

Prioritization of Watersheds for Perspective Landuse Planning Using Remote Sensing and Geographic Information System

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Abstract: Present study envisages the usefulness of soil information, derived from enhanced geocoded digital remote sensing data of IRS LISS II (Scale 1: 50,000), in combination with terrain slope, and watershed information generated from topographical maps (1:50,000), and aerial photographs (1: 25,000) for assessment of severity of soil erosion in 125 micro-watersheds of Kishanganj tehsil of Rajasthan. Thematic maps on soil, watershed and slope were digitized using AutoCAD software and converted to image file for working at ARC/INFO GIS environment. Area weighted averages of different soil types within the watersheds were ranked according to their erodibility and integrated with slope information and delivery ratio to arrive at Sediment Yield Index (SYI) values, which were further grouped into four categories (very high, high, medium and low). Terrain physiography and soil data obtained from interpretation and analysis of remotely sensed data can be effectively used in the framework of land evaluation for qualitatively assessing soil erosion hazard and priority watersheds.

Key words: Prioritization, remote sensing, GIS, micro-watershed, sediment yield index.

A systematic and planned development of any region calls for optimal use of available soil, water and other natural resources, based on their potentials and inherent limitations. Information regarding soil erosion, within a watershed, is vital for rational utilization of land and water resources for sustainability. One major unsolved problem in hydrologic research is to aggregate the dynamic behavior of hydrologic processes at various space and time scales in the presence of great natural heterogeneity. Ad-

ressing this issue will require new types of data and models, that are more universal in their structure and applicable to diverse regions of the globe. This paper discusses the use of remote sensing data to provide new and unique measurement capabilities for watershed research.

The study attempts to integrate soil information, derived from digital remote sensing data, with the terrain slope information generated from topographical maps, and distance of the watersheds from the reservoirs for first hand information about priority watersheds. The methodology fol-

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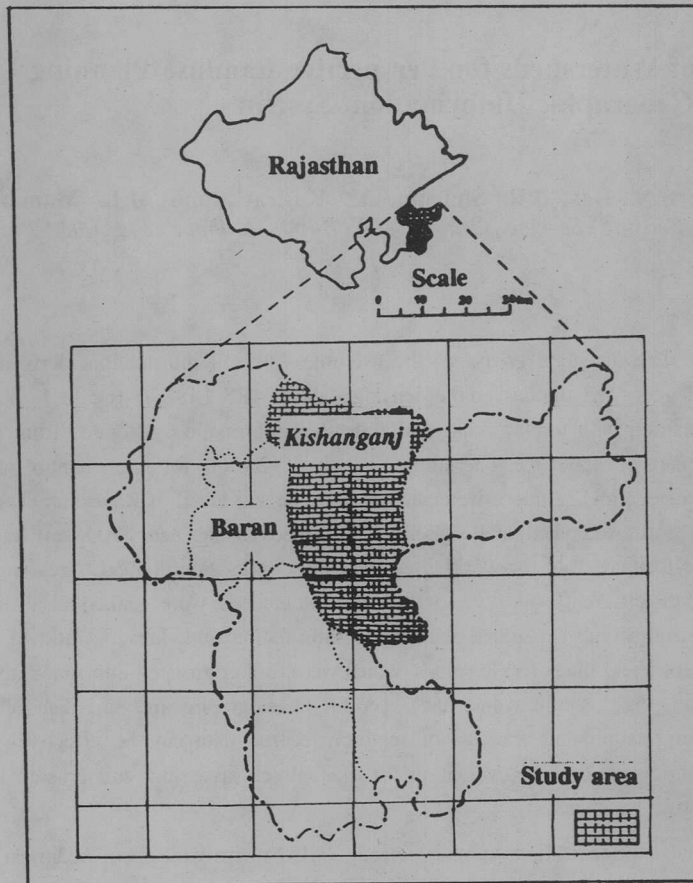


Fig 1. Location map of the study area.

lowed for prioritization of watersheds of a basin/catchment area is described by Karale *et al.* (1977), and Bali and Karale (1977). It is based on sediment yield index model (SYI), conceptualizing sedimentation of the reservoirs as a multiplicative function of two parameters, viz., (i) erosivity value, indicating the potential soil detachment, and (ii) the delivery ratio, expressing transportability of the detached soil material. The erosivity values in the mapping units in a small watershed reflect the influence of a set of factors, viz., climate, physiography,

slope, landuse/landcover conditions, soil characteristics and existing erosion and soil conservation measures.

