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WATERSHED PRIORITISATION OF UKAI DAM CATCHMENT USING REMOTE SENSING AND GIS

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PREFACE

Soil erosion is of great concern to humanity because, it affects food production through land degradation, limits the supply of hydro-electric power through siltation of reservoirs and creates floods damaging huge area of low lying fields and human settlements.

It is important to study the soil erosion by a systems-approach, analysing these multi-source watershed characteristics with multi-disciplinary expertise in an integrated manner. Watershed management programs, in terms of conservation planning over a large watershed, must identify the subsets of hydrological units that are contributing most of the sediment load from the watershed. It is these priority or critical hydrological units (or watersheds) that need preferential soil/water conservation measures to reduce maximum sediment loads to the reservoirs.

A plan scheme on remote sensing applications in water resources development and management is being operated in Central Water Commission to carry out studies in various application projects in water resources sector. Watershed prioritization of Ukai basin through remote sensing technique is one of such study and this study has been carried out at the National Institute of Hydrology, Roorkee. A study of sedimentation of reservoir in Ukai reservoir has already been completed in the Institute.

This study demonstrates the potential use of satellite based digitally derived NDVI and soil parameters and GIS derived terrain slope and drainage parameters for watershed prioritization. The study has been carried out by Mr. Sanjay K. Jain, Sc.'E', Remote Sensing Applications Division and Mr. M. K. Goel, Sc.'C', Water Resources Systems Division of the Institute. Mr. R. N. Sankhua, Dy. Director, Remote Sensing Directorate, CWC, New Delhi was also involved in the preparation of this report.

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ABSTRACT

Investigation of basins for conservation planning is quite cumbersome and expensive. Therefore, it requires a selective approach to identify smaller hydrological units, which would be suitable for more efficient and targeted resource management programs. The identification of these critical sub-basins, which need soil and water conservation measures on preferential basis, is particularly important in the areas that are close to a reservoir. A criterion, which can be used to determine priority for conservation planning, may be the soil erosion or sediment yield of a basin.

In the present study, watershed prioritization of the catchment immediately upstream of the Ukai reservoir has been carried out using remote sensing technique. For this purpose, Watershed Response Model (WRM) has been used. This model utilizes the Normalized Difference Vegetation Index (NDVI) and the Soil Brightness Index (SBI), the two important parameters responsible for soil erosion. In this study, these two parameters have been determined using remote sensing data. ERDAS IMAGINE system has been used for carrying out the digital image analysis. The other two parameters, i.e. morphological and topographical have also been considered and ILWIS system has been used for their estimation. The immediately contributing catchment upstream of the Ukai reservoir has been divided into 16 watersheds and different vegetation, soil, topography and morphology related parameters have been estimated for all the watersheds separately. The integrated effect of all the parameters has been evaluated to recommend the priority rating of the watersheds for conservation planning.

CHAPTER - 1

INTRODUCTION

1.1 GENERAL

The development of land and water resources on a sustainable basis without deterioration and with constant increase in productivity is the mainstay of mankind. Soil erosion is a process of land denudation involving both, detachment and transportation of the surface soil materials. The detachment of particles of soil and surface sediments occurs by hydrological (fluvial) processes of sheet erosion, rill and gully erosion, and through mass washing and the action of wind. It is a complex dynamic process by which productive surface soils are detached, transported and accumulated at a distant place. It results in exposure of subsurface soil and siltation of reservoirs and natural streams. In India, a total of 1,75,0000 km^2 of land out of the total area of 3,28,0000 km^2 is prone to soil erosion. Thus, about 53% of the total land area of India is prone to erosion (Narayan and Rambabu, 1983).

A watershed is the total area of land from which a river or water body collects its water. Watersheds are delineated by ridge tops or mountain ranges. These drainage basins influence water flow, nutrient cycling, species distribution, and geomorphic processes. Geology, climate, and the history of natural and human disturbance in the region determine basin characteristics. These combined characteristics make every watershed unique. Watersheds play significant role in the development of any country. The main water related natural resources of a watershed are water, land, soil and vegetation. Depending upon the location, a watershed yields water for domestic, agricultural and industrial uses etc. Watersheds and drainage basins can be subdivided into smaller nested sub-watersheds. The watershed or hydrological units within large basins are considered more efficient and appropriate for necessary surveys and investigations for the assessment of these resources and subsequent planning and implementation of various development programs because of their similarity in land use, vegetation, ownership, and government authority (EPA 1994).

The watershed approach is also more rational because land and water resources have optimum interaction and synergetic effect when developed on watershed basis. The watershed approach is increasingly being employed in various development programs like soil and water conservation, command area development, erosion control in catchments of river valley projects and flood prone rivers, dryland/rainfed farming, reclamation of ravine lands, control of shifting cultivation etc. These hydrologic units are equally important for development of water resources through major, medium and minor storage projects and farm level water harvesting structures.

For formulation of proper watershed management programs for sustainable development, an inventory on quantitative erosion soil loss and the priority classification of watersheds are essential. The priority classification of watersheds can help in taking up soil conservation measures on a priority basis. The All India Soil and Land Use Survey (AISLUS) organization, established in 1958, has been assigned the task of priority delineation. Initially, the AISLUS conducted soil survey of upper parts of catchments using Survey of India topographic maps and village cadestral maps. Treatments were started in the upper parts of the catchments with a view that treatments taken up downstream later on would not get damaged due to unprotected upper reaches. During early and mid-1960, aerial photographs were used to demarcate severely eroded and critical spots in different catchments. Subsequently, soil conservation works were conducted in closer vicinity of the reservoirs and sediment carrier streams, as silt produced from these areas would reach the reservoir quickly.

Sediment yield is the main criteria for watershed prioritization purpose. The major parameters, which are responsible for soil erosion in a watershed, are related with morphology, topography, soil type and vegetation characteristics prevalent in the area. All these four parameters are considered in the present study. Effects of land use on sediment yield are closely linked to those of climate, geology and soil characteristics. Major contribution to erosion may be attributed to the influence of land use. Vegetation or plant covers reduce the soil erosion, its effectiveness depending on the height and continuity of canopy, density of ground cover and root density. Generally, forests are most effective in reducing erosion because of their large canopies. Dense grass is also considered equally effective. The classification and mapping of vegetation are fundamental tools for obtaining knowledge about vegetation cover and its relationship to earth's environment. A number of methods have been used to identify different phenological stages of vegetation including the application of Normalized Difference Vegetation Index (NDVI). NDVI is used as indicator of vegetation condition.

Physical properties of the soil affect its infiltration capacity and the extent to which the soil can be detached, dispersed and transported. The properties which most influence erosion include soil structure, texture, organic matter content, moisture content, density (compactness), shear strength as well as chemical and biological characteristics. Topographic features that influence erosion are degree of slope, length of slope and size and shape of the watershed. High water velocities occurring on steep slopes cause serious erosion by scour and sediment transportation.

Relations between the morphology of streams and sediment yield have been considered important for many decades, especially when changes in morphology might somehow be linked to changes in sediment yield from the landscape.

1.2 SCOPE OF THE REPORT

The Ukai reservoir is a major hydraulic structure on the Tapi River. The actual sedimentation rate assessed in this reservoir is quite high in comparison to the initial design rate assumed at the time of planning of the dam.

Accumulation of sediments in the reservoirs reduces the storage capacity and their ability to conserve water for various intended purposes. To check the siltation rate in the reservoir, it is essential to undertake soil conservation measures in the catchment upstream of the reservoir. Since the overall catchment area at the Ukai dam site is quite large (more than 62,000 sq. km), the immediately contributing area upstream of the dam (more than 5,000 sq. km) has been considered and divided into 16 watersheds. Based on the vegetation index, soil brightness index, topographical and morphological characteristics, prioritization of these watersheds has been fixed for the application of soil conservation measures. Vegetation index and soil index have been obtained from the remote sensing imageries. Topographical parameters in the form of slope factor, and morphological parameters such as drainage density, form factor, circulatory ratio, elongation ratio have been obtained for each watershed using the topographic information from the SOI toposheets at 1:50,000 scale in GIS environment. Finally, all the parameters have been integrated and the priority has been assigned to all the watersheds for planning soil conservation measures in the region.

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CHAPTER - 2
THE STUDY AREA & DATA USED

2.1 GENERAL

The Ukai is the largest multipurpose project so far completed in Gujarat state. The Ukai dam is located across river Tapi near village Ukai of Fort-Songadh taluka in district Surat in Gujarat State. It is located between longitudes 73° 32' 25" to 78° 36' 30" E and latitudes 20° 5' 0" to 22° 52' 30" N. The dam is located about 29 km upstream of the Kakrapar weir. The total catchment area of the Ukai reservoir is 62,225 sq. km that lies in the Deccan plateau. The catchment of the dam covers the large areas of 12 districts of Maharashtra, Madhya Pradesh & Gujarat. The districts that lie in the catchment include Betul, Hoshangabad, Khandwa and Khargaon of Madhya Pradesh; Akola, Amravati, Buldhana, Dhule, Jalgaon and Nasik of Maharashtra and Bharuch and Surat of Gujarat state.

The dam comprises of a 4927 m long earth cum masonry dam across the river Tapi. The reservoir impounds a live storage capacity of 0.71 Million Hectare meter at F.R.L. 105.156 m. The earth dam is 80.77 meter high above the lowest foundation level, while the masonry dam is 68.68 meter high above the lowest foundation. The storage extends irrigation facilities to an area of 3,76,000 acres under the Ukai left bank canal and Ukai right bank canal system besides firming up irrigation in area of 5,62,250 acres under the command of pick up weir at Kakrapar. Thus, the total irrigation facilities provided are for 9,38,250 acres under Ukai and Kakrapar. The hydropower house is constructed at the foot of the dam consisting of four units of 75 MW each. In addition to the irrigation benefits, an average of 190 MW of hydropower is being generated at present. The power generation utilizes about 368 cumec of water. The dam provides partial flood control for the downstream areas including the Surat City.

2.2 CATCHMENT CHARACTERISTICS

Various physiographic, climatic and drainage characteristics of the catchment are described in the following:

2.2.1 Physiography and Slope

The catchment is bounded on the north by the Satpura range, on the east by the Mahadeo hills, on the south by the Ajanta range and the Satmala hills and on the West by the alluvial plains. The catchment has an elongated shape with a maximum length of approx. 650 km from east to west and a maximum width of approx. 200 km from north to south.

Physiographically, the area is a basaltic landscape with major physiographic units of plateau lands, escarpments, hills, dykes, piedmont plains, colluvio-alluvial plains and valley plains.

2.2.2 Drainage

The Tapi, originating at Multai, district Betul in Gawaligarh hill ranges of the Satpura Mountains in Madhya Pradesh, is the principal river draining the area. The river is about 634 km long and flows generally east to west through Madhya Pradesh, Maharashtra and Gujarat states. The length of river in Madhya Pradesh, Maharashtra and Gujarat is 208, 323 and 103 km respectively. Major perennial tributaries, viz., the Buray, the Vaghur, the Purna, the Bori, the Gomai, the Aner, the Panjhra, the Girna, the Arunavati etc. emanate from the hill ranges on the north and south of the river Tapi and join the main stream. The drainage density is moderate to high. Broadly speaking, the pattern is dendritic with a sub-parallel system existing adjacent to stream courses, particularly in the alluvial belt.

2.2.3 Climate

The climate of the area is subtropical monsoonic, characterized by mild winter, hot summer and short monsoon. There are striking variations in rainfall from east to west. Temperature differences are associated with relief features. The annual rainfall in the area is around 840 mm while the average annual temperature is 27.2°C.

2.3 DELINEATION OF WATERSHEDS

For the present study, catchment area immediately upstream of the Ukai reservoir has been taken up for prioritization. The study area is shown in Fig. - 1. The All India Soil and Land Use Survey (AISLUS) Organisation of the Department of Agriculture and Co-operation has been engaged in conducting rapid reconnaissance surveys for prioritisation of smaller hydrologic units within the catchment areas of river valley projects and flood prone rivers. It has developed a system for delineating and codifying the catchment areas into smaller hydrologic units, i.e., watersheds following the four-stage delineation. They have divided the entire country into six major water resources regions. There are total 35 basins, 112 catchments, 500 sub-catchments and 3237 watersheds following a five stage delineation approach. The study area considered for this study falls under region 5 and the basin is Tapti having 86 watersheds and area covered is 65.95 lakh ha. The total area is covered in two catchment viz. LB Ukai dam to Purna confluence and RB Ukai dam to Purna confluence and there are five and seven watersheds respectively in these two catchments.

In the original codification scheme, the study area is covered in 12 watersheds but to handle the data, four watersheds were further subdivided. These four watersheds are 5C3A1, 5C3A3, 5C2A1 and 5C2A6 and now the total watersheds are 16. All these are shown in Fig. - 2 and also given in the Table - 1.

Table - 1: Watershed Codification According to Watershed Atlas

Region	Basin	Catchment	Subcatchment	Watershed	Stream Names	Districts Covered
5	5C	5C3	5C3A	5C3A1(1)	Rangavali	Dhulia, Surat
				5C3A1(2)		
				5C3A2	Nesu and Krdi	Dhulia, Surat
				5C3A3(1)	Shivnad	Dhulia, Surat
				5C3A3(2)		
				5C3A4	Bhad	Dhulia
				5C3A5	Amravati	Dhulia
5	5C	5C2	5C2A	5C2A1	Dadan, Dudni	Broach, Surat
				5C2A2(1)	Kanji, Teki	Broach, Surat, Dhulia
				5C2A2(2)		
				5C2A3		Surat, Dhulia
				5C2A4	Vaki	Dhulia
				5C2A5	Gomai	Dhulia, Khargaon
				5C2A6(1)	Umri	Khargaon, Dhulia
				5C2A6(2)	Umri	
				5C2A7	Lendi-Kordi	Dhulia

2.4 DATA USED FOR THE STUDY

For the present study, immediately contributing area upstream of the Ukai reservoir has been considered as explained in the previous section. Various watersheds in the area of interest were marked using the Watershed Atlas of AISLUS at 1:1,000,000 scale.

For preparation of Vegetation and soil index, the remote sensing data of LISS-II sensor of IRS-1B satellite, at a resolution of 36 m, have been used. The data of two different dates, i.e. December 17, 1993 and April 28, 1994 have been used in the present study to take account of the different vegetation conditions after the monsoon season and before the onset of new monsoon.

The remote sensing data of all watersheds is covered in quadrant A1 and B1 of Path 30 and Row 53 of the satellite. The False Colour Composite (FCC) of April and December image are shown in Fig. - 3 and Fig. – 4 respectively.

