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SEDIMENT YIELD ESTIMATION AND WATERSHED PRIORITIZATION IN SHAKKAR RIVER

NATIONAL INSTITUTE OF HYDROLOGY
JAL VIGYAN BHAWAN
ROORKEE - 247 667 (INDIA)

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ABSTRACT

Soil erosion occurs by both wind and water as agent of erosion. In humid areas water is a main cause of erosion. An area in Narmada basin namely Shakkar catchment is selected. Areal extent of the catchment is 2236 sq. Km. This lies in humid climatic region and is mainly forest covered mountainous catchment. IRS LISS I digital data are used to obtain land use and land cover map. The data are digitally processed by sequential clustering technique in PC ERDAS and themes are identified through color in GIS and classes in collateral data. Subwatersheds (89) are delineated from a report on Watershed prioritization. Areal extent of subwatersheds varies between 5077 Ha to 588 Ha. Erosion intensity mapping units (EIMU) are extracted by using GIS operations on collateral data and maps produced from remote sensing data and GIS. Various operations of map overlay, classification, reclassification are used. There are differences in EIMU extent. This is concluded based on general observation of EIMU derived here and that in collateral data. GIS operation has also been useful for extracting eroded stream bank area in northern plain region. Softwares used are PC ERDAS and ILWIS. There are 3, 50, 36 subwatersheds classified with very low, low and medium priority classes, respectively. Values of sediment yield indices for these classes are respectively 900- 1000, 1000- 1100 and 1100- 1200. Medium priority subwatersheds are located in alluvium, shale/ sandstone and basalt geology areas. In alluvium and shale/ sandstone areas of the northern plain, river bank erosion is a main cause for 'medium' priority class. 'Medium' priority areas are also located in hilly and upland areas due to higher slopes and open land class. For Other area of 'low' priority effort should be made to reduce soil loss from bare land, cultivated land and river banks. The sediment load transported at Gadarwara is estimated as 2121964 tonnes year^{-1}. The sediment yield from the catchment is 949 tonnes km^{-2} year^{-1}. This is the yield from Upper Narmada upto Jamatara.

CHAPTER 1 INTRODUCTION

Soil is eroded by the processes of detachment and transportation. The erosion is caused by agents namely wind, water, gravity etc. The soil erosion is a naturally occurring process. In deforested land, agricultural land greater soil erosion may occur than forested areas. Accelerated erosion may be a cause of concern. Ill effects of soil erosion are loss of nutrients from soil, siltation of reservoirs etc. The rate of sedimentation varies from 0.15 to 27.85 ham $10^{-2}m^{-2}year^{-1}$. Many major and medium reservoirs e.g., Sriramsagar, Nizamsagar, Matatila, Wyra etc. have lost more than 25% of their storage. The soil erosion rate varies widely for various land use and cover classes. The rate of soil erosion varies from 0 to 70 t $ha^{-1}year^{-1}$. The rate of soil erosion for forests, agriculture land, fallow land, grass and ravinous land varies respectively in ranges 0- 60, 1- 40, 4- 70, 0- 40 and 0- 20 t $ha^{-1}year^{-1}$. Soil erosion occurs at a high rate in ill managed land.

For conservation of soils schemes are sponsored by Central Government for river valley projects. To plan and implement soil conservation due to vastness of area under the projects, conservation works are need to be limited to selected watersheds only with greater erosion. For such purpose methodology has been developed by All India Soil and Land Use Survey (AISLUS), Department of Agriculture and Cooperation, Ministry of Agriculture. Under this methodology, subwatershed are identified with higher soil erosion potential.

AISLUS methodology

In this subwatershed prioritization methodology, SOI topographic maps are used coupled with field survey. This survey is called rapid reconnaissance survey. A map is prepared based on physiography, slope, land use/ cover, geology and soil. A legend is prepared for this map. Sediment delivery ratio and erosion weigtage are assigned to each mapping unit. Weight varies from 10 to 20 in increasing order for higher erosion. The sediment delivery ratio is adjusted for presence of traps in the subwatershed e.g. pond/ reservoirs etc. A sediment yield index is estimated for each mapping unit as a product of erosion weigtage and sediment yield expressed in percentage of gross erosion. Area weighted average is determined for sediment yield index for each subwatershed.

Physical variable- land use/ cover

Land use and cover map can be prepared from remotely sensing data. Remote sensing is a technique in which electromagnetic sensors acquire data of the earth and they are used to obtain useful information for an application. Digital remote sensing data are available as digital numbers (DNs). Digital numbers represent electromagnetic response of objects. A DN also depends on quantization of this response e.g. 8 bit quantization. In 8-bit, DNs are from 0 to 255.

Remote sensing data or image represents earth. Certain processing are performed on them to derive useful information. These processing are called image processing. They are performed on digital data. Example of digital image processing is clustering or unsupervised classification. This technique is described here.

Unsupervised classification: Clustering is a classification technique. In this technique, digital numbers in many spectral channels form clusters or groups in multi dimensional feature space. After partitioning of multi dimensional feature space, parameters are computed for each group. These values are used in classification of spectral data into spectral classes. The technique is also used for cleaning of training data in a supervised technique.

Other physical variable e.g. physiography, slope can be computed from a Digital Terrain Model (DTM). A DTM stores values in a grid format. The values in this digital representation are elevations. Other variables e.g. soil, geology can also be obtained from collateral data.

Watershed prioritization in ShakKar basin

Watershed prioritization is done in the Shakkar basin using rapid reconnaissance survey (Anonymous 1992). The subcatchment code for Shakkar is Nr'. Map legends are developed based on topographic maps, geology maps and ground survey. Map legends for basalt, alluvium and sand stone are given in the Table 1.1- 1.3. In the basaltic landscape, the valleys, and the upland (1-5% slope) with cultivation (class 'G1') are respectively partly bunded and well protected. In the alluvium, class 'N' is well bunded and classes 'N3' and 'N4 are unbunded. In sand stone landscape, the broad valleys are partly preserved and the stream banks are unbunded.

Sediment yield in Narmada basin: Upper Narmada

Sediment load measurements are done in Upper Narmada basin at Manot and Jamatara. Jamatara site is located 16 km downstream from Rani Avanti Bai Sagar. The reservoir was filled up in the year 1981. The suspended silt load measurement is done at Jamatara from 1972 to 1987. Due to the filling up of the Rani Avanti Bai reservoir, a lower quantity of the suspended silt load is observed since 1981-82. Discharge at Jamatara is measured from 1949 onwards. The discharge measurements at the Bargi was commenced from 1970.

The Bargi project is located at latitudes 22 56 30 and longitudes 79 55 30 across Narmada. It is 9 km from Bargi village in the district Jabalpur. Salient features of the project are given here.

Table 1.1 Mapping legend (Anonymous 1992) for basaltic landscape

EI M U	Physiography	Slope	Landuse	Soil					Erosion	Weightage	DR
				Depth	Texture	stoniness	rockyness	Gravelliness			
A	Mesa	3-10	Cultivation (Occasional)	Shallow to moderate	Fine loamy	Slight	None	None	Moderate to severe	16	.75
B	Mesa sides	>25	Moderately thick forest	-do-	Gravelly	Moderate	Moderate	Yes	Moderate	15	.8
C	-do-	10-25	-do-	shallow	Fine loamy	Moderate	None	Yes	-do-	14	.8
D	foot slopes	3-10	-do-	shallow to moderate	fine loamy associated with gravel	None	None	Yes	moderate to severe	15	.75
E	Valley	1-5	Cultivated	moderate to deep	Clay, calcareous	None	None	None	moderate	14	.8
F	Elongated hillocks	10-33	Very thin bushy vegetation	shallow	Loamy skeletal	Moderate	None	None	severe	18	.85
G	Upland	3-10	Cultivation with thin bushy vegetation	shallow to moderate	-do-	-do-	None	None	severe	16	.8
G1	Upland	1-5	Cultivated	-do-	Fine loam to clay	None	None	None	slight	12	.7
H	Upland	3-10	Grass land, waste land	-do-	Fine loam	Present	None	Slight	moderate	15	.85
M	Stream bank	3-10	Grass land and waste land with patches of cultivation	moderate to deep	Medium to fine texture	At places	None	None	severe rill and gully	20	.95