Study Area

Kishanganj tehsil is situated in the eastern part of Baran district ($76^{\circ}30'E$ to $76^{\circ}57'E$ longitude and $24^{\circ}50'N$ to $25^{\circ}25'N$ latitude) and occupies an area of 1430.93 sq. km (Fig. 1). About 50% of the area is under forest and 33% under alluvial plain formed by Parbati river and its tributaries.

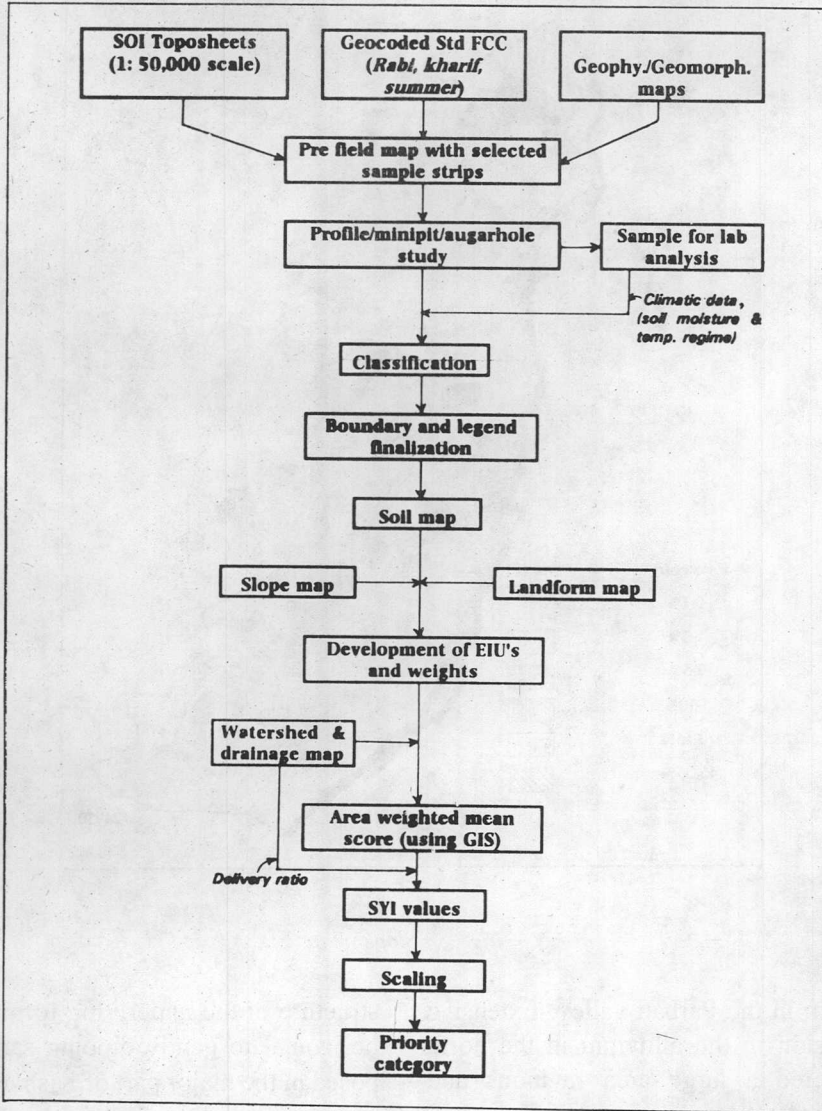


Fig. 2. Steps involved in watershed prioritization.