For the preparation of drainage and contour maps at higher scale, Survey of India toposheets at a scale of 1:250,000 and 1:50,000 were used. Listing of various toposheets that cover the watersheds at 1:50,000 scale is given in Table – 2 below.

Table - 2: Toposheets Covered under Each Watershed

Watershed Number	Toposheet Numbers
5C3A1(1)	46G/11,12,15,16, 46K/3,4,11
5C3A1(2)	46G/11,12,15,16, 46K/3,4,11
5C3A2	46K/3,4, 46G/11,15,16
5C3A3(1)	46K/2,3,4,6,7
5C3A3(2)	46K/2,3,4,6,7
5C3A4	46K/7,11
5C3A5	46K/3,4,7,8,11,12
5C2A1	46G/10,11,14,15
5C2A2(1)	46G/10,11,14,15, 46K/2,3
5C2A2(2)	46G/10,11,14,15, 46K/2,3
5C2A3	46K/2,6, 46G/14
5C2A4	46K/2,6, 46G/14
5C2A5	46K/5,6,7,9,10,11
5C2A6(1)	46K/6,9,10,13,14
5C2A6(2)	46K/6,9,10,13,14
5C2A7	46K/10,11,14,15

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CHAPTER - 3

INTERPRETATION AND ANALYSIS

3.1 GENERAL METHODOLOGY

A number of empirical and conceptual sediment yield models are being used to prioritize the watershed units to address soil and water management. Generally, such models utilize parameters like land use/land cover, soil, slope and drainage as inputs in spatial mode.

Depending upon the methodologies adopted for modeling the sediment yield from a basin, a large number of models are available. These models vary greatly in complexity, from a simple regression relationship linking spatial variation in annual sediment yield to climatic and physiographic variables, to complex simulation models. The simulation models provide a physically based representation of the process occurring in small segments of the catchment and route the response of these segments to the catchment outlet. The regression equations, that relate the sediment yield of a basin to its hydro-meteorological conditions, are mostly used for prediction of sediment yield from ungauged catchment. Garde et al. (1987) have reported various sediment yield equations used for Indian catchments as given below:

a. Khosla (1953) provided the following equation to estimate the annual sediment yield:

$$V_s = 3.23 * 10^{-3} A^{0.72}$$

where V_s = Annual sediment yield in Mm^3 and A = Catchment area in sq. km.

b. Dhurva Narayan et al. (1983) used the following equation:

$$T_l = 5.5 + 11.1\ Q$$

$$T_l = 5.3 + 12.7\ Q.W$$

where T_l= Annual sedimentation rate (metric tonne/year), Q = Annual runoff (M ha m.) and W = T_l/A, where A = Catchment area.

c. Garde et al. (1983) used following equation for sediment yield estimation:

$$V_s = 1.182*10^{-6}\ P^{1.29}\ A^{1.03}\ D_d^{.40}\ S^{0.08}\ F_c^{2.42}$$

where A is catchment area in Km^2, L is stream length in km, S is catchment slope, D_d is drainage density, F_c is Vegetation cover factor, P is Annual mean precipitation in mm and V is sediment yield rate in m^3/100 sq. km/year.

d. Another equation used by Garde et al. (1983) was:

$$V_s = 1.067*10^{-6}\ P^{1.38}\ A^{1.29}\ D_d^{.40}\ S^{0.130}\ F_c^{2.51}$$

where A is catchment area in Km^2, L is stream length in km, S is catchment slope,

D_d is drainage density, F_c is Vegetation Cover factor, P is Annual mean precipitation in mm, and V is sediment yield rate in Mm^3.

Review of literature shows that there are a number of regression equations available that were applied to various Indian catchments. For the estimation of sediment yield, mostly three parameters, viz., land use, topographical/morphological parameters and rainfall/discharge data have been considered.

The use of sediment yield index (SYI) model developed by All India Soil and Land use Survey, Government of India, is a well known model of providing criteria for priority delineation in river valley projects and flood prone rivers (AISLUS, 1991). The SYI model conceptualises sediment delivery into the water body as a multiplicative function of potential soil detachment representing the erosivity factor (weighted value) and the transportability of the detached material (delivery ratio value).

3.2 METHODOLOGY ADOPTED

In the present study, Watershed Erosion Response Model (WERM) has been used. In this method, four parameters, namely morphological, topographical, vegetation index and soil brightness index have been used. The morphological parameters (drainage density, form factor, circulatory ratio and elongation ratio) are termed as erosion risk assessment parameters that have been used for prioritizing watersheds. Vegetation and soil parameters of a catchment are the other main factors, which govern the soil erosion process in the catchment. The generation and calculation of all these parameters is explained below:

3.2.1 Preparation of Vegetation Maps

Vegetation is an important layer while prioritizing the watersheds. Presence of vegetation reduces both, the detachment of sediments and their transportation. Erosion is greatly reduced in the presence of vegetation. The classification and mapping of vegetation from the remotely sensed data is a fundamental tool for obtaining knowledge about vegetation cover. Normalized Difference Vegetation Index (NDVI) is one of the most commonly used indicator of vegetation condition. The NDVI is expressed as:

$$NDVI = (NIR-VIS)/(NIR+VIS)$$

where, NIR and VIS are reflectance in near infrared and visible (Chlorophyll absorption) bands. The normalization minimizes the effect of illumination geometry as well as surface topography.

However, the ratioing does not eliminate the additive effects due to atmospheric attenuation. It has been established that the basic spectral information structure of visible/near-infrared multi-spectral land observations is two dimensional, consisting of signals from the photosynthetically active green foliage component of vegetation canopies mixed with signals of varying brightness from background soils and litter. The normalized difference vegetation index (NDVI) referenced to IRS-1A/1B LISS-I and LISS-II data is expressed as:

$$NDVI = (B4 - B3)/(B4 + B3)$$

where B4 & B3 is reflectance in band 4 (0.77-0.86 μm) and band 3 (0.62-0.68 μm), respectively.

IRS-1B LISS-II scenes of catchment area (quadrant A1 and B1) for December and April were loaded in the image processing system ERDAS IMAGINE 8.3.1. The images were geometrically rectified with respect to the Survey of India (SOI) topographical maps on 1:50,000 scale. After geo-referencing the two quadrant images separately, the two images was stitched together using MOSAIC function. The base map of the area of interest, containing the catchment boundary and the watershed boundaries, was prepared using the toposheets at 1:250,000 scale. This base map was used to extract the remote sensing data of the area of interest from the full scene of the satellite. Different watersheds were also separated from the full catchment area.

For deriving the NDVI image from the geo-referenced raw image, the INDICES function of the processing system was used. In this system, functions are available for deriving NDVI for data of Landsat satellites of U.S. This function was modified so as to derive the NDVI image for the IRS-1B satellite data. After obtaining the NDVI image for each watershed separately, the same was classified into six different classes using the technique of unsupervised classification. Water was assigned a separate class and the other five classes represented the extent of NDVI. To calculate the area weighted value of vegetation, relative weights were given to each vegetation category as presented in the Table - 3. The classified NDVI images for the April, 1994 and December, 1993 are presented in Fig. – 5 and Fig. – 6 respectively.

Table – 3: Weights for Different Vegetation Category

Vegetation Category	Weights
Very high vegetation	5
High vegetation	4
Medium vegetation	3
Less vegetation	2
Very less vegetation	1

Area Weighted Vegetation (AWV) was calculated for each watershed by calculating the sum of the product of area of each vegetation category and its weight divided by the total area of that watershed as given in the following equation :

$$AWV = \frac{A1 * wV1 + A2 * wV2 + A3 * wV3 + A4 * wV4 + A5wV5}{A1 + A2 + A3 + A4 + A5}$$

where AWV is area weighted vegetation, A1...A5 are the areas under each vegetation category, and wV1...wV5 are the weights for each vegetation category. After calculating the area weighted vegetation for each watershed, the range of AWV was classified into five classes of weights 1 to 5. High AWV is given the lowest weight and vice versa. This is based on the reasoning that the watershed with higher vegetation amount must have the lesser erosion, as far as the vegetation factor is concerned. Thus, a watershed with higher vegetation content must be given low priority and vice versa. Table - 4 gives the AWV and the vegetation related weights for all the sixteen watersheds for the purpose of prioritization.

Table - 4 : AWV and Corresponding Weights for Prioritization

Watershed Number	For December, 1993		For April, 1994	
	AWV	Weights	AWV	Weights
5C3A1(1)	2.99	3	2.82	4
5C3A1(2)	2.98	3	2.75	5
5C3A2	2.88	4	2.86	4
5C3A3(1)	2.80	4	2.95	2
5C3A3(2)	2.83	4	2.80	5
5C3A4	2.83	4	2.99	2
5C3A5	2.75	5	2.99	2
5C2A1	3.00	2	2.98	2
5C2A2(1)	3.09	2	2.95	2
5C2A2(2)	2.68	5	2.99	2
5C2A3	2.62	5	2.80	5
5C2A4	2.75	5	2.79	5
5C2A5	3.26	1	2.88	4
5C2A6(1)	2.94	3	2.94	3
5C2A6(2)	2.79	4	3.07	1
5C2A7	2.94	3	2.99	2

3.2.2 Preparation of Soil Brightness Index Maps

To study the effect of soil conditions in the watersheds, Soil Brightness Index (SBI) was estimated for each watershed. For this purpose, a methodology given by Sharma et al. (1990) was used. Sharma et al. have given coefficients for calculation of brightness coefficients using the data of IRS-1B LISS-II. For computation of these coefficients, they took about sixty soil patches with wide range in physical properties, tone and texture over the whole scene. A principal component analysis was performed on the combined soil data to determine the overall distribution of the soil spectral data in 4-dimensional space. A positive linear relationship was found among all the four bands, with maximum correlation between band 2 and 3. They have given brightness coefficients for IRS 1A and 1B satellite separately. In the present study, coefficients for the IRS - 1B, LISS - II data have been used. These are presented in the following

Band 1	0.2623
Band 2	0.6432
Band 3	0.6302
Band 4	0.3471

The formula used for the calculation of soil brightness index is as follows:

$$SBI = 0.2623*B1 + 0.6432*B2 + 0.6302*B3 + 0.3471*B4$$

where B1, B2, B3 and B4 are bands 1, 2, 3 and 4 respectively of IRS-1B, LISS-II sensor. Using this formula, the SBI image for all the watersheds was prepared using the MODELER option of the processing system. The SBI image of the total catchment area under consideration is presented in Fig. – 7 and Fig. – 8 for April, 1994 and December, 1993 image respectively.

As for the case of NDVI, after obtaining the SBI image for each watershed separately, the same was classified into six different classes using the technique of unsupervised classification. Water was assigned a separate class and the other five classes represented the extent of SBI. To get area weighted SBI, relative weights were given to each SBI category as given in the Table - 5.

Table – 5: Soil Erosion Categories and their Weights

Erosion Category	Weights
Very high erosion	5
High erosion	4
Medium erosion	3
Less erosion	2
Very less erosion	1

In the similar way as for the vegetation, Area Weighted Soil (AWSo) values have been calculated for all the watersheds. After calculating the AWSo for each watershed, the range of AWSo was classified into five classes of weights 1 to 5. High AWSo has been given the higher weight and vice versa. The AWSo values for different watersheds and the corresponding weight for prioritization have been tabulated in the Table – 6.

Table - 6 : Area Weighted Soil and Corresponding Weights for Prioritization

Watershed Number	For December, 1993		For April, 1994	
	AWSo	Weights	AWSo	Weights
5C3A1(1)	2.67	1	1.96	1
5C3A1(2)	2.84	4	2.48	2
5C3A2	2.91	5	2.91	5
5C3A3(1)	2.81	3	2.58	2
5C3A3(2)	2.84	4	2.23	1
5C3A4	2.84	4	2.84	5
5C3A5	2.87	4	2.54	2
5C2A1	2.91	5	2.52	2
5C2A2(1)	2.77	2	2.73	4
5C2A2(2)	2.83	3	2.54	2
5C2A3	2.87	4	2.73	4
5C2A4	2.85	4	2.66	3
5C2A5	2.88	5	2.63	3
5C2A6(1)	2.75	2	2.61	3
5C2A6(2)	2.77	2	2.69	3
5C2A7	2.78	2	2.51	2

3.2.3 Estimation of Morphological/Topographical Parameters

For the estimation of morphological and topographical parameters, Survey of India toposheets were used. The drainage network was derived from the Survey of India toposheets at a scale of 1:50,000. The area is covered in 19 topographical maps, in part or full. As the area at 1:50,000 scale was quite large and the drainage network and contours were very dense, it was very difficult to digitize all the maps manually. So the drainage and contour related data were first traced on the tracing sheets (for each watershed separately) and then converted to digital form using the scanner and the data was stored in raster files. The data in raster format was converted to vector form using R2V software. The data in vector format was required for two reasons :

a) To provide elevation values to the contours as mentioned in the toposheets.

b) To evaluate the drainage network for stream ordering and deriving related information.

Using the tracing, scanning and converting to vector format, all the information was generated for each watershed separately and the database was created. For drainage networking and creation of DEM, the GIS software ILWIS (Integrated Land and Water Information System) was used. The drainage pattern for all watersheds was imported in ILWIS and checked for proper joining of all the streams. For stream ordering, the Strahler's system, which is the slightly modified form of Horton's method, was used. Using this ordering system, all the watersheds were found to be in the range of sixth or seventh order. After networking, the lengths of streams of each order were evaluated separately for each watershed.

As for the drainage maps, the contour maps of all watersheds (in vector form) were imported in ILWIS. Each contour line was selected one by one and elevation value was assigned. After assigning elevations to all the contours, the same were converted to raster format. Then the function of Interpolation from iso-lines was applied to each rasterised contour map and the DEM was generated. This interpolated map contained the elevation values at each pixel in the watershed. The resulting DEMs was classified into elevation ranges of 100 m and the number of pixels in each class was noted. The drainage networks of all the watersheds are presented in Fig. - 9 to Fig. - 16. The digital elevation models (DEM) were prepared from the contour maps. The DEMs for the four critical watersheds are presented in Fig. - 17 to Fig. – 20. Using this GIS database, additional physical characteristics of the watersheds like the drainage density, form factor, circulatory ratio, and elongation ratio were estimated.

3.2.3.1 Morphological Parameters

In the present study, quantitative analysis of watersheds was carried out for the evaluation of morphological parameters like form factor, elongation ratio, circulatory ratio and drainage density. The topographic data was generated from the Survey of India toposheets.