Table 1.2 Mapping legend (Anonymous 1992) for alluvial plain

EIMU	Physiography	Slope	Landuse	Soil					Erosion	Weightage	DR
				Depth	Texture	stoniness	rockyness	Gravelliness			
N	Alluvial Plain	0-3	Cultivated	Very deep	Fine calcareous	None	None	None	Slight	12	.7
N1	-do-	1-5	-do-	-do-	-do-	None	None	None	Sheet,rill and gully	18	.85
N3	Plain	1-5	Grass land with bushy vegetation	-do-	-do-	None	None	None	Severe gully	17	.85
N4	Stream bank	3-10	Cultivated with bushy vegetation at places	-do-	fine loamy to clay, calcareous	None	None	None	-do-	20	.95

Table 1.3 Mapping legend (Anonymous 1992) for sand stone quartzite landscape

EI MU	Physiography	Slope	Landuse	Soil					Erosion	Weightage	DR
				Depth	Texture	stoniness	rockyness	Gravellin ess			
P	Hill top	3-10	Bushy vegetation and grass land	Very shallow to shallow	Coarse to fine loamy	Moderate	Moderate	Moderate	Severe	13	.75
Q	Side slopes	5-15	Moderately thick bushy vegetation	Shallow	-do-	None	Moderate	None	Moderate to severe	14	.75
Q1	Escarpments	10-33	Thin to moderately thick forest	Very shallow to shallow	loamy fragmental	Moderate	Severe	None	Severe	12	.8
R1	Foot slopes	3-10	Moderately thick forest	Shallow to moderately deep	fine	Moderate	None	Moderate	Moderate to severe	15	.75
R2	Lower foot slopes	3-5	Cultivated with thin bushy vegetation at places (20%)	Deep to very deep	fine loamy to fine	None	None	Slight	Moderate	15	.75
R3	Broad valley	1-5	Intensively cultivated	Very deep	fine loamy	None	None	None	Slight to moderate	13	.7
R4	Stream banks	3-5	Grassland and waste land with thin patches of cultivation at places	-do-	coarse to fine loamy	none	none	none	severe	19	.9

Gross storage	3.92 lakh ha m
Live storage	3.18 lakh ha m
Catchment area	14556 sq. km
Catchment area upto Jamatara	16576 sq. km
Peak flood	45296 cumec
Actual flood (9.7.71)	11876 cumec
FRL	422.76 m
Water spread (FRL)	27297 ha
Water spread (Dead storage)	4750 ha
Total length of dam	5374.39 m
Av. annual rainfall upto Jamatara	1284 mm
Av. discharge up to Jamatara (years 1949- 1979)	7.191 Bm^3
Average suspended load (June- November)	13663441 tonnes
Average suspended load (December- May)	8228 tonnes
Average annual suspended load	13671670 tonnes
Average annual total sediment load	15722420 tonnes
Total silt load (suspended bed)	949 t $year^{-1}$ km^{-2}

From the data at Jamatara (Table 1.1) (Anonymous 1990) a suspended load/ rainfall verses runoff/ rainfall regression relationship is obtained (Eq. 1.1). The correlation coefficient between the variables is 0.85. The variables (Table 1.2) are plotted in the Fig. 1.1. The regression equation (Eq. 1.1) is used to extend the suspended sediment load data up to the year 1985- 86. The measured and estimated suspended sediment data are used to find average value. The average value (the measured data) differs by 2.8% from the above average. Silt load is measured in three fractions at the measurement site namely coarse, medium and fine (respectively >0.2, 0.2- 0.075 and <.075 mm). Bed load is assumed to be 15% of the suspended sediment load.

$S/P = -0.44 + 16.23\ R/P$ (Eq. 1.1)

Where S is suspended sediment load during June to November in tonnes

P is annual rainfall in ha m

R is annual runoff in ha m

The sediment load as estimated above at Jamatara can be used for design purpose in the Narmada basin at other sites.

Table 1.1 Rainfall, Runoff and suspended sediment load at Jamatara, Narmada basin

			Monsoon		Non-monsoon
Year	P mm	R cumecday	S tonnes	Measured/ Estimated S tonnes	S tonnes
1972-73	1033.6	101508	11704381	11704381	21741
1973-74	1595.7	150661	22990240	22990240	4446
1974-75	1090.6	68281	9231801	9231801	1960
1975-76	1569.7	153590	22411504	22411504	2403
1976-77	975.9	57758	6208891	6208891	1119
1977-78	1346.3	135274	17690590	17690590	15592
1978-79	1179.2	97689	8192145	8192145	38217
1979-80	855.3	34588	5751198	5751198	556
1980-81	1368.3	148685	22208052	22208052	1827
1981-82	1096	53689		6731150	1031
1982-83	1062.5	80880		10568557	457
1983-84	1292.7	123499		16377517	4069
1984-85	1208.9	125021		16651943	13389
1985-86	1193.3	110095		14570207	12108
1986-87					4512
Average			14043200.22	13663441	8228
% difference			2.8		

Table 1.2 R/P vs S/P regression variables at Jamatara, Narmada basin

Year	P ham	R ham	R/P	Monsoon S tonnes	S/P
1972-73	1713295	877029	0.51	11704381	6.83
1973-74	2645032	1301711	0.49	22990240	8.69
1974-75	1807779	589948	0.33	9231801	5.11
1975-76	2601935	1327018	0.51	22411504	8.61
1976-77	1617652	499029	0.31	6208891	3.84
1977-78	2231627	1168767	0.52	17690590	7.93
1978-79	1954642	844033	0.43	8192145	4.19
1979-80	1417745	298840	0.21	5751198	4.06
1980-81	2268094	1284638	0.57	22208052	9.79