The lower Bhandar Sandstone occupies almost the entire area of Kishanganj tehsil. It occurs in almost horizontal beds and forms monotonous plateau surfaces. Qua-

ternary alluvium conceals the sandstone along the Parbati river and its tributaries and also in the depressions on the plateau surface. Thickness of alluvium ranges from

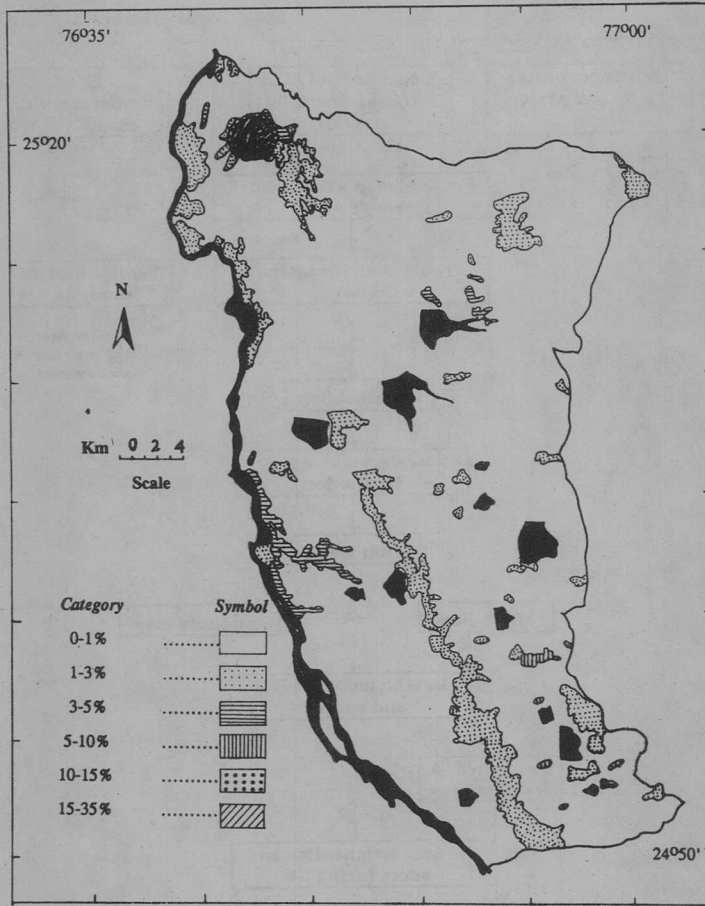


Fig. 3. Slope map.

10 to 15 m in the Parbati valley. Extensive gully erosion in the alluvium in the north has rendered a large area ravinous and badlands-infested.

The area is traversed by few lineaments, some of which are faults. Lineaments in the form of master joints are common in sandstone and they mostly control the drainage network. The geomorphology of the area is highly influenced by lithology and

structure of the underlying formations. The horizontal to gently dipping sandstone exposed in the major part of Kishanganj forms a vast plateau surface with gentle slope towards west. The geomorphic units in this area include dissected plateau, pediments (dissected), buried pediments, valley fills, ravinous area and alluvial plain.

The area is characterized by dry sub-humid climate with microthermal tempera-

ture regime and water surplus during July to September. The mean annual rainfall varies from 800 to 900 mm and temperature from 43°C to 10°C.

Materials and Methods

Soil mapping

IRS LISS II georeferenced multispectral data, enlarged to 1:50,000 scale as paper print, and corresponding to SOI toposheets number 54C - 11, 12 and 54D - 9,13 were used for this study. For precise mapping and to remove any ambiguity data of three seasons (May 1991, October 1991 and January 1992) were used. Visual interpretation was done following stratified approach (Fig. 2) in a 4 tier sequence. These are: (i) pre-field interpretation, mapping and sample strip selection; (ii) field profile analysis and sampling for physico-chemical analysis and confirmation of aerial extent of soil boundaries on the basis of minipits and auger hole data; (iii) soil analysis for various properties to supplement profile information and correlation with field observations, existing maps and reports, soil classification at family level and finalization of legend; and (iv) field validation and random checking in the field. The soil survey manual published by NBSS & LUP (1989) was also used.

Erosion intensity units

The soils were mapped as physiographic association due to scale limitation. In each mapping unit soil depth, dispersion ratio, texture, structure and land characteristics like slope (Fig. 3) and existing landuse were evaluated for assigning weightages to different mapping units. An arbitrary

scale was chosen for assigning weightages towards erodibility of different mapping units in which the value 10 was given to a soil which manifests neither erosion nor deposition, less than 10 denotes accumulation, whereas, more than 10 is attributed to erosion.