Drainage density is defined as the quotient of the cumulative length of the streams to the total drainage area and is expressed in length per unit area. Higher drainage density represents a relatively higher number of streams per unit area and thus a rapid storm response. Higher drainage density represents conditions favourable for higher erosion from the catchment. Based on the length of each stream order, drainage density was calculated for each watershed separately and divided in five classes. Table - 7 gives the drainage density for various watersheds and corresponding weights for prioritization. Higher the drainage density, higher will be the erosion and hence, higher the weight for prioritization.

Table – 7 : Drainage Density (km per sq. km) and Corresponding Weights for Prioritization

Watershed	Drainage Density	Weights
5C3A1(1)	3.01	4
5C3A1(2)	2.58	3
5C3A2	1.77	2
5C3A3(1)	2.65	3
5C3A3(2)	1.66	2
5C3A4	2.49	3
5C3A5	2.38	3
5C2A1	2.09	3
5C2A2(1)	3.49	4
5C2A2(2)	4.13	4
5C2A3	2.6	3
5C2A4	6.02	5
5C2A5	0.954	1
5C2A6(1)	5.2	5
5C2A6(2)	2.75	3
5C2A7	2.54	3

Form factor is another morphological parameter that indicates the erosion potential of a catchment. It is defined as the ratio of the basin area to the square of basin length. Form factor was calculated for each watershed and divided in five classes. Weights were assigned for different range of form factors assuming that higher form factor induces lesser erosion and vice versa. Table - 8 gives the values of form factor and their weights for different watersheds.

Table – 8 : Form Factor and Corresponding Weights for Prioritization

Watershed	Form Factor	Weights
5C3A1(1)	0.134	4
5C3A1(2)	0.128	4
5C3A2	0.105	4
5C3A3(1)	0.123	4
5C3A3(2)	0.241	2
5C3A4	0.182	3
5C3A5	0.268	2
5C2A1	0.118	4
5C2A2(1)	0.273	2
5C2A2(2)	0.376	1
5C2A3	0.371	1
5C2A4	0.063	5
5C2A5	0.276	2
5C2A6(1)	0.115	4
5C2A6(2)	0.180	3
5C2A7	0.174	3

Circulatory ratio is defined as the ratio between the area of the basin and the area of the circle having the same perimeter as that of the basin. Circulatory ratio was calculated for each watershed and divided in five classes. Weights were assigned for different range of circulatory ration assuming that higher circulatory ratio induces lesser erosion and vice versa. Table - 9 gives the values of circulatory ratio and corresponding weights for prioritization.

Table – 9 : Circulatory Ratio and Corresponding Weights for Prioritization

Watershed	Circulatory Ratio	Weights
5C3A1(1)	0.513	3
5C3A1(2)	0.506	3
5C3A2	0.453	4
5C3A3(1)	0.443	4
5C3A3(2)	0.623	2
5C3A4	0.730	1
5C3A5	0.486	4
5C2A1	0.554	3
5C2A2(1)	0.612	2
5C2A2(2)	0.590	2
5C2A3	0.719	1
5C2A4	0.430	4
5C2A5	0.340	5
5C2A6(1)	0.382	5
5C2A6(2)	0.512	3
5C2A7	0.711	1

Elongation ratio is the ratio between the diameter of the circle having the same area (as that of the basin) and the maximum length of the basin. Elongation ratio was calculated for each watershed and divided in five classes. Weights were assigned to different range of elongation ratio assuming that higher elongation ratio induces lesser erosion and vice versa. Table - 10 gives the elongation ratio and corresponding weights for prioritization of different watersheds.

The different weights obtained for each morphological parameter, i.e. drainage density, form factor, circulatory ratio and elongation ratio were averaged out and divided into five different classes. Weights were assigned to different range of average morphological weight assuming that higher morphological weight induces higher erosion and vice versa. Table – 11 gives the calculation of the overall morphological weight to be considered along with the vegetation, soil and slope weight during the final prioritization of watersheds.

Table – 10: Elongation Ratio and Corresponding Weights for Prioritization

Watershed	Elongation Ratio	Weights
5C3A1(1)	0.412	4
5C3A1(2)	0.403	4
5C3A2	0.365	5
5C3A3(1)	0.396	4
5C3A3(2)	0.553	2
5C3A4	0.481	3
5C3A5	0.584	2
5C2A1	0.387	4
5C2A2(1)	0.692	1
5C2A2(2)	0.589	2
5C2A3	0.687	1
5C2A4	0.283	5
5C2A5	0.593	2
5C2A6(1)	0.382	4
5C2A6(2)	0.479	3
5C2A7	0.471	3

Table - 11: Overall Weight of Morphological Parameters for Prioritization

Watershed	Weight of				Overall Weight
	DD	FF	CR	ER	
5C3A1(1)	4	4	3	4	4
5C3A1(2)	3	4	3	4	4
5C3A2	2	4	4	5	4
5C3A3(1)	3	4	4	4	4
5C3A3(2)	2	2	2	2	1
5C3A4	3	3	1	3	2
5C3A5	3	2	4	2	2
5C2A1	3	4	3	4	4
5C2A2(1)	4	2	2	1	2
5C2A2(2)	4	1	2	2	2
5C2A3	3	1	1	1	1
5C2A4	5	5	4	5	5
5C2A5	1	2	5	2	2
5C2A6(1)	5	4	5	4	5
5C2A6(2)	3	3	3	3	3
5C2A7	3	3	1	3	2

3.2.3.2 Slope Layer

In addition to the basin characteristics, slope is other prominent factor for soil erosion. Higher the slope, more will be the erosion. Table - 12 gives the different slope categories and their weights:

Table - 12 : Slope Range and their Weights

Slope range	Category	Slope Group	Weight
0-1%	1	Level land	1
1-3%	2	Very gentle sloping	2
3-5%	3	Gentle sloping	3
5-10%	4	Moderately sloping	4
>10%	5	Steep sloping	5

In the present case, ILWIS system was used for evaluation of slope maps. Using the DEM of each watershed, the slope at every pixel in the X and Y directions was calculated by using the DX and DY functions and then average slope was worked out using the SLOPE function. Since a watershed contains many slope categories, area weighted slope (AWS) was calculated for each watershed using the following equation :

$$AWS = \frac{A1 * wS1 + A2 * wS2 + A3 * wS3 + A4 * wS4 + A5wS5}{A1 + A2 + A3 + A4 + A5}$$

where AWS is area weighted slope, A1.......A5 is the area under each slope category, wS1... ...wS5 are weights for each slope category. Then the slope image was classified into different categories as per Table – 12 and the number of pixels in each category were noted.

Using the weights in the Table – 12 for each category, the AWS was calculated for all the watersheds separately. Table - 13 shows the area weighted slope values and corresponding weights for prioritization. Higher slope causes higher erosion and is given higher weight.

Table - 13: AWS and Corresponding Weights for Prioritization

Watershed	AWS	Weights
5C3A1(1)	2.72	5
5C3A1(2)	2.56	5
5C3A2	1.67	2
5C3A3(1)	2.01	2
5C3A3(2)	2.13	3
5C3A4	2.25	4
5C3A5	1.78	2
5C2A1	1.32	1
5C2A2(1)	2.32	4
5C2A2(2)	2.35	4
5C2A3	2.58	5
5C2A4	2.05	3
5C2A5	1.29	1
5C2A6(1)	2.14	3
5C2A6(2)	2.27	4
5C2A7	2.23	4

3.3 PRIORITIZATION OF WATERSHEDS

Based on the evaluation of different parameters as described in last section, prioritisation of the watersheds was carried out. To account for the integrated effect of all the four parameters under consideration, the individual weights of all the parameters were added together. For incorporating the effect of different morphological parameters, average weight was worked out from the individual weights of all the four morphological parameters. The summation of the weights was then further sub-divided into four different categories for the purpose of prioritization and priority codes were assigned to each category. Watersheds with higher summations of weights have lesser priority code (means higher priority, say, 1 has top priority) and were considered to be most vulnerable for soil erosion and vice versa. Thus, the watershed with priority code equal to 1 must be given the highest priority for the purpose of watershed treatment and for adopting soil conservation measures. Table – 14 and 15 present the relative prioritization status of the watersheds derived using the data of April 1994 and December 1993 imageries respectively. Range of accumulated weights and the corresponding priority code is given in the following:

Range of Accumulated Weights	Priority Code
> 14	1
13 – 14	2
11 – 12	3
< 11	4

Table – 14: Priority Code Derived for All Watersheds Using April 28, 1994 Data

Watershed Number	Weight				Sum of Weights	Priority Code
	Morphology	Soil	Vegetation	Slope		
5C3A1(1)	4	1	4	5	14	2
5C3A1(2)	4	2	5	5	16	1
5C3A2	4	5	4	2	15	1
5C3A3(1)	4	2	2	2	10	4
5C3A3(2)	1	1	5	3	10	4
5C3A4	2	5	2	4	13	2
5C3A5	2	2	2	2	8	4
5C2A1	4	2	2	1	9	4
5C2A2(1)	2	4	2	4	12	3
5C2A2(2)	2	2	2	4	10	4
5C2A3	1	4	5	5	15	1
5C2A4	5	3	5	3	16	1
5C2A5	2	3	4	1	10	4
5C2A6(1)	5	3	3	3	14	2
5C2A6(2)	3	3	1	4	11	3
5C2A7	2	2	2	4	10	4

Table – 15 : Priority Code Derived for All Watersheds Using December 17, 1993 Data

Watershed Number	Weight				Sum of Weights	Priority Code
	Morphology	Soil	Vegetation	Slope		
5C3A1(1)	4	1	3	5	13	2
5C3A1(2)	4	4	3	5	16	1
5C3A2	4	5	4	2	15	1
5C3A3(1)	4	3	4	2	13	2
5C3A3(2)	1	4	4	3	12	3
5C3A4	2	4	4	4	14	2
5C3A5	2	4	5	2	13	2
5C2A1	4	5	2	1	12	3
5C2A2(1)	2	2	2	4	10	4
5C2A2(2)	2	3	5	4	14	2
5C2A3	1	4	5	5	15	1
5C2A4	5	4	5	3	17	1
5C2A5	2	5	1	1	9	4
5C2A6(1)	5	2	3	3	13	2
5C2A6(2)	3	2	4	4	13	2
5C2A7	2	2	3	4	11	3

* * *

CHAPTER - 4

RESULTS AND CONCLUSION

Depending upon the methodologies adopted for modeling the sediment yield from a basin, a large number of models are available for prioritization of watersheds for adopting soil conservation measures. These models vary greatly in complexity, from a simple regression relationships, linking spatial variation in annual sediment yield to climatic and physiographic variables, to complex simulation models. For prioritization purpose, sediment yield simulation models can be used but they have extensive data requirement. In such conditions, the topographical/morphometric data along with the soil brightness index (SBI) and the normalized difference vegetation index (NDVI) could be an easy approach for deriving useful information about the watersheds for the purpose of prioritization.

In the present report, prioritization studies have been carried for a part of the catchment area of the Ukai reservoir located on the Tapi river in Gujarat state. The total catchment area at the dam site is approx. 62,000 sq. km. In this study, the immediately contributing catchment upstream of the reservoir has been taken up for prioritization. The area of the study catchment is approx. 5,000 sq. km. Based on the Watershed Atlas of the All India Soil and Land Use at 1:1,000,000 scale, the study area is divided into 12 watersheds. Further, for the sake of data handling and management, four watersheds were further created and the prioritization among the sixteen watersheds was evaluated.

The Watershed Erosion Response Model (WERM) was used. In this model, four parameters, namely morphological, topographical, vegetation density and soil brightness are considered. The morphological parameters (drainage density, form factor, circulatory ratio and elongation ratio) are termed as erosion risk assessment parameters that have been used for prioritizing watersheds. Vegetation and soil parameters and slope of a catchment are the other main factors that govern the soil erosion process in the catchment. All these parameters were evaluated in the present study for each watershed separately. Vegetation and soil parameters were obtained from the remote sensing data of IRS-1B satellite and LISS-II sensor. The image processing was carried out on the ERDAS IMAGINE system. The data of two different dates, i.e. one after the monsoon season (December 17, 1993) and the other before the onset of next monsoon (April 28, 1994) were used and the analysis was carried out separately for both the dates. Most frequently used vegetation parameter that is derived from the satellite data is the normalized difference vegetation index (NDVI). Such NDVI images were derived for all the watersheds and then classified into five different categories. In the same way, using the coefficients developed by Sharma et al. (1997) for the LISS-II data, soil brightness index (SBI) were derived for all the watersheds and then classified in five categories. Based on the number of pixels of each category of NDVI and SBI in each image, the area weighted vegetation index (AWV) and the area weighted soil index (AWSo) were finalised. The area weighted indices were further classified into five categories for the purpose of prioritization.

For the estimation of morphological and topographical parameters, Survey of India toposheets were used. The drainage network was derived from the Survey of India toposheets at 1:50,000 scale. The drainage network and the contours were transferred to digital form using the scanner and raster to vector conversion software. The GIS analysis was carried out in the ILWIS system. The drainage network was generated and the lengths of various stream orders were evaluated. Based on the area, perimeter and the maximum length of a watershed, various parameters such as drainage density, form factor, circulatory ratio and the elongation ratio were calculated. For the computation of overall weight of morphological parameters, individual weight of all the four parameters were averaged and classified into five categories.

Using the contour maps, the digital elevation models were prepared for all the watersheds and the slope maps were created. The slope maps were classified into five different categories and the area of each category was noted for calculating the area-weighted slope for each watershed (AWS). Area weighted slopes were further classified in five categories for prioritization purpose.

Based on the weights of different parameters, prioritization of the watersheds was carried out. To account for the integrated effect of all the parameters under consideration, the individual weights of all the parameters (morphological, topographical, vegetation, and soil) were added together. While doing so, it was assumed that the relative importance of all the parameters under consideration is same and weights were simply added. The summation of the weights was then further sub-divided into four different categories for the purpose of prioritization. Priority codes were assigned to each category. Watersheds with higher summations were assigned lesser priority code (means higher priority, say, 1 has top priority) and were considered to be most vulnerable for soil erosion and vice versa. The final results of prioritization are presented in the tabular form below. In this table, the accumulated weights obtained using the analysis of data of each date of satellite imagery were added together and then categorised into four different priority classes considering 19 – 21 as Low priority, 22 – 25 as Medium priority, 26 – 29 as High priority, and 30 – 33 as Very High priority. The final results are presented in Table – 16.