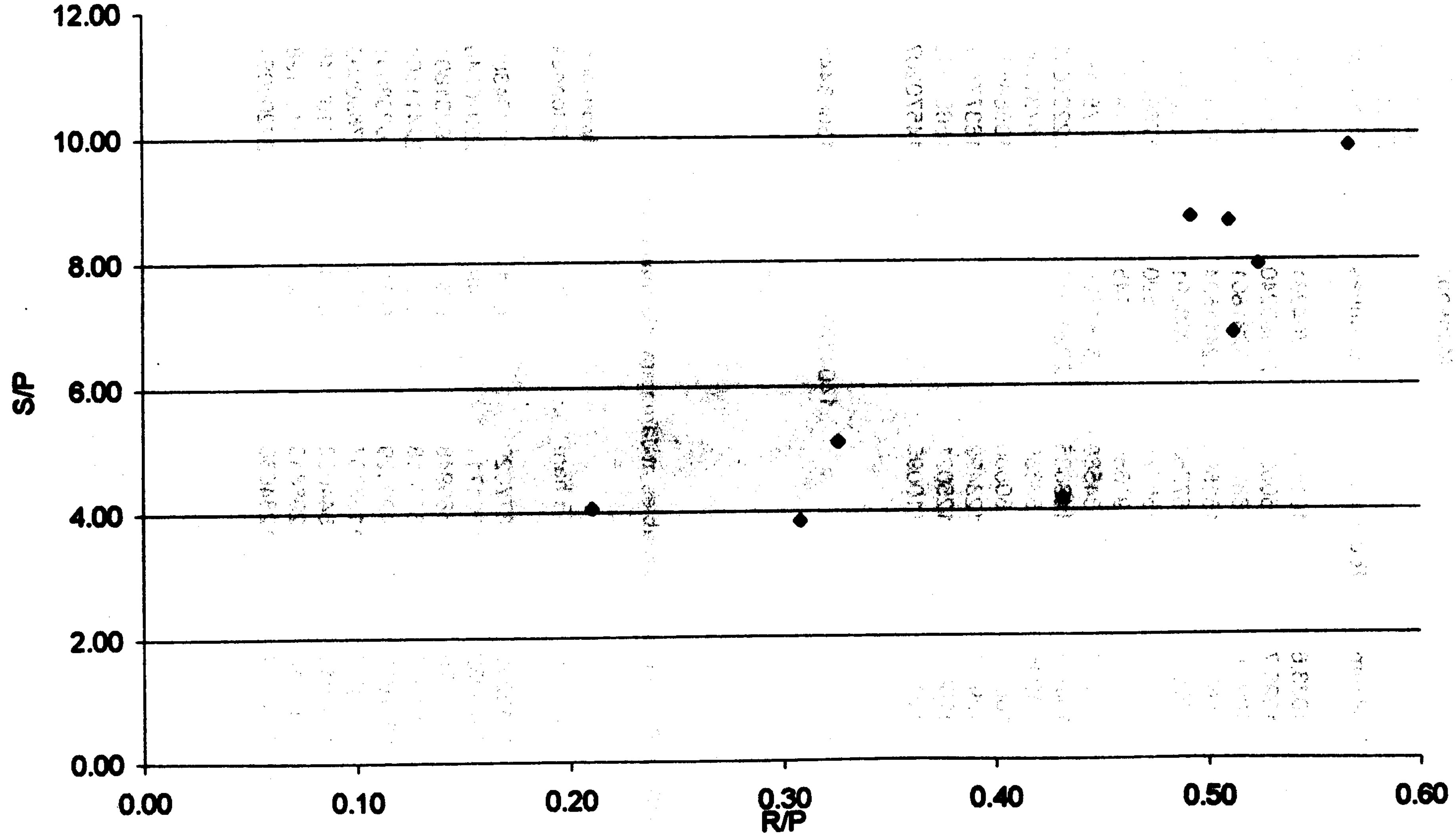

Fig. 1.1 Sediment/ Rainfall Vs Runoff/ Rainfall plot at Jamatara, Narmada basin

CHAPTER 2 LITERATURE REVIEW

Prioritization in a river valley project of Mahanadi river is carried out. Extent of study area is 7333 sq. Km. It covers two sub catchments of major tributaries of Mahanadi in States of Madhya Pradesh (Raigarh and Sarguja districts), Orissa (Sambalpur and Sundargarh districts) and Bihar (Ranchi district). Climate is tropical monsoons. Mean annual rainfall at Raigarh is 1494 mm. Area has mainly quartzite, sandstone, granite and gniess lithology. Main physiography has gently sloping plains with few local undulations. Soils are widely varying e.g. very shallow, very deep etc. On hill-slopes soils are very shallow to shallow. Texture is coarse to fine. Area of sub watersheds ranges from 10 to 59 sq. km. Mid upland plain in the basin is under rice cultivation. Rice cultivation area are bunded. There is insignificant erosion from rice fields and rocky areas (Biswal and others 1989).

A watershed priority delineation survey is done in Masani Barrage catchment of Sahibi river valley project using remote sensing based approach. The area is located in Alwar and Jaipur districts of Rajasthan and Mahendragarh district of Harayana. Major part of the basin is under agriculture and very deep alluvial and aeolian soils. Other land use categories are scrub, grass, ravine and forests. There is small part of the basin under skeletal soil. The mean annual rainfall and mean annual temperature are respectively 621 mm and 24.7 C. Data used are Landsat MSS FCC of October and February at 1:250000 scale, black and white aerial photographs for small area. Priority delineation reports are also used that used conventional approach. Erosion intensity mapping units are delineated using interpretation of satellite data. A interpretation key is developed to facilitate interpretation. Other estimations are similar to that of AISLUS methodology for priority delineation using rapid reconnaissance survey except that averages are determined at the watershed level than the subwatershed level in later method. There are 27 watersheds in the catchment of area 4838 sq. km. Due to the difference in the scale of the mapping high priority watersheds have increased in number. The difference in scale, limits more details to be mapped in remotely sensed data based approach (Shanware and others 1989).

CHAPTER 3 STUDY AREA

Shakkar river is a left bank tributary of Narmada river. Main town near its confluence with Narmada is Gadarwara. Area is studied upto Gadarwara. Total area of the basin is 2292 sq. km. The area of the basin studied is 2236 sq. km in extent. Length of the river is 161 km. The elevation ranges from 320 m to 1140 m above MSL. Maximum elevation lies in Chitarewa sub basin. There are two main tributaries of the river namely Chitarewa and Hard (Fig 3.1). River flows in Satpura range. Mean annual rainfall ranges from approximately 1600 mm to 1200 mm. Mean annual rainfall is higher on western side. Mean annual temperature at Jabalpur and Bhopal are respectively 24.4 and 24.9 C. Soils are 'mixed red and black clay' and 'deep black clay' in respectively upper and lower catchments. Upper catchment soils are associations of alfisols and vertisols. Lower catchment soils are vertisols. Wheat and millet are grown in upper catchment (Dutta G.K. et al., 1987, Kundu A.K., 1989). Revenue districts in the catchment are Narsinghpur and Chhindwara. Upper catchment lies in Chhindwara (south west catchment) and Amarwara Tehsils of Chhindwara district. Lower catchment lies in Gadarwara Tehsil of Narsinghpur district. Main towns are Gadarwara, Chichli and Harrai.