Watershed delineation

Ridge line demarcation of the watersheds was done with the aid of aerial photographs (1:25,000 scale) and SOI toposheets of 1:50,000 scale following the procedure given by All India Soil Survey Organisation (AIS & LUS and SAC, 1987). Upto watershed level the boundaries were kept according to Watershed Atlas of India (Anonymous, 1988) and further macro and micro level classification of watersheds was carried out following the guidelines of NRSA (IMSD Technical guidelines, NRSA, May 1995). In the tehsil, all the watersheds belong to Parbati river basin. The nomenclature of the watersheds was given in standard alphanumeric form. Micro-watersheds were designated by alphabets like a,b,c, etc., and care was taken to keep the area between 5-10 sq. km. There are altogether 125 micro-watersheds in the tehsil, some of which occupy areas in the adjacent tehsil/district also. While computing various parameters for those micro-watersheds falling at the boundary of the tehsil, the entire area of the concerned watersheds were considered even though these extended beyond the administrative boundary.

Prioritization of watersheds

The method is described by Karale *et al.* (1977) and Bali and Karale (1977). It is based upon sediment yield index model

(SYI), conceptualizing sedimentation of the dam/reservoirs as a multiplicative function of two parameters, viz., (i) erosivity value indicating the potential soil detachment, and (ii) the delivery ratio, expressing transportability of the units in a small watershed, and reflecting the influence of a set of factors like climate, physiography, slope, existing landuse/landcover, soil characteristics and existing soil conservation measures. Area-weighted average value of erosivity (E) of different soil units falling in a micro-watershed was calculated as :

$$E = \frac{\sum A_{ei} W_{ei}}{A_{ws}}$$

where,

A_{ei} is area of erosion intensity unit (EIU) or soil mapping unit,

W_{ei} is weightage assigned to corresponding EIU, and

A_{ws} is area of the micro-watershed.

For fixing priorities of the watersheds, it is necessary to consider the distance of the watershed from the reservoir. Generally, the silt load from nearby watersheds have

Table 1. Delivery ratio with distance of the watersheds from river/stream

Distance from reservoir (km)	Delivery ratio
0-2	0.7
2-4	0.6
4-6	0.5
6-16	0.4
16-40	0.3
40-80	0.2
80-160	0.1
> 160	0.05

more chance of reaching the reservoir as compared to the load from farther away. In order to consider the effect of distance, additional weightages were assigned (Table 1) and multiplied with erodibility index to get the sediment yield index (SYI) as follows:

$$SYI = E \times Dr \times 100,$$

where,

Dr is delivery ratio.

The following priority categories were assigned:

Category	SYI
Very high (VH)	>990
High (H)	740-990
Medium (M)	480-740
Low (L)	< 480

Topology creation under GIS environment

For computing the micro-watershed area and weighted average EIU values, ARC/INFO GIS was used. For performing above analysis, the soil, watershed and slope maps were digitized and projected to UTM projection to calculate all spatial units in metres. These were then edited and topology was created. Various feature attributes of the watersheds were appended in INFO database. Watershed and soil erosion intensity maps were then superimposed using "UNION" function and area weighted values were generated through "STATISTICS" function of ARC/INFO.

Results and Discussion

Soil physiographic association

The details of physiographic soil association are summarized in Table 2 and presented in Fig. 4. The soils developed under sandstone land system are either *in situ* or have alluvial material originating from the sandstone and transported by the existing river system. The following physiographic units were delineated by visual analysis of IRS LISS II data and supplemented by profile observation and physico-chemical analysis.

Alluvial plain (SS1): This unit has developed from the alluvium deposited by the Parbati river and its tributaries. The landscape is level to gently undulating with micro-relief variation. Based on erosion susceptibility and slope, it has further been subdivided into nearly level, gently undulating and moderately eroded areas. Slope varies from 0 to 3%. Soils are very deep, clayey to fine loamy in texture, sub-angular blocky to blocky, well drained and characterized by low EC and ESP, high to medium fertility and capability class II or IIIe. These soils are classified as fine typic Chromustert, fine typic/vertic Haplustalf and fine loamy typic Ustochrept. Spatial extent is 24.07% (Table 2).