Table - 16 : Relative Priority of Different Watersheds for Soil Conservation

Watershed Number	Sum of Weights for April	Sum of Weights for December	Total Weight	Priority
5C3A1(1)	14	13	27	High
5C3A1(2)	16	16	32	Very High
5C3A2	15	15	30	Very High
5C3A3(1)	10	13	23	Medium
5C3A3(2)	10	12	22	Medium
5C3A4	13	14	27	High
5C3A5	8	13	21	Low
5C2A1	9	12	21	Low
5C2A2(1)	12	10	22	Medium
5C2A2(2)	10	14	24	Medium
5C2A3	15	15	30	Very High
5C2A4	16	17	33	Very High
5C2A5	10	9	19	Low
5C2A6(1)	14	13	27	High
5C2A6(2)	11	13	24	Medium
5C2A7	10	11	21	Low

From the Table – 16 and Fig. 21, it is inferred that the watersheds 5C3A1(2), 5C3A2, 5C2A3 and 5C2A4, are very high priority watersheds from the point of view of soil conservation. Similarly, watersheds 5C3A1(1), 5C3A4 and 5C2A6(1) are high priority watersheds. The major factors that contribute to soil erosion potential in these watersheds were analysed. For the very high priority watersheds, it is seen that all, but soil/vegetation for 5C3A1(2), slope for 5C3A2 and 5C2A4 and morphology for 5C2A3, are the dominant factors of soil erosion. For the high priority watersheds, 5C3A1(1) is affected by all factors except soil, while soil plays dominant role for watershed 5C3A4 and morphology plays dominant role for 5C2A6(1).

As expected, there is no major difference between the accumulated weights of the results of December and April. From Table – 15, it is seen that the Very high priority (Priority code 1) watersheds for both the cases are same. The reason is that the vegetation may show high vigour during and after the monsoon season because of rich moisture content but may show poor vigour before the onset of monsoon because of possible deficient water supply. However, the vegetation can still be easily recognised in the remote sensing data since its signatures are quite different from other surface features. So it is observed that such analysis can be carried out with the data of one date imagery (preferably just after the monsoon season).

Secondly, if recognisable difference in the land use/land cover has occurred in the catchment within a time span which can be identified in the remote sensing imagery, then change in the soil erosion scenario can be estimated using satellite data. So, if some conservation measures have been adopted in the catchment or land use practices have undergone some change, then their impact on soil erosion can be analysed using the remote sensing technique.

* * *

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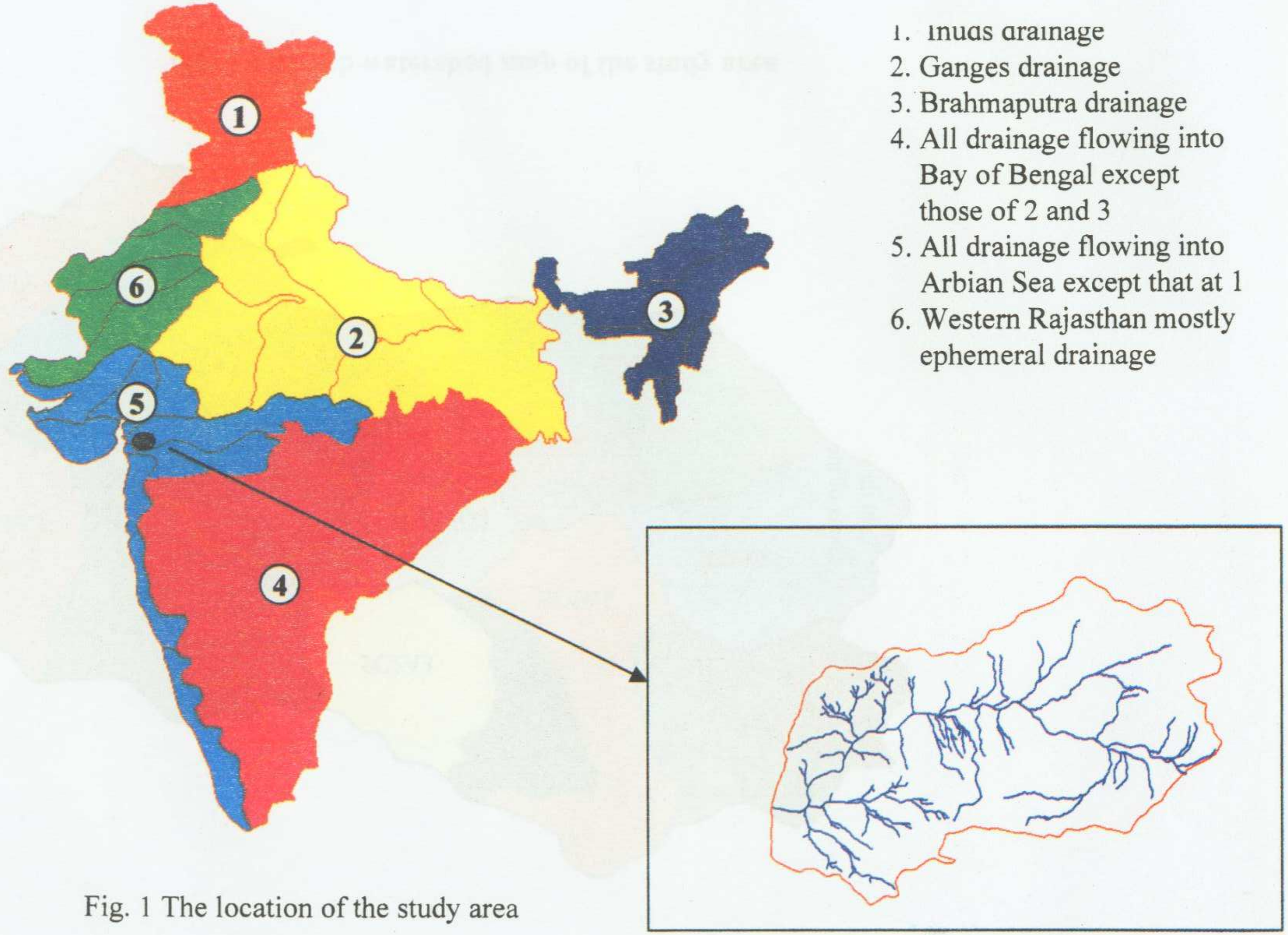