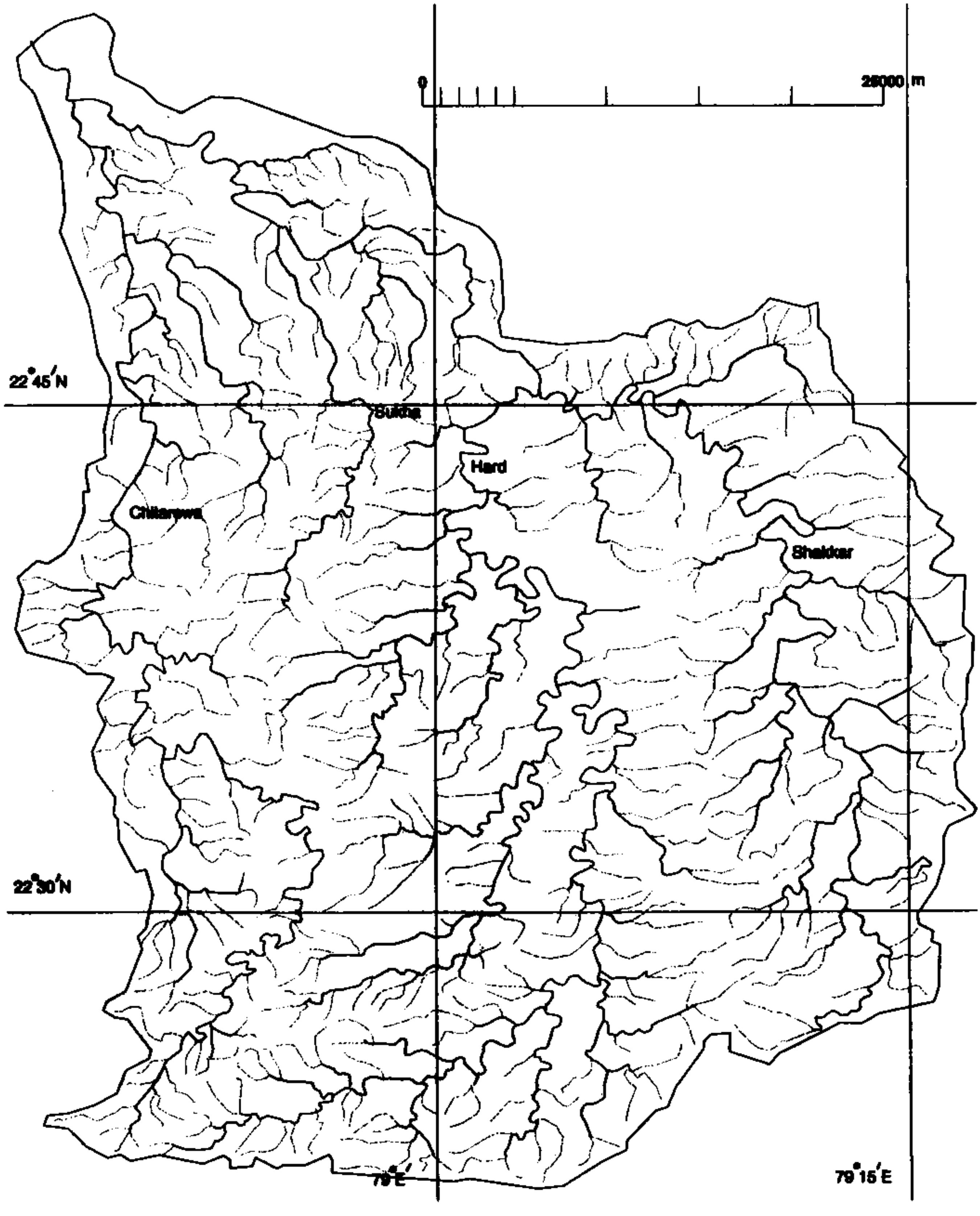

Fig. 3.1 Study area

CHAPTER 4 STATEMENT OF PROBLEM

Soil erosion by water is accelerated due to deforestation, improper agricultural practices etc. Large erosion due to water occurs in region of high rainfall. Many parts in Narmada basin receive high rainfall amounts. A catchment namely Shakkar catchment in the Narmada basin is selected. This is a mountainous forest catchment. Many land use and cover and physiography classes occur in the catchment. This renders analysis of these data for prioritization of watersheds difficult.

Studies in the Narmada basin has been completed by All India Soil and Land Use Survey (AISLUS) Organization. In this approach physiography, soil, landuse, slope, slope lengths, drainage, geology, delivery ratio are derived and rapid reconnaissance (R/R) surveys is done to prioritize watersheds. This approach is manual. In a manual approach error will occur in the delineation of slope classes. In deriving slope classes from digital method namely utilizing digital elevation model (DEM), there is less likelihood of error is this delineation. For the land use and cover classes, the remotely sensed data will provide up-to-date maps. The land use maps, thus prepared, will be more useful in delineating erosion intensity mapping units in the subwatersheds. Digital technique will be faster than the manual technique. Thus, there is need for using GIS based approach and integrating it with remote sensing.

Remotely sensed data provide land use and cover information. Remote sensing is defined as a science of obtaining information about earth surface from electromagnetic radiation sensors. Thus, remote sensing data provide information about land use and cover easily. This information is extracted from the data by applying image processing and interpretation techniques. Digital image processing approach is selected here, since land use and cover information may be obtain easily with this approach.

Collateral data will be used to create maps within GIS for other physical variables needed in prioritization. These will be analysed in GIS to create composite maps. The procedure developed, thus, will be useful in other catchments and also provide a new prioritization based on digital approach for this catchment.

CHAPTER 5 DATA AND METHODOLOGY

5.1 DATA USED

Digital satellite data of IRS LISS 1 sensor is available for date 13.04.89 and scene 26-52. Other than this, IRS LISS-2 FCC at 1:250000 scale are also available before and after monsoon around the same period as the digital data. The study area is covered in topographic maps 55 J/13,14,15 and 55 N/1,2,3,6,7. A watershed prioritization report prepared by AISLUS, Nagpur Regional Centre (Anonymous 1992) is also available for the study area.

5.2 METHODOLOGY

A methodology for watershed prioritization is developed by AISLUS. This methodology is selected here. Both remote sensing and GIS are used for data input and analysis instead of only topographic maps, collateral data and rapid reconnaissance survey as envisaged in AISLUS methodology. Total sediment yield from the catchment is estimated using sediment yield at another catchment in the Narmada basin.

5.2.1 DATA PREPARATION

The preparation of the input data is briefly described here. Details of the map projection for the geographic data are as follows:

Map projection	polyconic
Central meridian	79 E
Geoid	Everest (India 1956)
False Easting	500000 m
False northings	0 m

Watershed boundary

Watershed boundary is delineated using SOI topographic maps at scale of 1:250000 scale. Watershed boundaries are digitized in ILWIS. This map is used in masking image outside the study area in the rectified satellite data.

Subwatersheds

Subwatersheds are digitized in ILWIS from watershed prioritization maps prepared by AISLUS (Anonymous 1992) (Fig 5.1). There are 89 subwatersheds delineated. Area of subwatersheds varies from 588 ha (nr'4a) to 5077 ha (nr'7d).

Landuse and cover

Land use and cover map is prepared from digital classification of remotely sensed data (Fig 5.2). Satellite data are geometrically rectified. From the rectified image, study area is extracted. The pixel size in the rectified satellite image is 100 m X 100 m. This is completed in ILWIS. This image is digitally classified using sequential clustering in PC ERDAS 7.5 software.

Sequential clustering

Satellite data are clustered using sequential clustering technique. Default parameters are selected in the clustering, except X and Y skip factor. The value of X and Y skip factors are selected both equal to 5. The cluster classes are identified by observing the color of the display and using topographic maps. In this classification, percentage area for agriculture, forest, sand, open land (wasteland/ grass) are respectively 20.3, 55.0, 0.3, 22.3. An area approximately equal to 2.1 % remained unclassified.

There are total 23 cluster obtained in sequential clustering. Out of these, number of clusters with agriculture, forest, sand and open classes are respectively 4, 7, 2 and 1. The remaining clusters (9) are unclassified. The unclassified classes are mainly obtained due to the reason that they are difficult to be identified due to their small extent. On satellite FCC of LISS II sensor it was observed that many forest areas are black in color in pre monsoon image and red with smooth texture in post monsoon image. Pink and red signatures are also observed for forest classes in the GIS display. This class is observed in Chiterewa basin and in northern plain area of the basin. Agriculture area has white and cyan signature. Open land (waste land and grass) class has green signature. River sand has bluish white signature.

Digital Elevation model (DEM)

Contour lines are digitized from topographic maps at an scale of 1:250000. From topographic maps of 1:50000 scale, few contours are also digitized in flat areas. Spot heights are also digitized. From these height data, contour interpolation is completed in ILWIS. From DEM thus generated (Fig 5.3) a slope map is prepared in ILWIS using standard X and Y gradient filters and a standard formula. This slope map is exported to ERDAS for further processing. The slope map is classified in ERDAS to percentage slope classes 0-3, 3-5, 5-10, 10-15, 15-25, more than 25 (Fig 5.4).

Geology map

Geology map is obtained from collateral data. The scale of the input map is 1:6000000. The map is digitized in ILWIS. Stream network shown on the geology map is also digitized. This is used as control for registering the geology map with other maps. The pixel size of the rectified map is 100 m X 100 m (Fig 5.5).

Drainage map

Drainage map is digitized from 1:250000 scale topographic map in ILWIS. Streams of 2nd and higher order are extracted for further analysis. Also, based on AISLUS maps of erosion intensity mapping units (EIMU) stream reach where 'gullied and severely eroded stream banks' (EIMU: 'M', 'R4') occur are identified.

5.2.2 ANALYSIS

Sediment yield estimation

The sediment yield estimation in the basin is done based on sediment yield in the Upper Narmada basin. Both the basin lies in the physiographic province- Satpura range. Thus, sediment yield may be assumed to be same from the basins. The sediment yield may be calculated as follows:

Total sediment yield at Jamatara, Upper Narmada	949 tonnes km^{-2} $year^{-1}$
Av. annual sediment load transported at Gadarwara, Shakkar	949 * 2236 = 2121964 tonnes $year^{-1}$

Prioritization

<u>Mesa and hill top</u>

A composite class of Mesa top/ hill and slope higher than 10 % classes are separated by digitizing map in ILWIS. The background map namely map with slope > 10% is used for digitizing.

<u>Valley (EIMU- 'E' and 'R3')</u>

These classes are delineated in GIS by running 'search' operation of equal to 3 pixels from stream map of order 2nd or higher. This map is recoded. The width of the class is 7 pixels or 700 m.

<u>Stream bank (EIMU- 'M' and 'R4')</u>

This class is generated by running 'search' operation from a specially prepared map from the drainage map and EIMU 'M' and 'R4' (Anonymous 1992) during data preparation. The search operation is run for 2 pixels creating width of output map equal to 5 pixels or 500 m. This map is recoded.