Ravines/Gullies (SS2): This unit is severely eroded, resulting in the formation of gullies of various dimensions. Soil associations are fine loamy aridic Ustochrept and coarse loamy typic Ustorthent. Soils are deep to very deep, clay to clayey loam in texture, sub-angular blocky to blocky in structure with low EC, ESP, organic

matter and fertility. The slope is 1-5% with land capability of VIes and the unit is the fourth major physiographic soil unit, occupying 7.25% area. It is subdivided into severely eroded and less eroded areas (SS21 and SS22).

Valley fills (SS3): These areas are characterized by narrow valleys in the pediments, controlled by fractures and formed by colluvial materials deposited therein. It occurs in small patches along both sides of the rivers. Soils are deep, fine loamy with low EC, ESP and medium fertility status. Land is nearly level to gently sloping and belongs to capability class II. Soil is fine loamy aerice Haplaquept and fine vertic Ustochrept. It occupies only 2.79% area.

Buried pediments (SS4): This physiographic unit is developed by the deposits brought from the higher areas (pediment and plateau) or by *in situ* weathering of rocks. The slope is level to gentle (0 - 1%). The soils are well developed, deep, silty loam to clay loam, sub-angular blocky and are cultivated. EC and ESP are low, fertility is medium and capability class is II. Soil associations in this unit are fine typic Haplustalf and fine vertic Haplustalf. It covers 9.47% area.

Pediments (SS5): This physiographic unit occupies the largest area of the tehsil (49.24%; Fig. 4) and has scanty vegetation, including trees with stunted growth. It is subdivided into fractured and non-fractured (SS51 and SS52) areas. The soil is characterized by fragmental lithic Ustorthent/fragmental shallow typic Ustochrept, developed on 1-3% slope. Texture is clayey loam with low EC and ESP, and having

