28.0	III
10-09-2009	0.0	13.0	II
11-09-2009	0.0	6.0	I
12-09-2009	0.0	0.0	I
13-09-2009	0.0	0.0	I
14-09-2009	0.0	0.0	I
15-09-2009	15.0	0.0	I
16-09-2009	0.0	15.0	II
17-09-2009	0.0	15.0	II
18-09-2009	20.0	15.0	II
19-09-2009	0.0	35.0	III
20-09-2009	0.0	35.0	III
21-09-2009	8.0	20.0	II
22-09-2009	6.0	28.0	III
23-09-2009	17.0	34.0	III
24-09-2009	0.0	31.0	III
Date	**Rainfall (mm)**	**Sum of 5 Days rainfall (mm)**	**AMC**
25-09-2009	0.0	31.0	III
26-09-2009	0.0	31.0	III
27-09-2009	0.0	23.0	II
28-09-2009	1.0	17.0	II
29-09-2009	4.0	1.0	I
30-09-2009	5.0	5.0	I
01-10-2009	18.0	10.0	I
02-10-2009	1.0	28.0	III
03-10-2009	10.0	29.0	III

04-10-2009	8.0	38.0	III
05-10-2009	7.0	42.0	III
06-10-2009	6.0	44.0	III
07-10-2009	5.0	32.0	III
08-10-2009	0.0	36.0	III
09-10-2009	0.0	26.0	II
10-10-2009	0.0	18.0	II
11-10-2009	0.0	11.0	I
12-10-2009	1.0	5.0	I
13-10-2009	0.0	1.0	I
14-10-2009	0.0	1.0	I
15-10-2009	0.0	1.0	I
16-10-2009	0.0	1.0	I
17-10-2009	0.0	1.0	I
18-10-2009	0.0	0.0	I
19-10-2009	0.0	0.0	I
20-10-2009	0.0	0.0	I
21-10-2009	0.0	0.0	I
22-10-2009	0.0	0.0	I
23-10-2009	0.0	0.0	I
24-10-2009	0.0	0.0	I
Date	**Rainfall (mm)**	**Sum of 5 Days rainfall (mm)**	**AMC**
25-10-2009	0.0	0.0	I
26-10-2009	0.0	0.0	I
27-10-2009	0.0	0.0	I
28-10-2009	0.0	0.0	I
29-10-2009	0.0	0.0	I
30-10-2009	0.0	0.0	I
31-10-2009	0.0	0.0	I

01-11-2009	0.0	0.0	I
02-11-2009	0.0	0.0	I
03-11-2009	0.0	0.0	I
04-11-2009	0.0	0.0	I
05-11-2009	0.0	0.0	I
06-11-2009	0.0	0.0	I
07-11-2009	0.0	0.0	I
08-11-2009	0.0	0.0	I
09-11-2009	19.0	0.0	I
10-11-2009	2.0	19.0	II
11-11-2009	26.0	21.0	II
12-11-2009	34.0	47.0	III
13-11-2009	7.0	81.0	III
14-11-2009	0.0	88.0	III
15-11-2009	0.0	69.0	III
16-11-2009	30.0	67.0	III
17-11-2009	13.0	71.0	III
18-11-2009	9.0	50.0	III
19-11-2009	3.0	52.0	III
20-11-2009	0.0	55.0	III
21-11-2009	0.0	55.0	III
22-11-2009	0.0	25.0	II
23-11-2009	0.0	12.0	I
Date	**Rainfall (mm)**	**Sum of 5 Days rainfall (mm)**	**AMC**
24-11-2009	0.0	3.0	I
25-11-2009	0.0	0.0	I
26-11-2009	0.0	0.0	I
27-11-2009	0.0	0.0	I
28-11-2009	0.0	0.0	I

29-11-2009	0.0	0.0	I
30-11-2009	0.0	0.0	I
01-12-2009	0.0	0.0	I
02-12-2009	0.0	0.0	I
03-12-2009	0.0	0.0	I
04-12-2009	0.0	0.0	I
05-12-2009	0.0	0.0	I
06-12-2009	0.0	0.0	I
07-12-2009	0.0	0.0	I
08-12-2009	0.0	0.0	I
09-12-2009	0.0	0.0	I
10-12-2009	0.0	0.0	I
11-12-2009	0.0	0.0	I
12-12-2009	0.0	0.0	I
13-12-2009	0.0	0.0	I
14-12-2009	0.0	0.0	I
15-12-2009	0.0	0.0	I
16-12-2009	0.0	0.0	I
17-12-2009	0.0	0.0	I
18-12-2009	0.0	0.0	I
19-12-2009	0.0	0.0	I
20-12-2009	0.0	0.0	I
21-12-2009	0.0	0.0	I
22-12-2009	0.0	0.0	I
23-12-2009	0.0	0.0	I
Date	**Rainfall (mm)**	**Sum of 5 Days rainfall (mm)**	**AMC**
24-12-2009	0.0	0.0	I
25-12-2009	0.0	0.0	I
26-12-2009	0.0	0.0	I

27-12-2009	0.0	0.0	I
28-12-2009	0.0	0.0	I
29-12-2009	0.0	0.0	I
30-12-2009	0.0	0.0	I
31-12-2009	0.0	0.0	I

APPENDIX III

CN I, CN II, CN III values for different combinations of LULC and HSG

Sr. No.	LULC + HSG	CN I	CN II	CN III
1.	Water body + HSG B	100.00	100.00	100.00
2.	Fallow land + HSG B	71.30	85.00	92.99
3.	Dense forest + HSG B	47.09	67.00	82.62
4.	Cultivated area + HSG B	60.85	78.00	89.25
5.	Scrub + HSG B	62.25	79.00	89.81
6.	Settlement + HSG B	71.30	85.00	92.99
7.	Water body + HSG D	100.00	100.00	100.00
8.	Fallow land + HSG D	85.35	93.00	96.89
9.	Dense forest + HSG D	68.16	83.00	91.96
10.	Cultivated area + HSG D	78.01	89.00	94.99
11.	Scrub + HSG D	78.01	89.00	94.99
12.	Settlement + HSG D	83.45	92.00	96.42

APPENDIX IV

Runoff Coefficient values

Sr. No.	LULC + HSG	$R_C = Q/P$ (Where, P = 1319 mm)
1.	Waterbody + HSG B	1.01
2.	Fallow land + HSG B	0.49
3.	Dense forest + HSG B	0.29
4.	Cultivated area + HSG B	0.39
5.	Scurb + HSG B	0.40
6.	Settlement + HSG B	0.13
7.	Waterbody + HSG D	1.01
8.	Fallow land + HSG D	0.66
9.	Dense forest + HSG D	0.46
10.	Cultivated area + HSG D	0.56
11.	Scurb + HSG D	0.56
12.	Settlement + HSG D	0.63