Fig. 1 The location of the study area

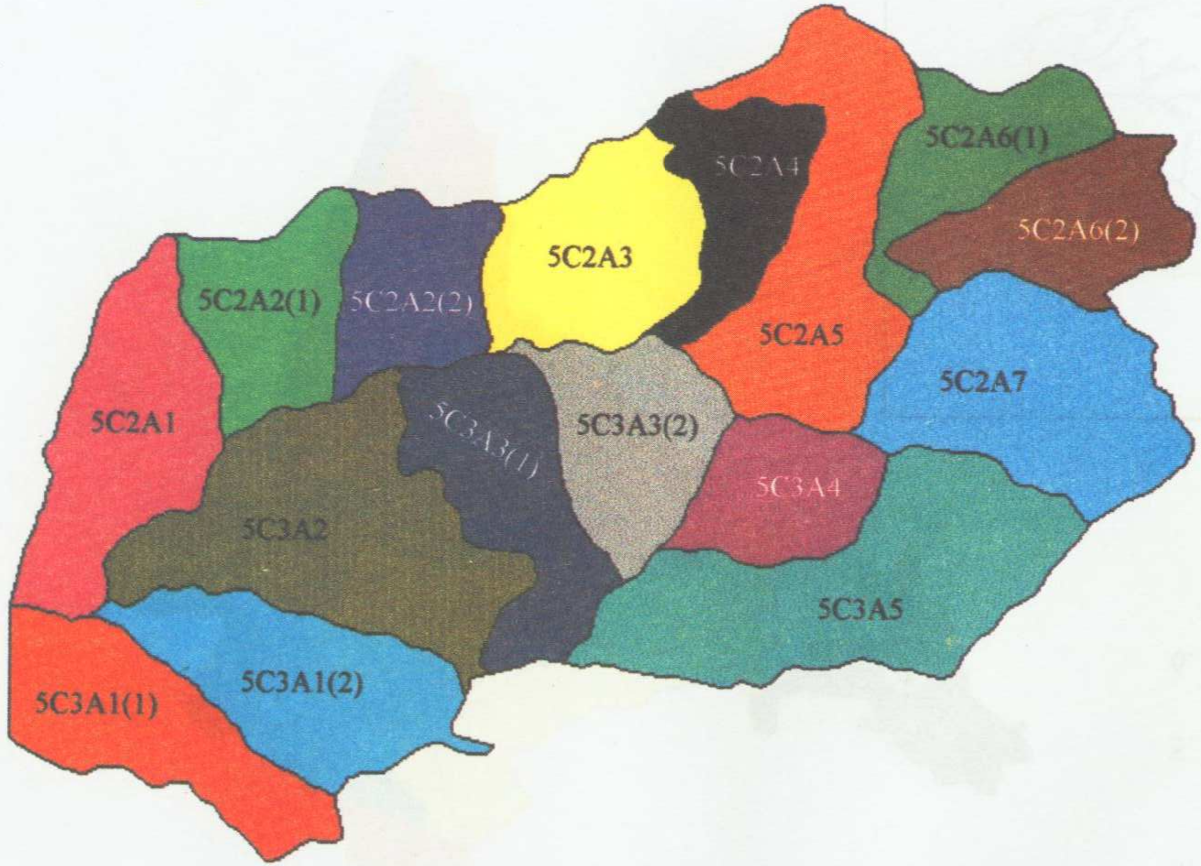


Fig. 2 The Sub watershed map of the study area

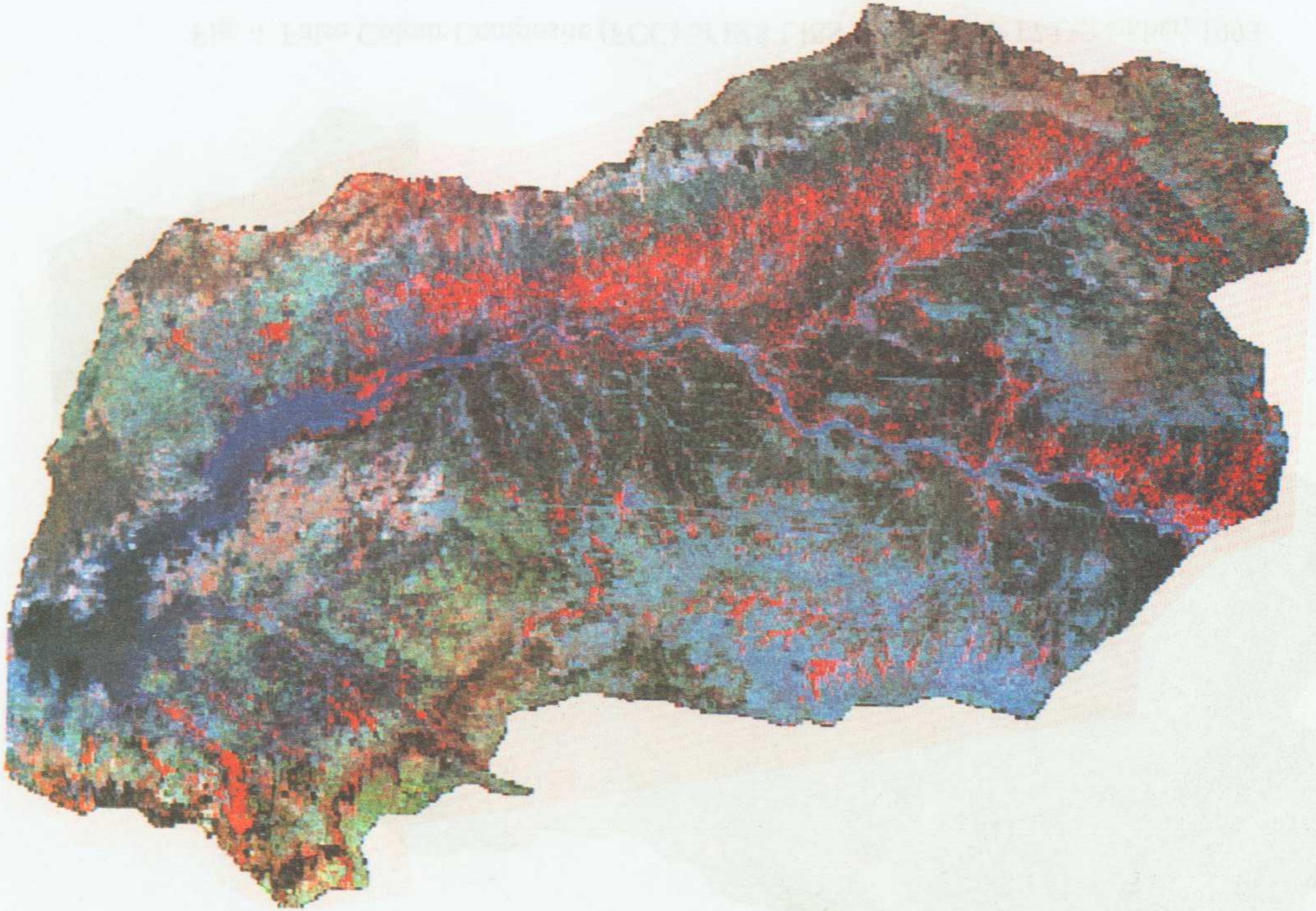


Fig. 3 False Colour Composite (FCC) of IRS LISS II Image of 28 April, 1994

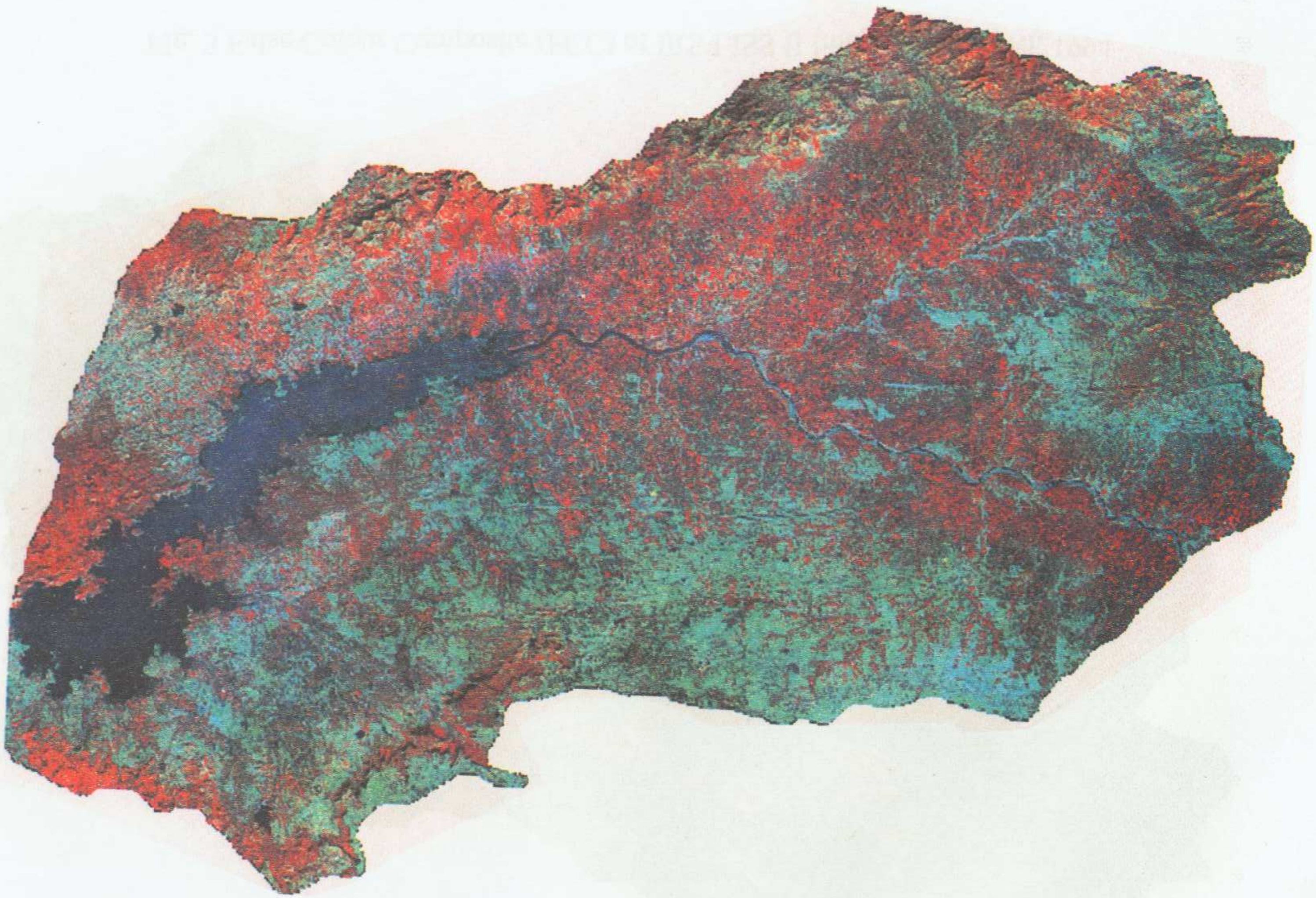


Fig. 4 False Colour Composite (FCC) of IRS LISS II Image of 17 December, 1993

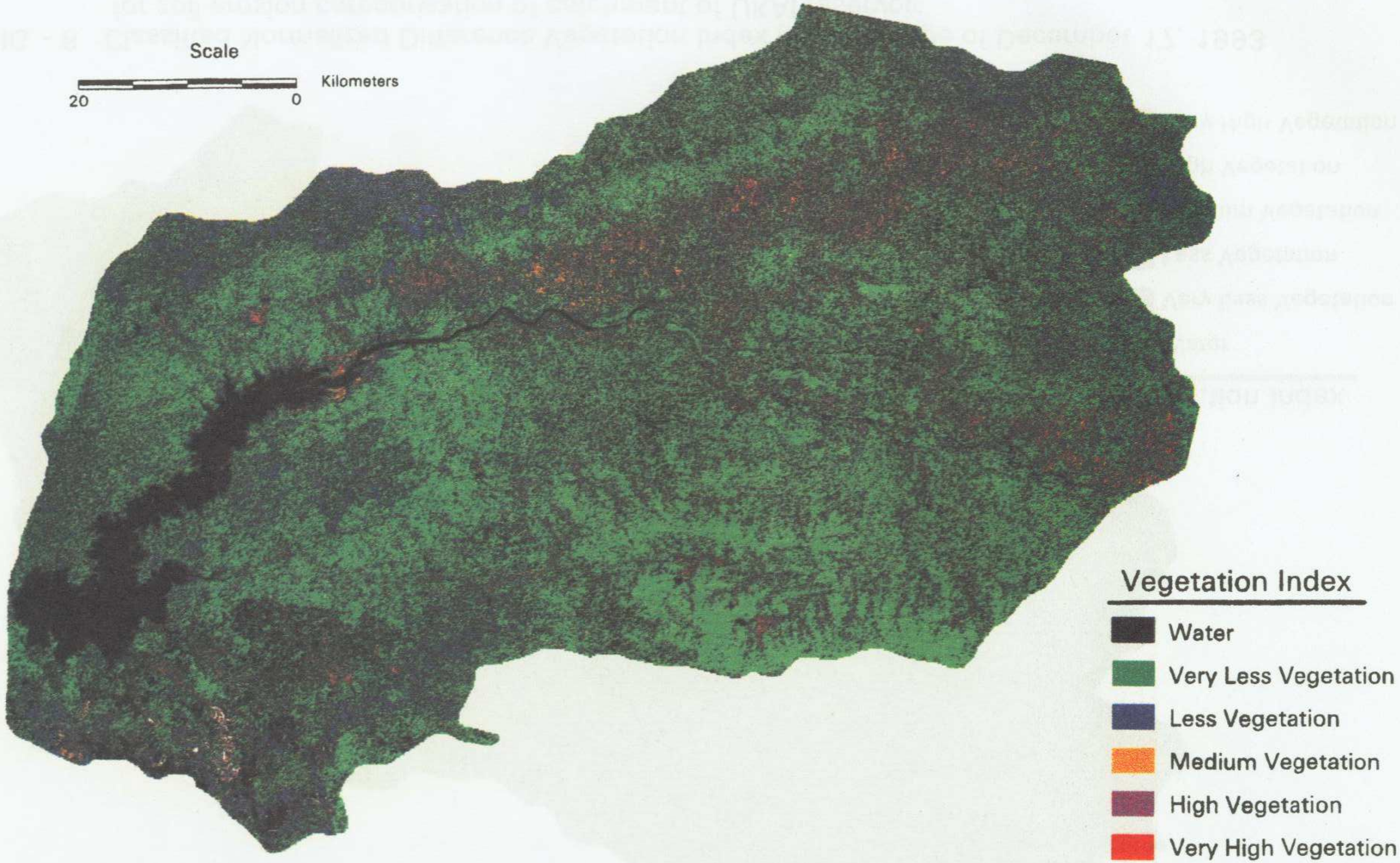


FIG. - 5 Classified Normalized Difference Vegetation Index (NDVI) image of April 28, 1994 for soil erosion categorisation of catchment of UKAI reservoir

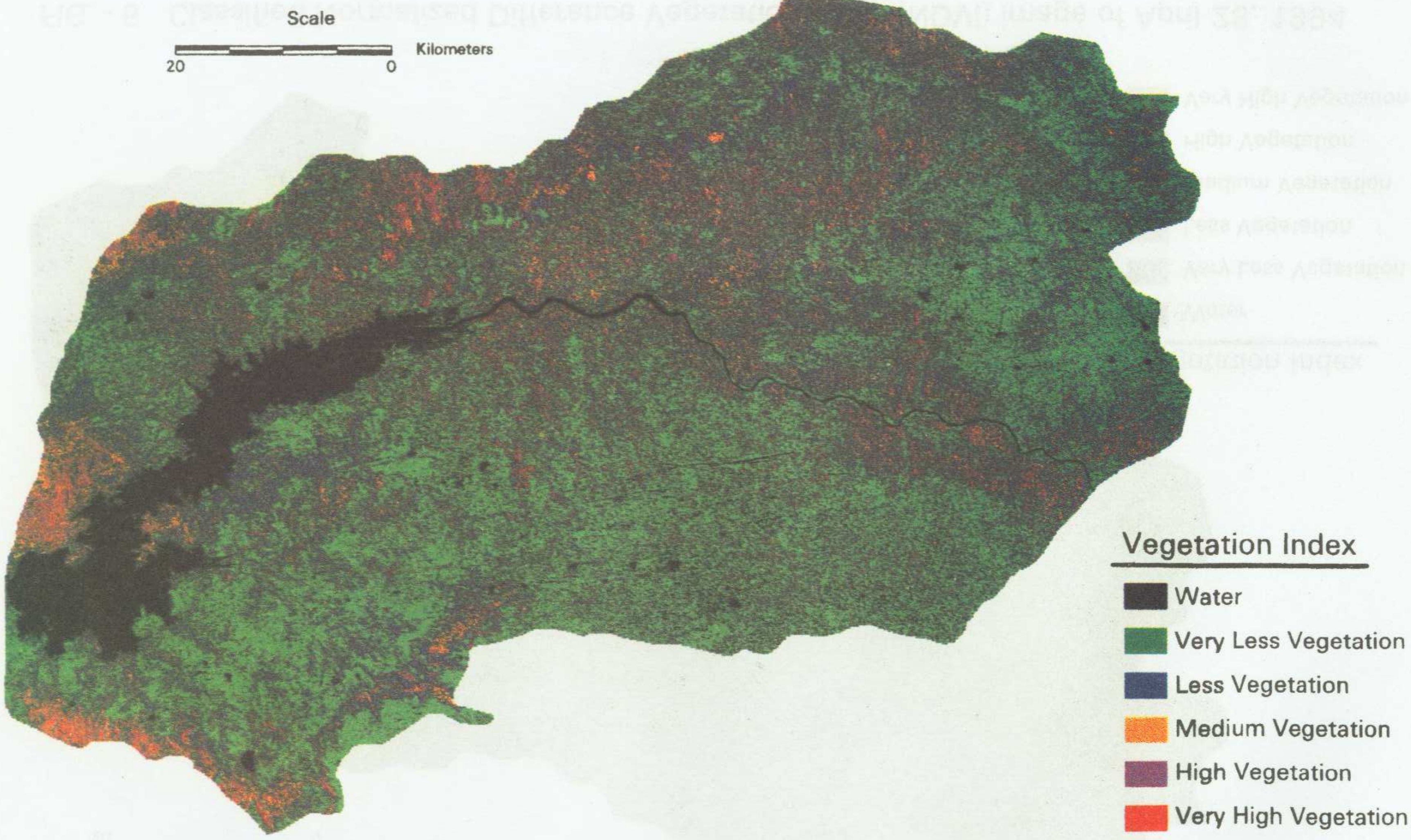


FIG. - 6 Classified Normalized Difference Vegetation Index (NDVI) image of Decembet 17, 1993 for soil erosion categorisation of catchment of UKAI reservoir

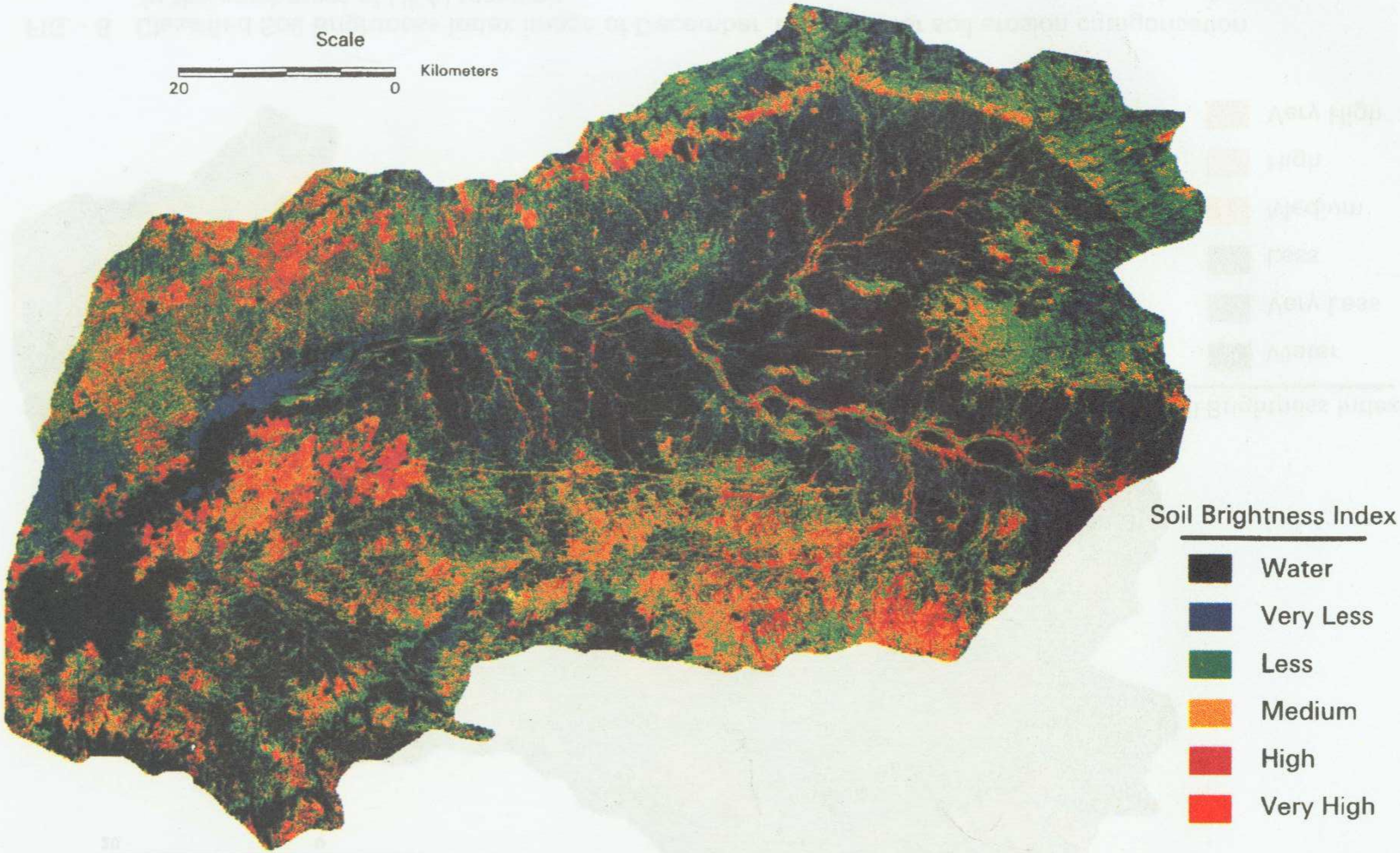


FIG. - 7 Classified Soil Brightness Index image of April 28, 1994 for soil erosion categorisation in the catchment of UKAI reservoir