<u>Foothill (EIMU- 'D' and; 'R1' or 'R2')</u>

This map is created by running 'search' operation for 6 pixels creating a width of 600 m. This map is recoded. The search operation is run for union of maps for mesa top or hill and map with slope greater than 10 %. The union of maps is generated by map overlay operation.

EIMU map

EIMU map is created from map overlay operation. The sequence of maps in the overlay operation is namely % slope classes 10- 15, 15- 25 or more than 25, mesa or hill top map, eroded stream bank map, valley map, foothill map. In 2nd overlay operation this map is crossed with geology map to create EIMU based on geology. The 'unclassified' units in the first operations are assigned values of the geology classes instead. In another overlay operation, these 'unclassified' units are assigned EIMU values. This is done by overlaying EIMU map, slope map and land use and cover map. The map overlay criteria are given in Table 5.1.

Yield index

For each EIMU, values for weight and delivery ratio are available (Anonymous 1992). A product of weight and delivery ratio is multiplied with 100 to obtain yield index value for each EIMU. From the above product, yield indices map is generated using GIS operation of map reclassification. A mean value of yield index for each subwatershed is determined in ERDAS. These mean values are used in prioritization of the subwatersheds. Value of sediment yield indices varies from 1144 (nr'6j) to 985 (nr'3k) for subwatersheds (Table 5.2).

Priority map

Priority map is computed using map reclassification operation in GIS. This is based on mean yield index values for subwatersheds. The yield indices 900- 1000, 1000- 1100 and 1100-1200 are assigned very low, low and high priorities respectively (Fig. 5.6). There are respectively 3, 50 and 36 subwatersheds in these classes. Yield indices for subwatersheds are area weighted sum of yield indices for EIMUs in a subwatershed. For an EIMU the yield index is computed as 100 times the multiple of a weight and a delivery ratio. The weight signifying soil erosion is assigned values from 10 to 20 for the increasing order of soil erosion susceptibility of an EIMU. The value 10 signifies that no soil erosion is occurring in the EIMU.

Improvement in sediment yield index method

A remote sensing and GIS based method is developed here for generating EIMU in the 'sediment yield index' method. A map overlay criteria, simplified from the original map legend is used here. There are many advantages in the remote sensing and GIS based approach. They are given here.

1. Various maps can be easily overlaid in a GIS.

2. Physiographic units e.g. hill top, hill side slopes, escarpments, mesa, mesa side slopes, foot hill, valley, stream banks are easily delineated using GIS. Except mesa and hill top all other classes are generated automatically.
3. Land use map is obtained from remotely sensed data and is used in generating EIMU. Thus, recent land use map is used in these maps.
4. Stream banks with severe erosion in the alluvial plain are easily identified from remotely sensed data directly.
5. The computations for the priority delineation are done in the GIS. Thus, cumbersome manual calculations are eliminated.

Table 5.1 Map Overlay criteria

EIMU	Physiography	Slope (%)	Landuse
Basalt landscape			
A	Mesa	0-10	All
B	Mesa sides	>25	All
C	-do-	10-25	All
D	foot slopes	0-10	All
E	Valley	0-10	All
G	Upland	3-10	Agriculture
G1	Upland	0-3	All
H	Upland	3-10	Non-agriculture
M	Stream bank	0-10	All
Alluvial plain			
N	Alluvial Plain	All	Non forest
N4	Stream bank	All	Forest (gully erosion)
Sand stone quartzite landscape			
P	Hill top	0-10	All
Q	Side slopes	10—15	All
Q1	Escarpments	>15	All
R1	Foot slopes	0-10	All
R2	Lower foot slope	3-10	Non- forest
R3	Broad valley	0-3	Non-forest
R4	Stream banks	0-3	Forest

Table 5.2 Sediment yield index

Subwater- -shed	Yield index	Subwater- -shed	Yield index
nr'6j	1144	nr'7g	1089
nr'6t	1143	nr'7f	1089
nr'6y	1143	nr'7j	1087
nr'3y	1141	nr'7b	1086
nr'6h	1139	nr'3j	1085
nr'6r	1139	nr'7h	1084
nr'6a	1137	nr'7k	1082
nr'6z	1137	nr'6c	1082
nr'6k	1136	nr'7d	1081
nr'6n	1135	nr'4r	1080
nr'6q	1134	nr'4q	1080
nr'7t	1131	nr'6m	1080
nr'7w	1129	nr'5a	1080
nr'6v	1129	nr'6w	1078
nr'3x	1128	nr'4f	1077
nr'6x	1128	nr'4d	1077
nr'5j	1127	nr'3s	1076
nr'7a	1126	nr'4g	1074
nr'3w	1126	nr'6g	1069
nr'3t	1125	nr'7n	1067
nr'5f	1123	nr'7p	1066
nr'3u	1121	nr'3b	1066
nr'5b	1120	nr'5p	1065
nr'5n	1119	nr'6s	1063
nr'5g	1115	nr'6u	1061
nr'6p	1111	nr'5m	1060
nr'6f	1110	nr'4n	1060
nr'6b	1110	nr'4p	1059
nr'7m	1109	nr'3d	1059
nr'7c	1108	nr'3c	1058
nr'7v	1108	nr'7r	1058
nr'4a	1107	nr'3h	1055
nr'5d	1105	nr'3a	1046
nr'4h	1104	nr'4m	1043
nr'7s	1104	nr'3o	1038
nr'7u	1103	nr'3p	1036
nr'7q	1099	nr'4c	1027
nr'5c	1099	nr'3r	1022
nr'6d	1099	nr'3f	1020
nr'5h	1095	nr'3q	1015
nr'5k	1095	nr'3m	1003
nr'4b	1094	nr'3g	999
nr'3v	1094	nr'3n	995
nr'4k	1092	nr'3k	985
nr'7x	1090		