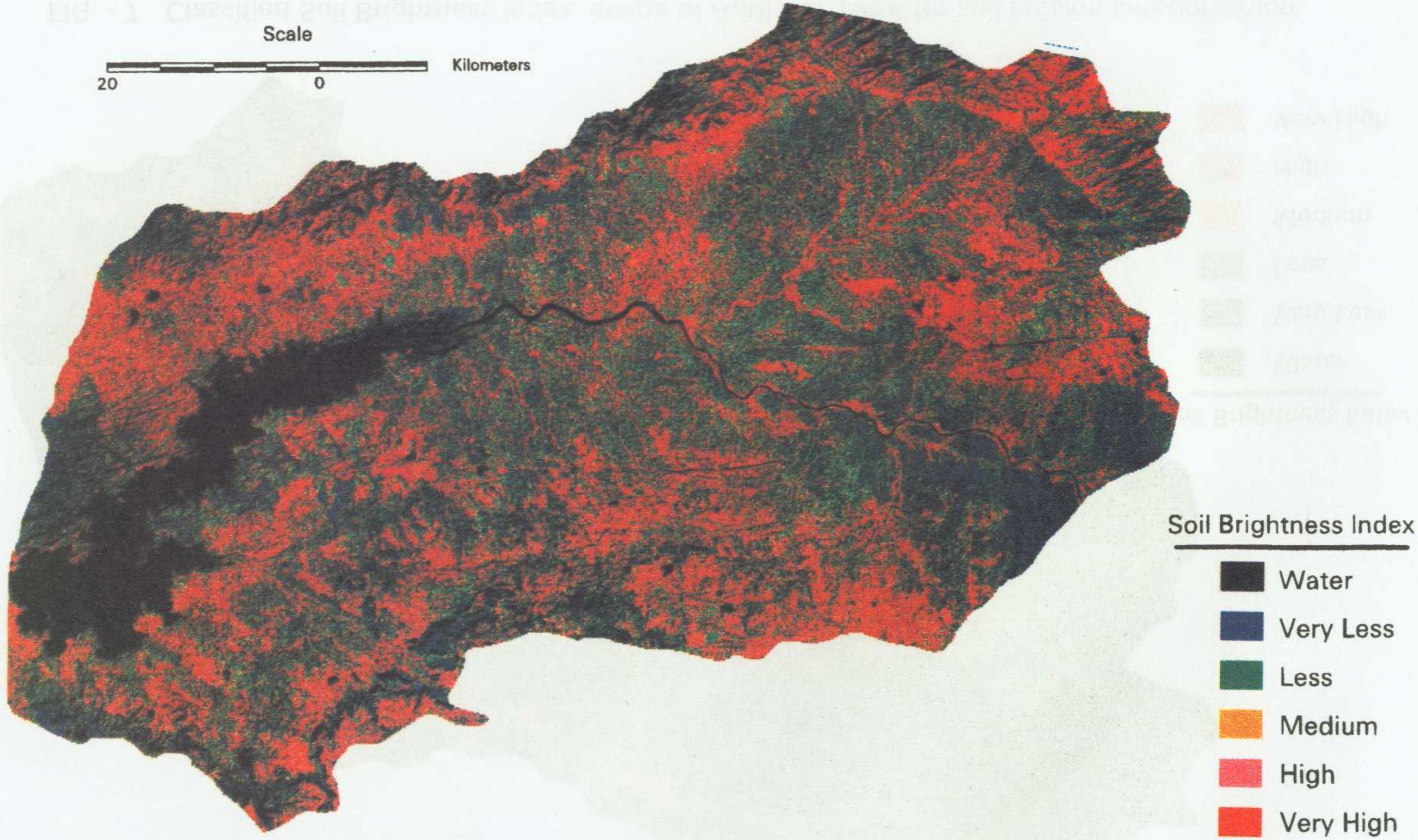
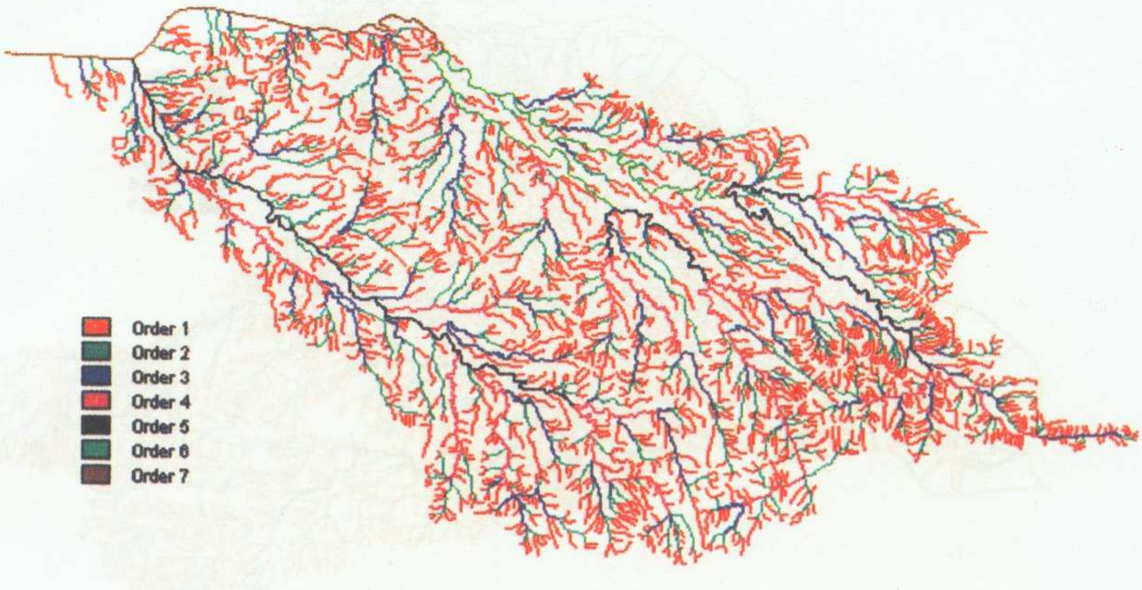


FIG. - 8 Classified Soil Brightness Index image of December 17, 1993 for soil erosion categorisation in the catchment of UKAI reservoir



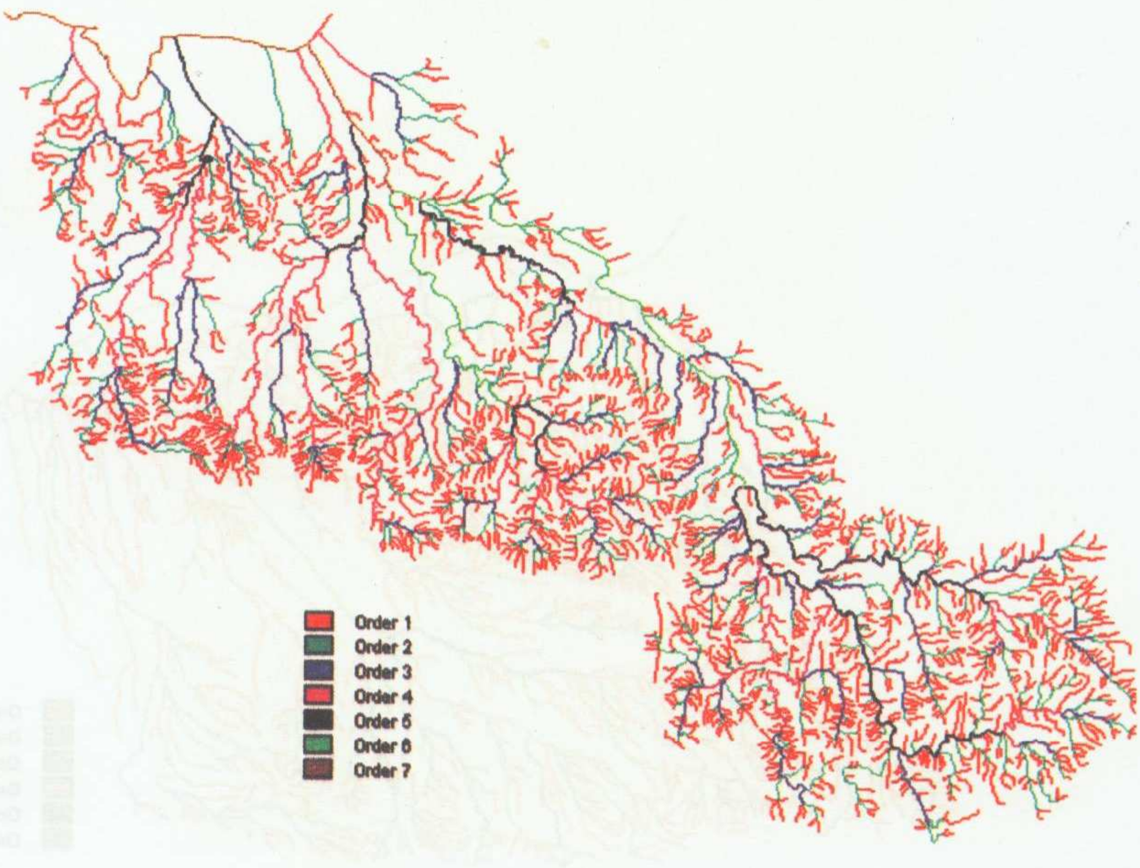


Fig. 9 Drainage network map of 5C3A1(1) and 5C3A1(2)