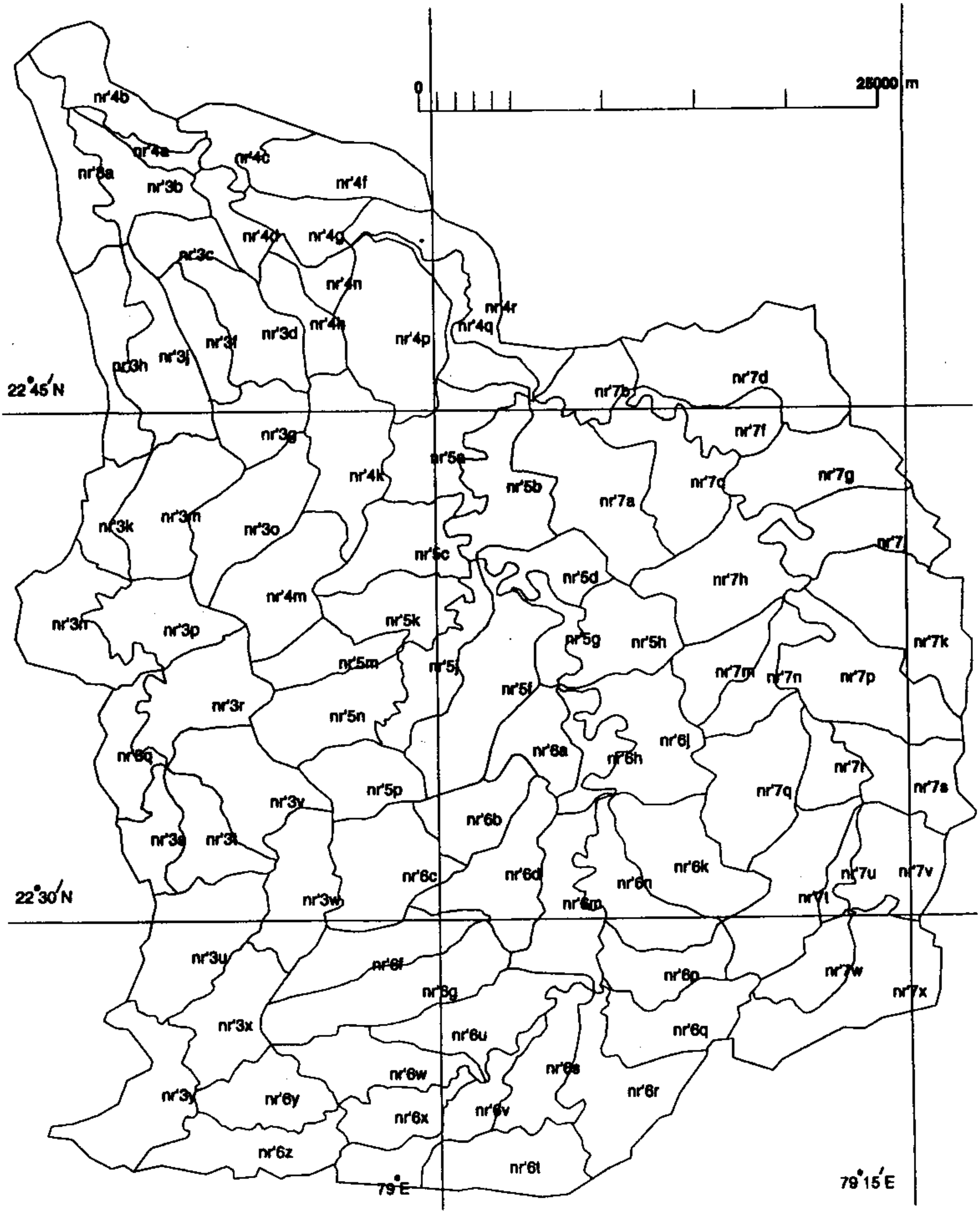

Fig. 5.1 Subwatersheds

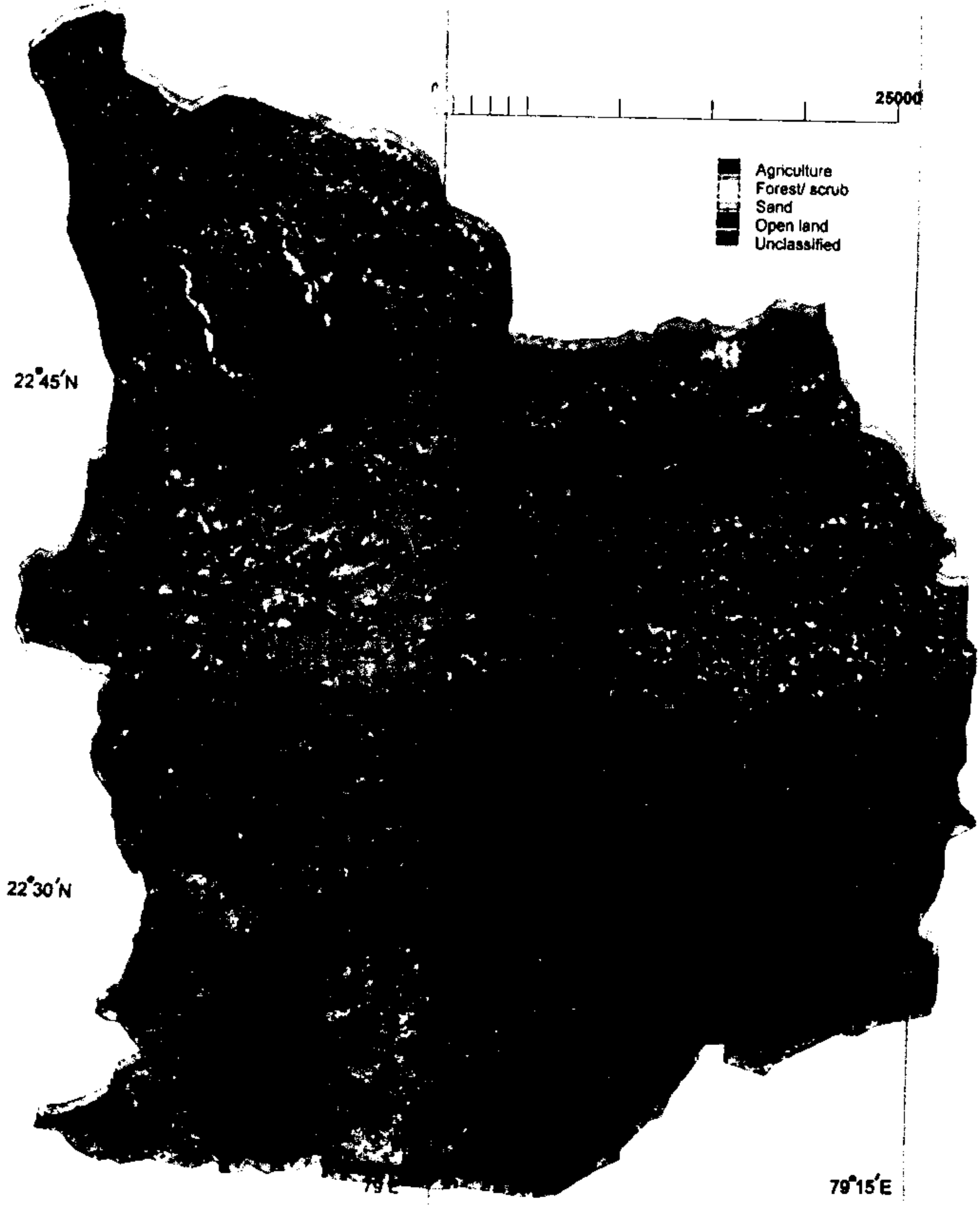

Fig. 5.2 Land use