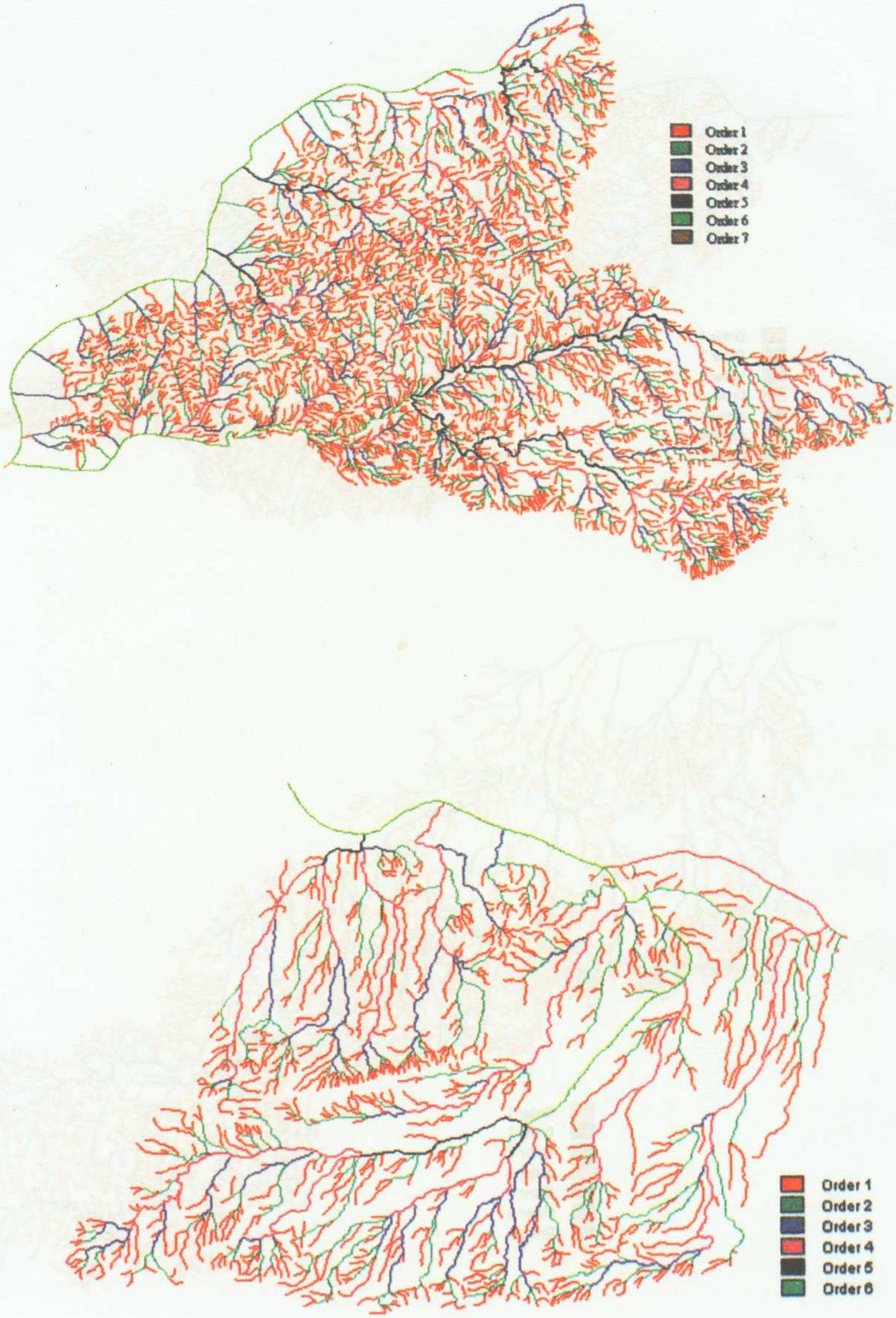


Fig. 10 Drainage network map of 5C3A2 and 5C3A4

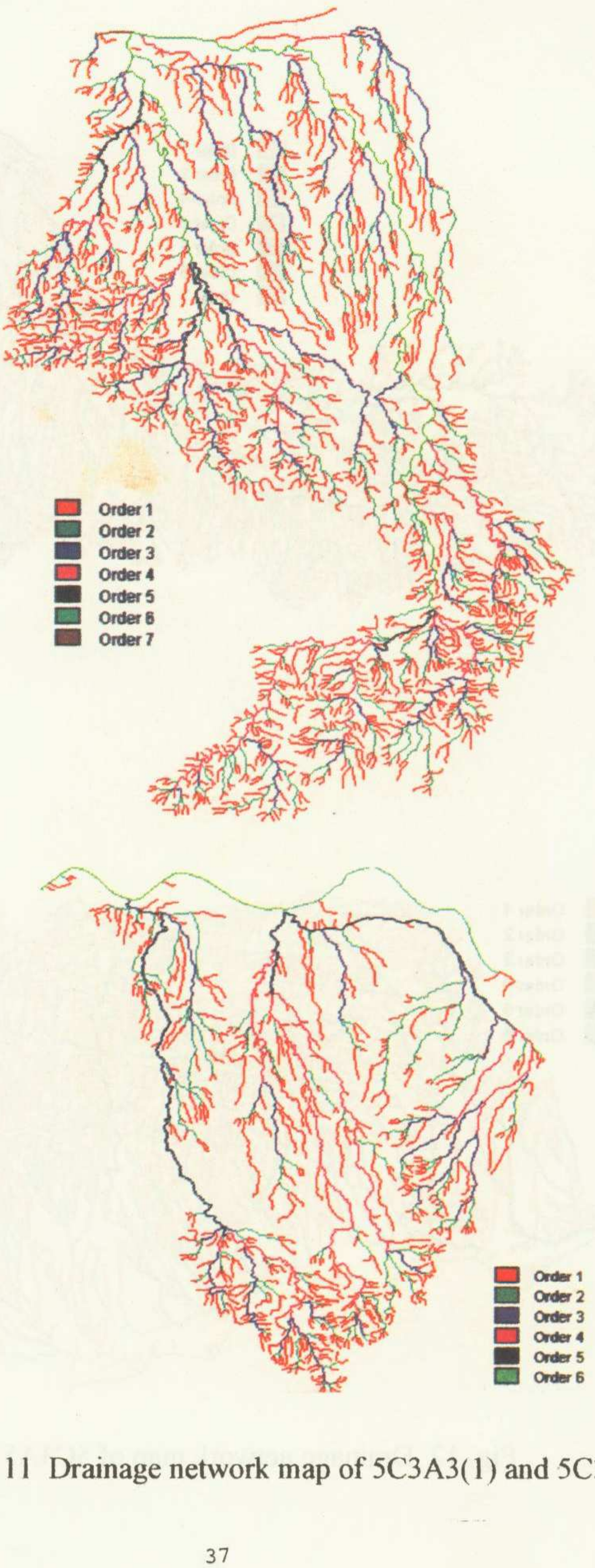
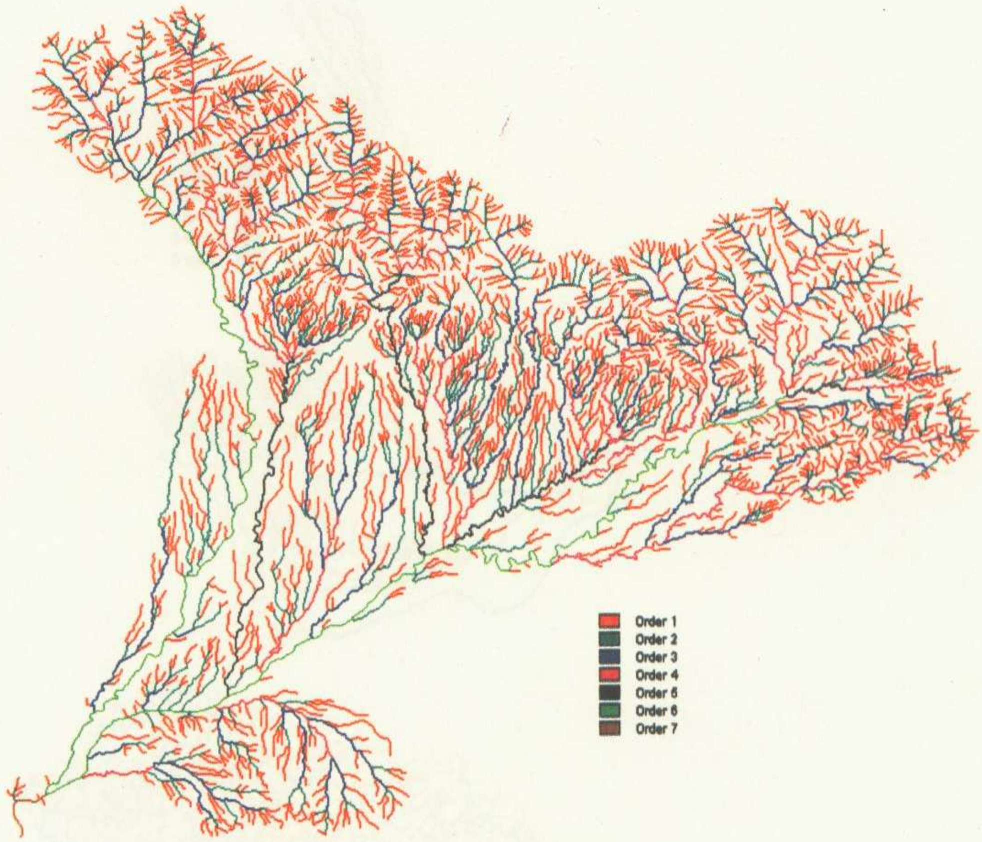


Fig. 11 Drainage network map of 5C3A3(1) and 5C3A3(2)

Fig. 12 Drainage network map of 5C3A5 and 5C2A7



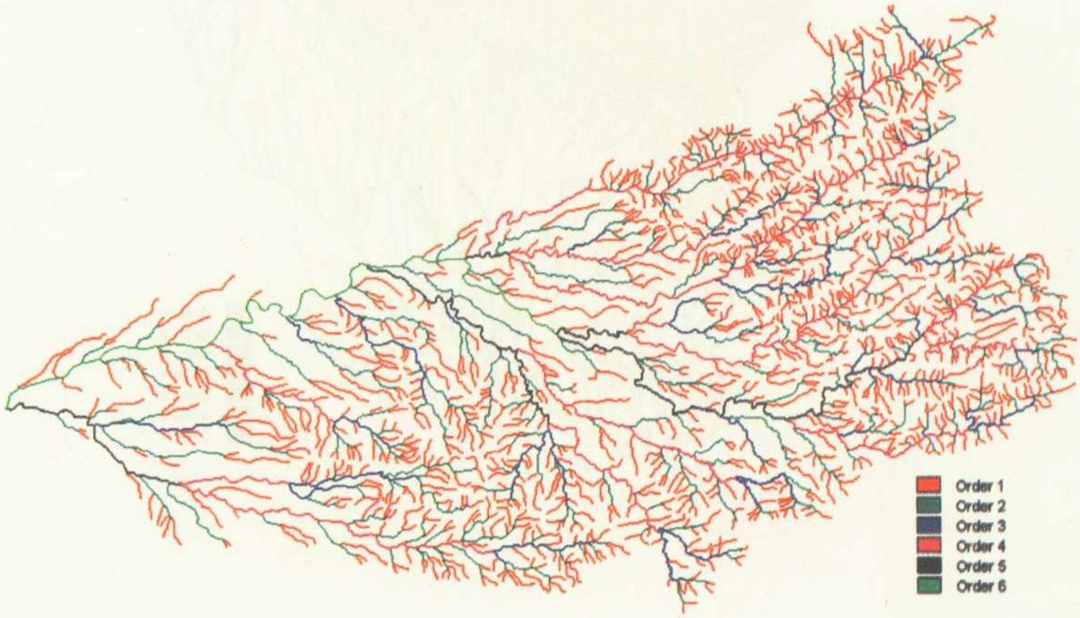
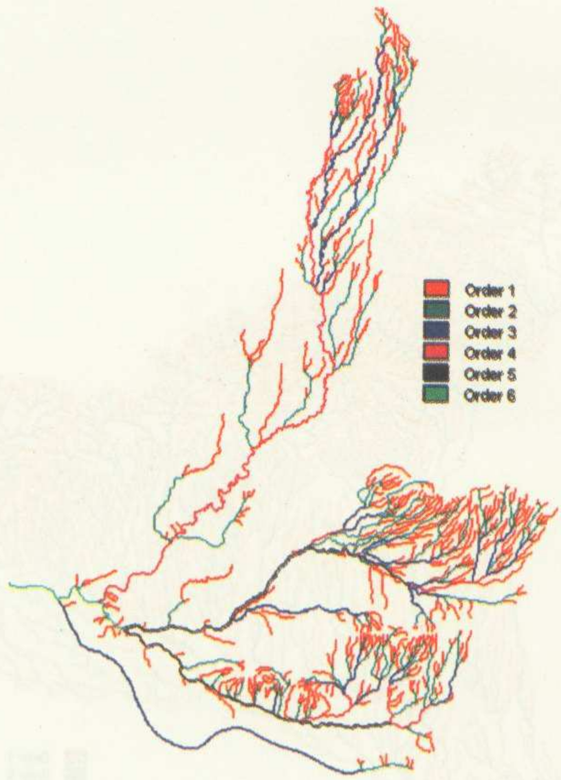


Fig. 13 Drainage network map of 5C2A6(1) and 5C2A6(2)



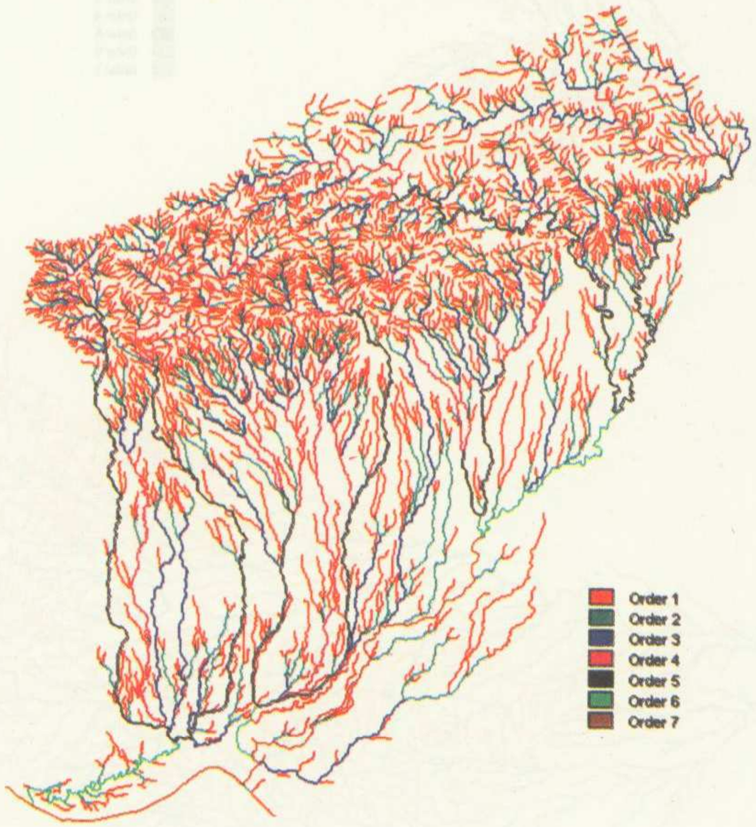
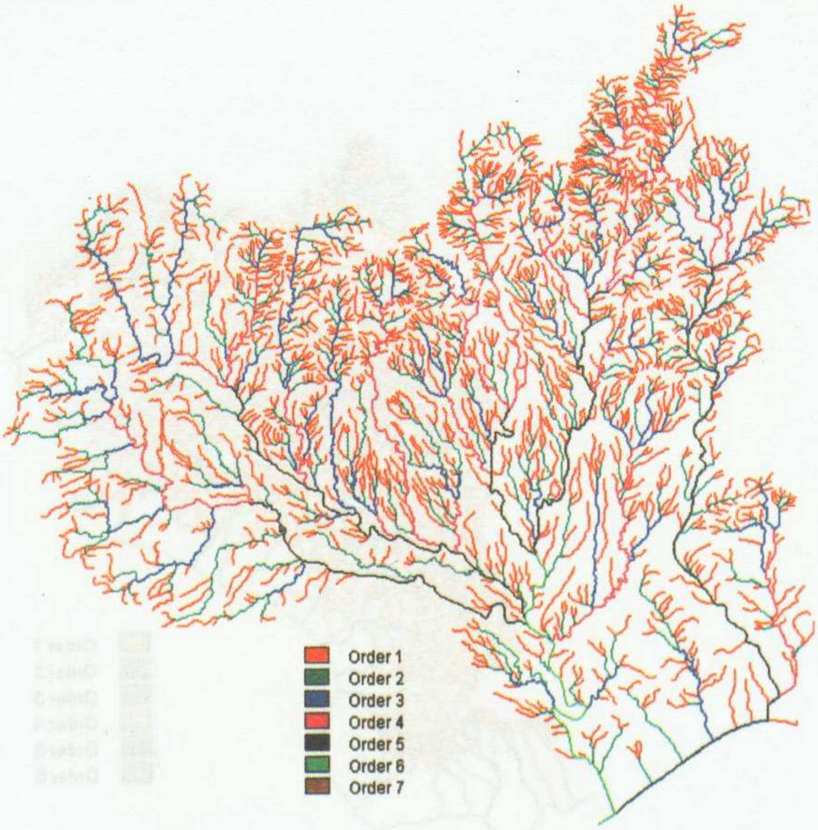


Fig. 14 Drainage network map of 5C2A4 and 5C2A5



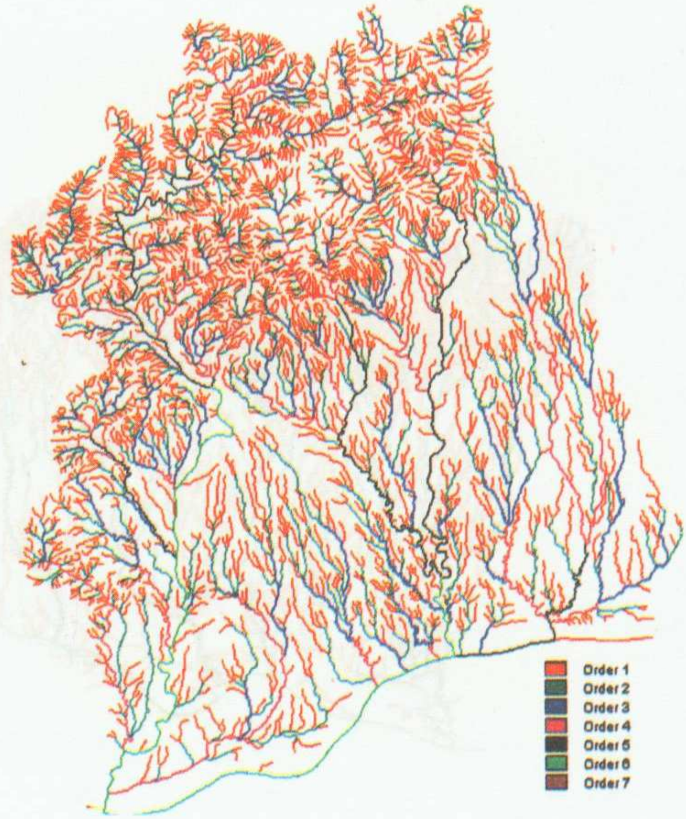


Fig. 15 Drainage network map of 5C2A2(1) and 5C2A2(2)

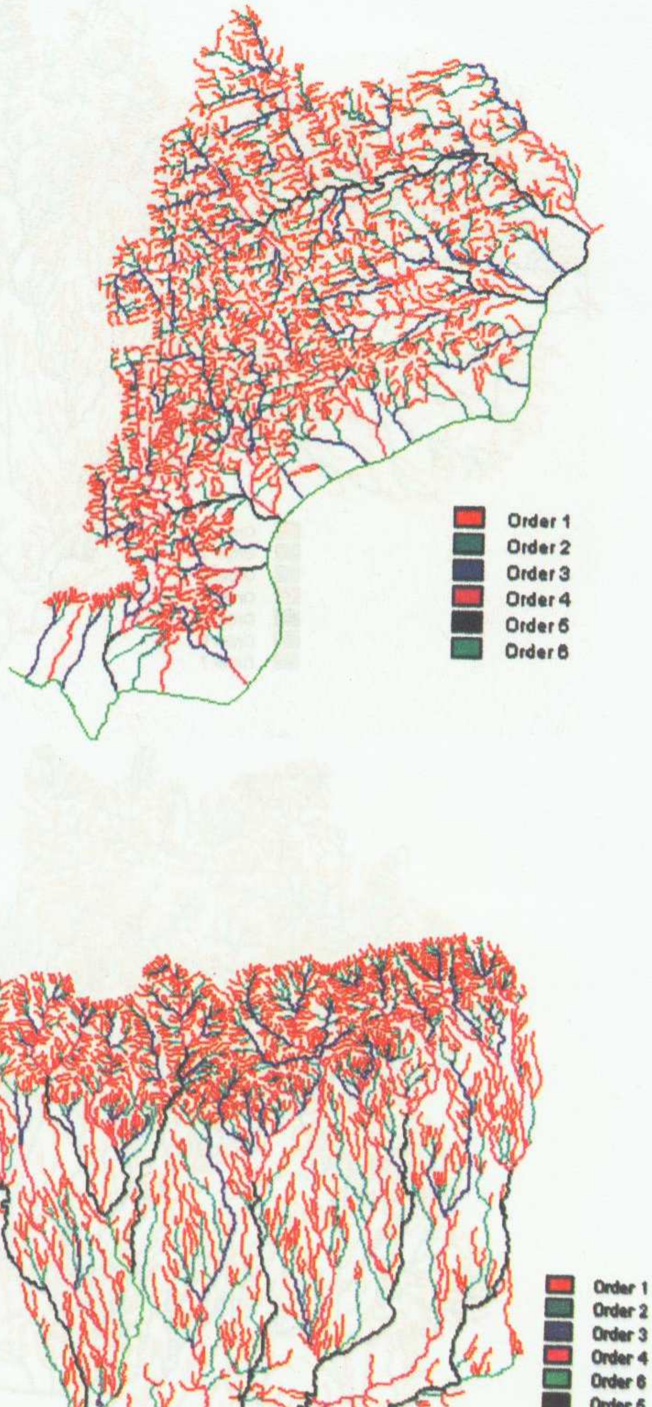


Fig. 16 Drainage network map of 5C2A1 and 5C2A3

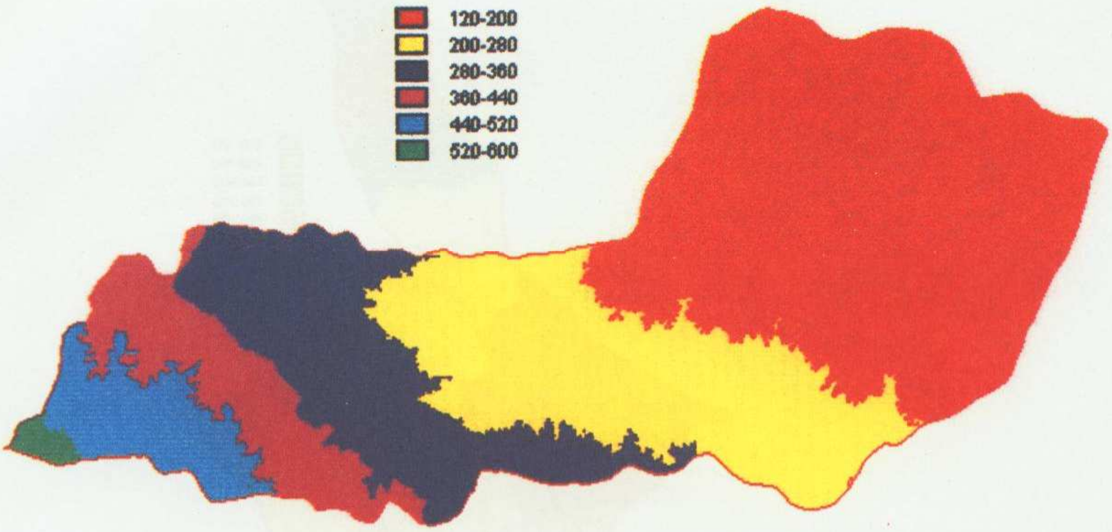


Fig. 17 Digital Elevation Map (DEM) of the watershed No. 5C3A5

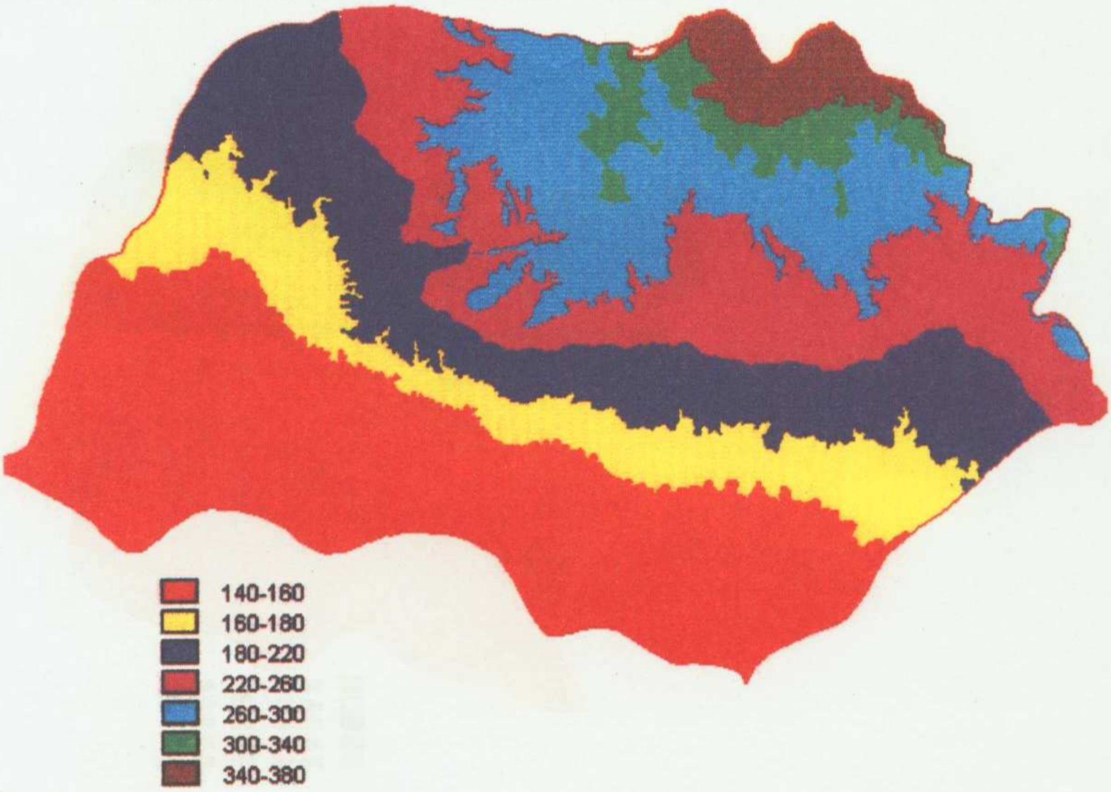


Fig. 18 Digital Elevation Map (DEM) of the watershed No. 5C2A7

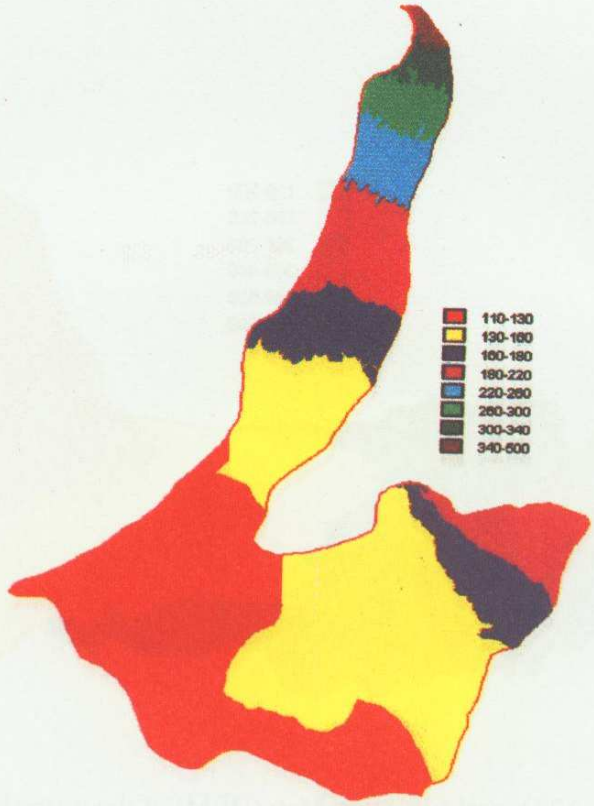


Fig. 19 Digital Elevation Map (DEM) of the watershed No. 5C3A5

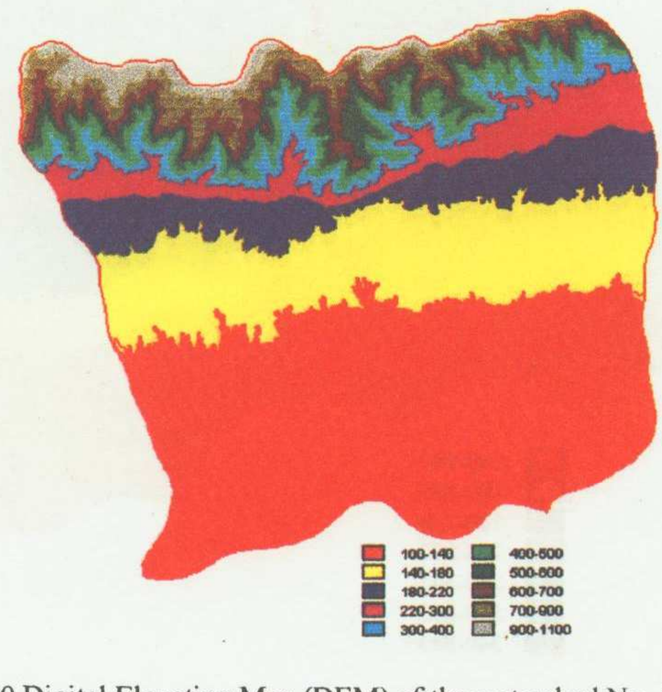
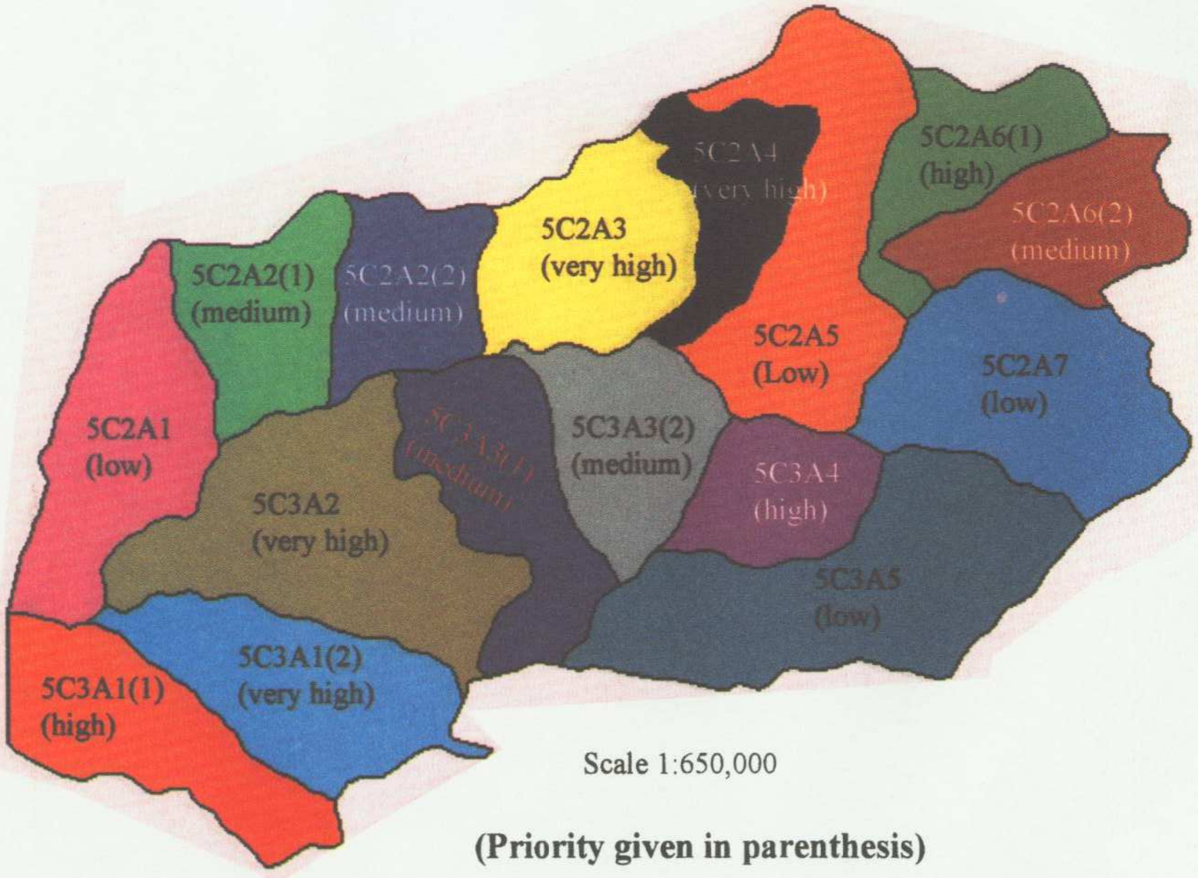


Fig. 20 Digital Elevation Map (DEM) of the watershed No. 5C2A3



Scale 1:650,000

(Priority given in parenthesis)

Fig. 21 Relative priority of different watersheds for soil conservation

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