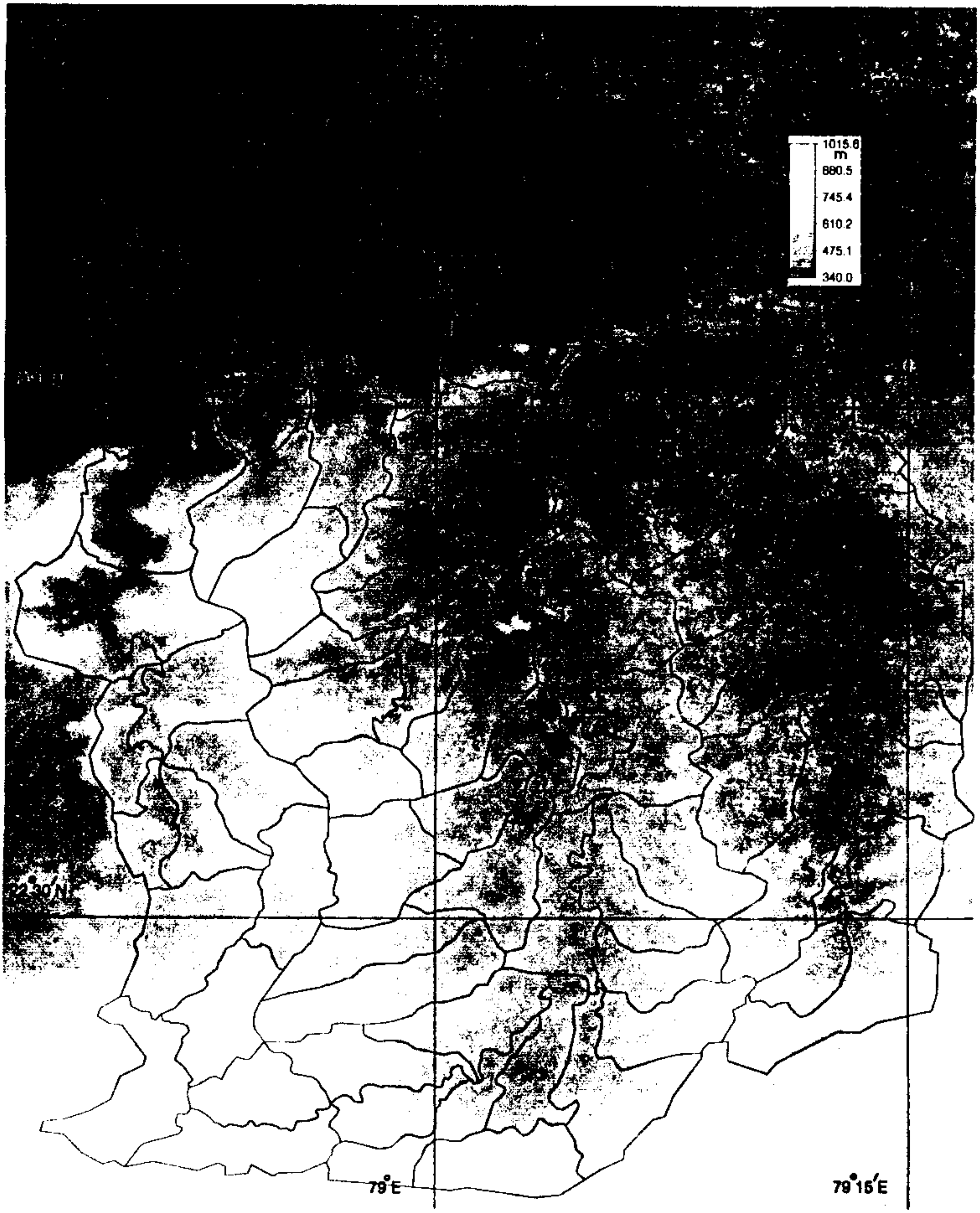

Fig. 5.3 DEM

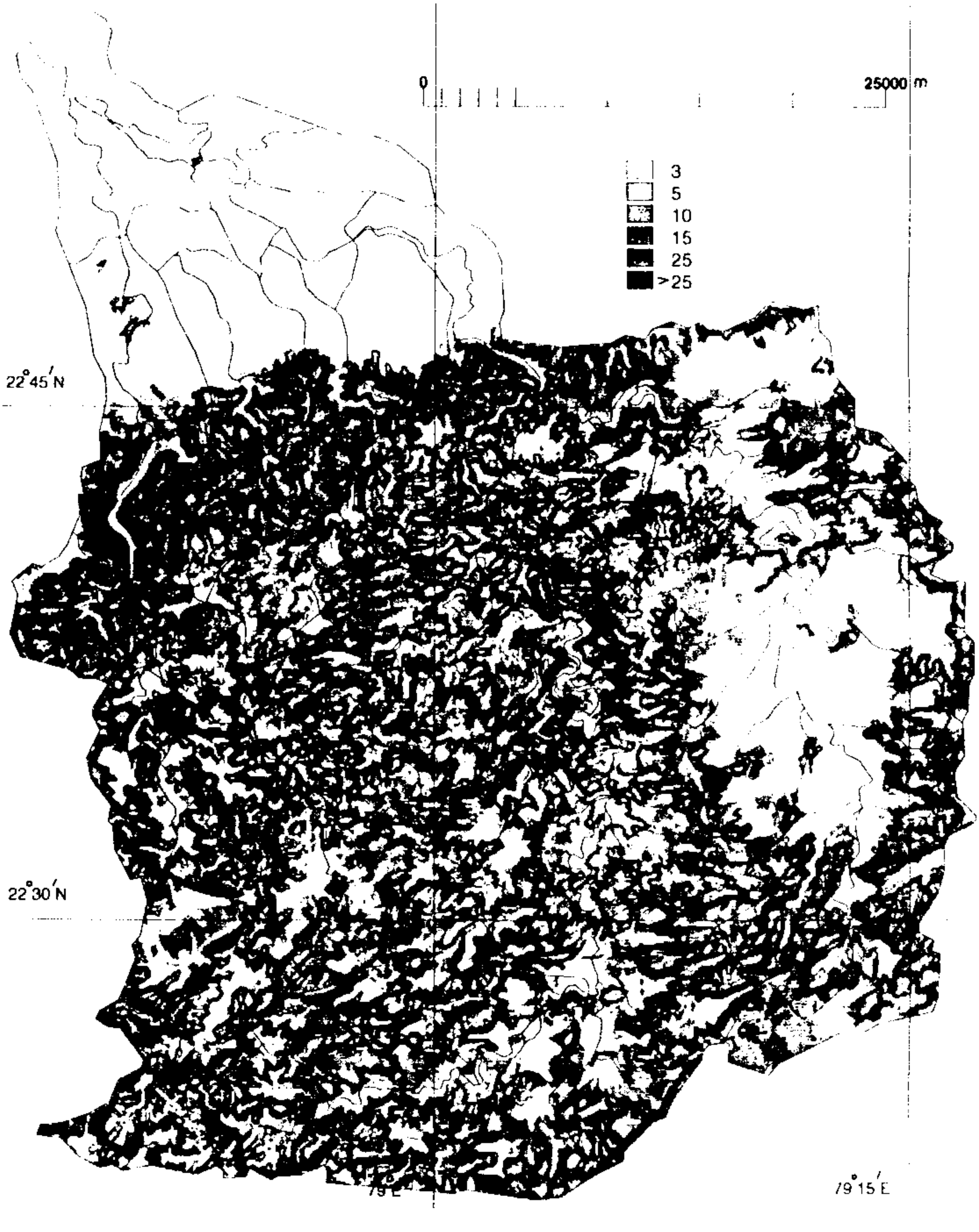

Fig. 5.4 Slope classes (%)

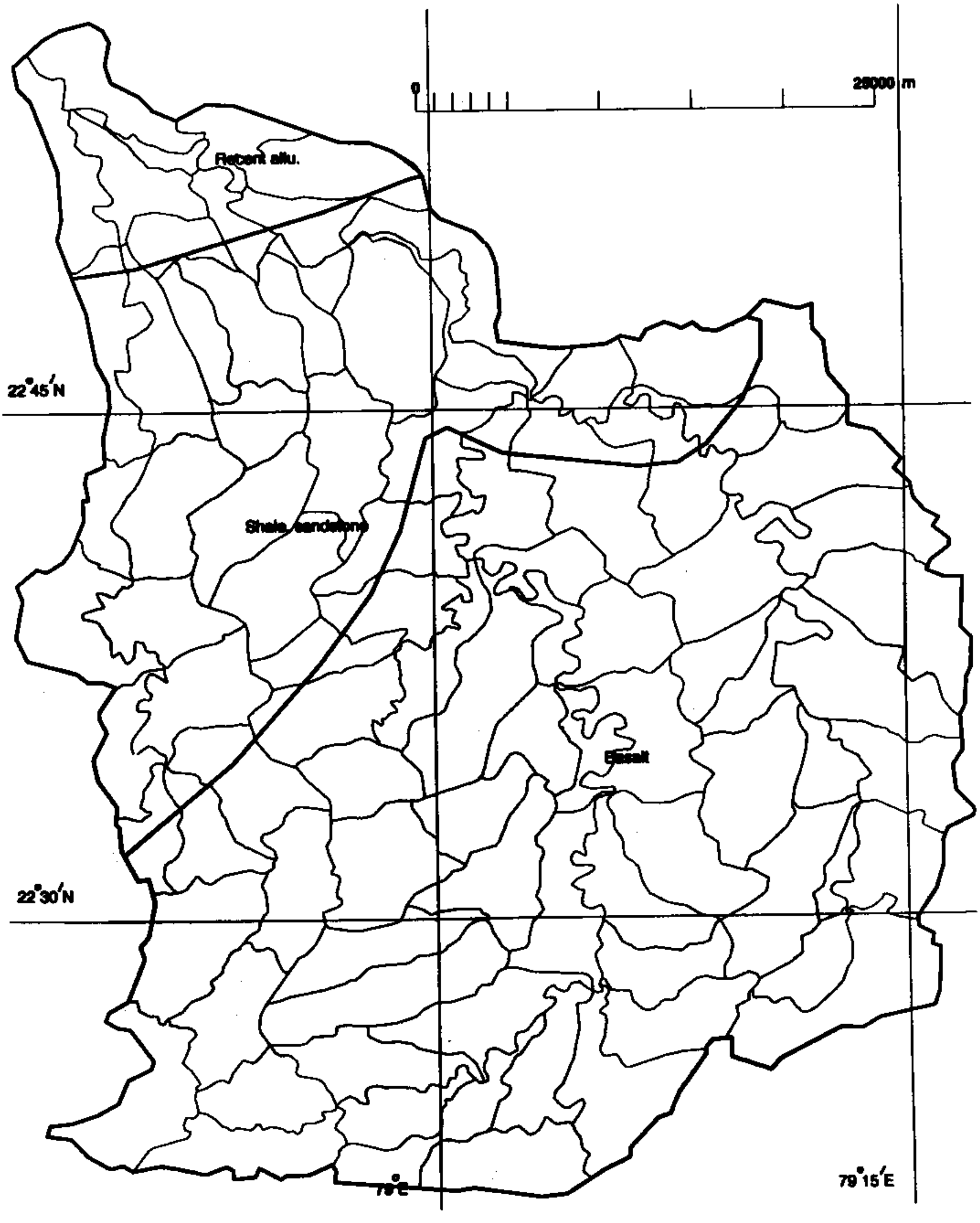

Fig. 5.5 Geology

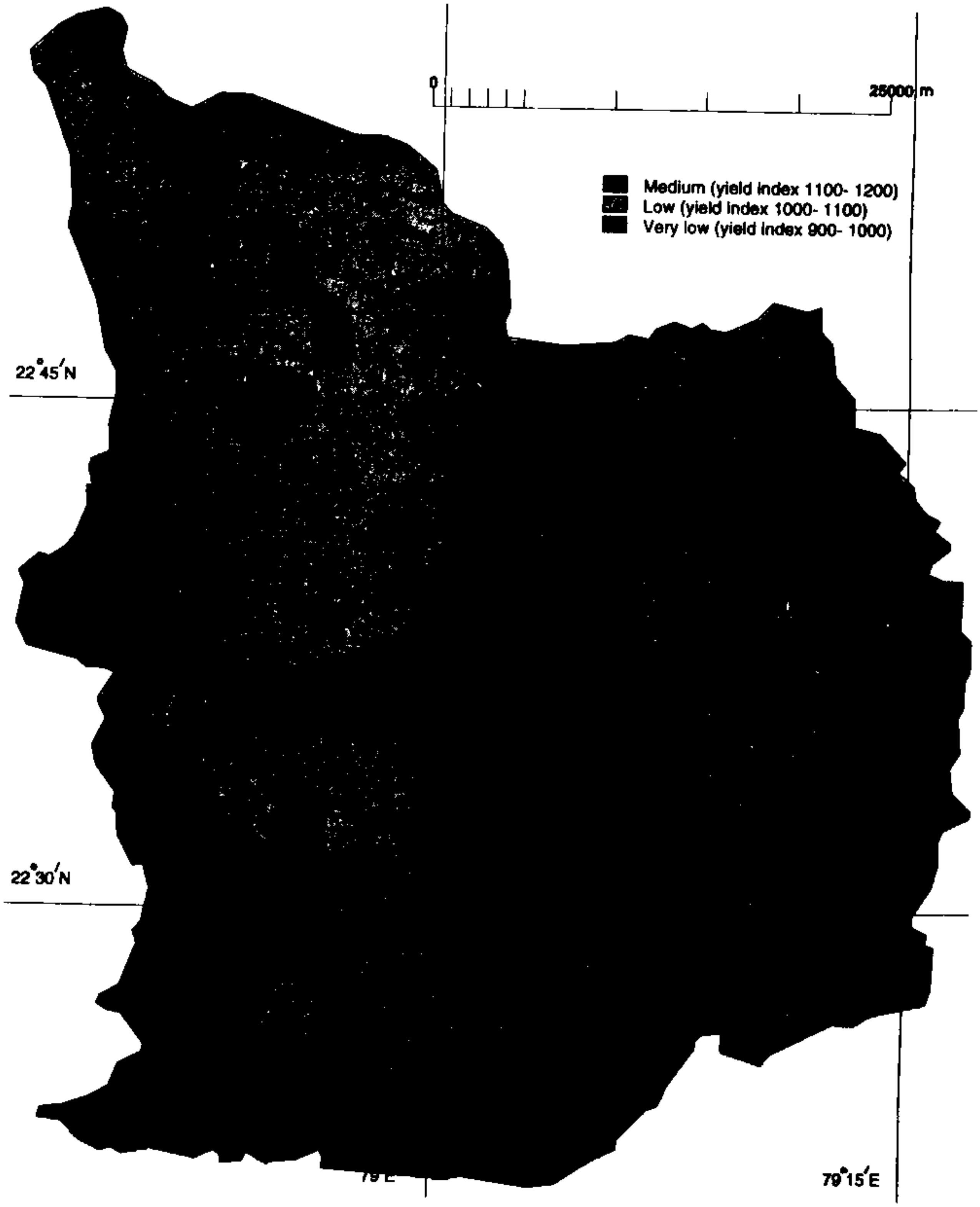

Fig. 5.6 Subwatersheds priority

CHAPTER 6 RESULTS

Landuse and cover

The catchment is predominantly forest catchment. The land use and cover map is prepared from satellite data of a pre monsoon date. Thus, it is difficult to identify crop area, since satellite data do not coincide with crop calendar. Further, agriculture area is also misclassified as scrub class (based on toposheets information). Scrub area is also misclassified as forests. This may be due to differences in classes or similar spectral signatures. On topographic map also the catchment is seen as predominantly forest catchment. The gully land adjacent to stream in northern plain area in the catchment has forest and scrub land cover. This is classified well and thus could be utilised in prioritization of subwatersheds. Direct identification of gully erosion is difficult in digital classification attempted here. However, through GIS analysis such area could be identified.

Sediment yield

Sediment yield at Jamatara, Upper Narmada basin and Gadarwara, Shakkar catchment are assumed to be equal. From this rate, the annual sediment load transported at Gadarwara by the Shakkar river is 2121964 tonnes $year^{-1}$. The sediment yield at Jamatara is high. It is due to high erodibility of Deccan Trap weathered rocks, gully erosion at the river banks, rill erosion on foot hills etc. The Shakkar basin also predominantly has Deccan Trap formation. Thus, high sediment yield is resulted here.

Prioritization

The watershed prioritization map reveals that subwatershed of Chitarewa catchment in shale and sandstone geology has low and very low priority. This is mainly due to thin soil cover assumed is assigning weight, that signifies low erosion potential. Basalt landscape in upper catchment and high relief areas has medium priority. In alluvium and shale/ sandstone increase in priority in subwatersheds is due to highly eroded stream bank.

These results are based on weights and delivery ratio values taken from Anonymous (1992) developed at AISLUS. The priority determined here may differ from that arrived in this report. This will be due to differences in EIMU delineated from GIS and remote sensing approach and those delineated in Anonymous (1992).

CHAPTER 7 CONCLUSIONS

1. Total average sediment load transported at Gadarwara is 2121964 tonnes $year^{-1}$. high sediment yield is due to predominantly Deccan Trap lithology and hill physiography is the catchment. The sediment yield is 949 tonnes km^{-2} $year^{-1}$.

2. There are respectively 3, 50 and 36 subwatersheds in very low, low and medium priority classes. These classes respectively possess yield indices 900- 1000, 1000- 1100 and 1100-1200. The medium priority classes occur in the alluvium, shale/ sandstone and basalt geology regions. In northern plain region with alluvium, shale/ sandstone geology, river bank erosion is more predominant. In the hilly terrain in the central and southern part of the catchment, 'medium' priority subwatersheds occur due to the occurrence of higher slope classes and open land. In 'low' priority areas soil conservation should be done in agriculture areas, open land and at the river banks to bring this class to 'very low' priority.

3. Shakkar catchment has in general 'low' priority subwatersheds. There are also significant number of subwatersheds with 'moderate' priority. Thus, there will be need for erosion control measures in the catchment.

4. A procedure is successfully implemented for prioritization using GIS and image processing on ERDAS and ILWIS software.

5. GIS allows to combine many geographic data together with great ease. GIS together with image processing is also useful in delineating erosion status.

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DIRECTOR: DR S.M. SETH

STUDY GROUP:

MR. D.S. RATHORE