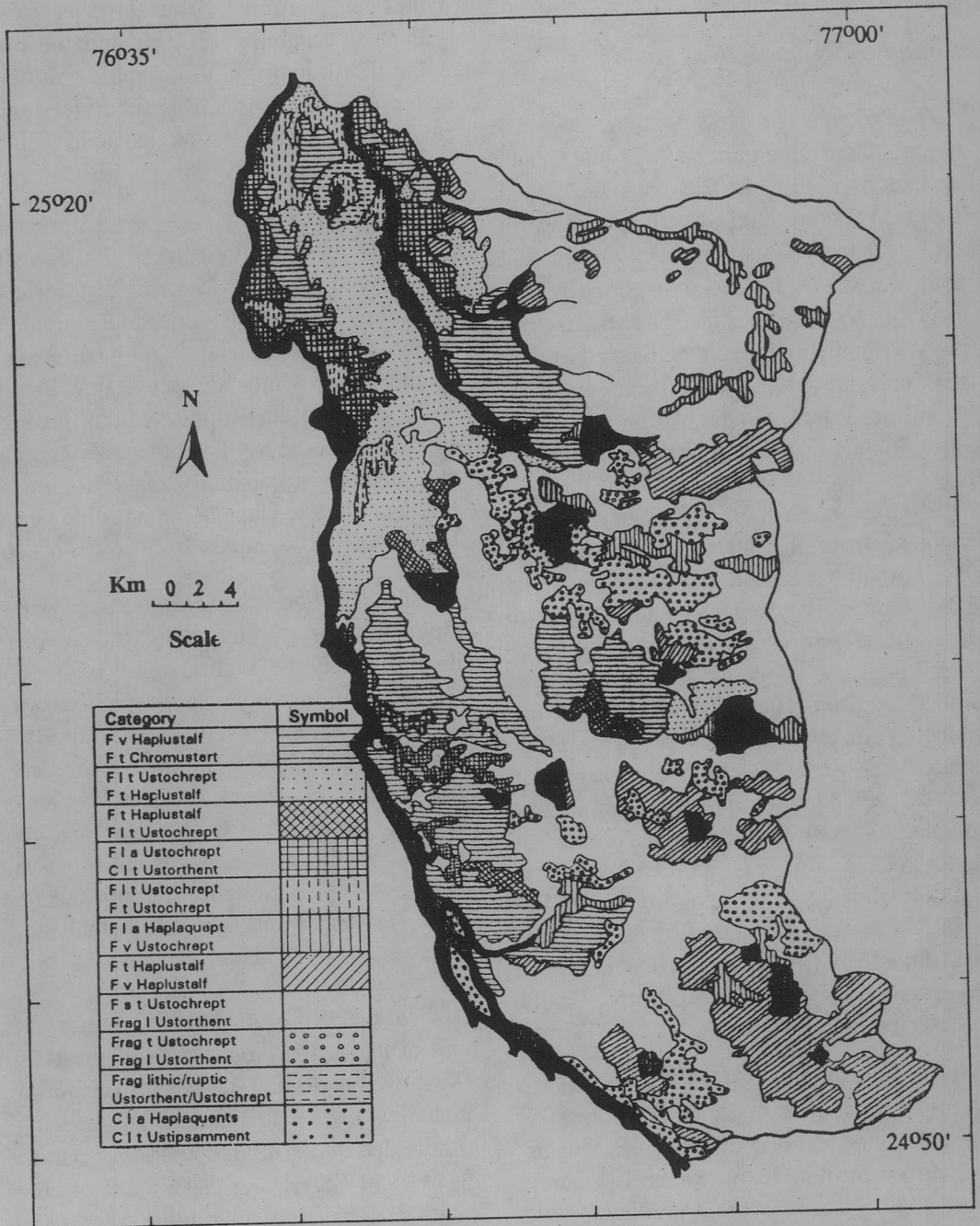


Fig. 4. Physiographic soil association map.

Table 2. Physiographic soil association with weightages and spatial distribution

EU	Wt	Physiography	Slope (%)	Soil association	Geog. area (%)
SSSt11	11	Alluvial plain (nearly level)	0-1	Fine vertic Haplustalf Fine typic Chromustert	14.49
SSSt12	13	Alluvial plain (gently undulating)	1-3	Fine loamy typic Ustochrept Fine typic Haplustalf	8.61
SSSt13	14	Alluvial plain (mod. eroded)	1-3	Fine typic Haplustalf Fine loamy typic Ustochrept	0.97
SSSt21	18	Ravines (severely eroded)	3-5	Fine loamy aridic Ustochrept Coarse loamy typic Ustorthent	5.50
SSSt22	16	Peripheral lands, less ravenous	1-3	Fine loamy typic Ustochrept Fine typic Ustochrept	1.75
SSSt3	9	Valley fills	0-1	Fine loamy aeric Haplaquept Fine vertic Ustochrept	2.79
SSSt4	11	Buried pediment	0-1	Fine typic Haplustalf Fine vertic Haplustalf	9.47
SSSt51	13	Pediment - non fractured	1-3	Fragmental lithic Ustorthent Fragmental shallow typic Ustochrept	43.21
SSSt52	14	Pediment - fractured	1-3	Fragmental shallow typic Ustochrept Fragmental lithic Ustorthent	6.03
SSSt6	15	Structural hills	>25	Fragmental lithic/ruptic Ustorthent/Ustochrept	0.53
SSSt8	14	Sub recent flood plain	0-1	Coarse loamy aeric Haplaquent Coarse loamy typic Ustipsamment	0.94

SSSt = Sandstone land system.

low fertility status. Soils are shallow and moderately eroded; capability class is IVes.

Structural hills (SSSt6): This unit occurs as the Ramgarh dome in the north of the tehsil. It has steep slope (25%). The unit is highly susceptible to erosion. Soils are shallow, coarse in texture and the capability class is VIIes. Soil association is fragmental lithic-ruptic Ustorthent/ Ustochrept. This unit occupies 0.53% area of the tehsil.

Sub-recent flood plains (SSSt8): These are very recent deposits, carried by the Parbati river system from the areas of higher elevation. Slope is nearly level and lands are cultivated. Soils are coarse, sandy loam

to clay loam in texture, sub-angular blocky, very deep and poorly drained. Free calcium carbonate is common throughout the profile, characterized by medium fertility, low ESP and EC. The soils are well drained and belong to capability class IVes. Soil association is coarse loamy aeric Haplaquent and typic Ustipsamment.

Watershed prioritisation

There are 125 micro-watersheds, some of which are extended to adjoining districts/tehsils (Fig. 5). All watersheds finally drain into Parbati river directly or through its tributaries. Out of the 125 micro-watersheds, only 4 (A-1b,c,i,m) are under very

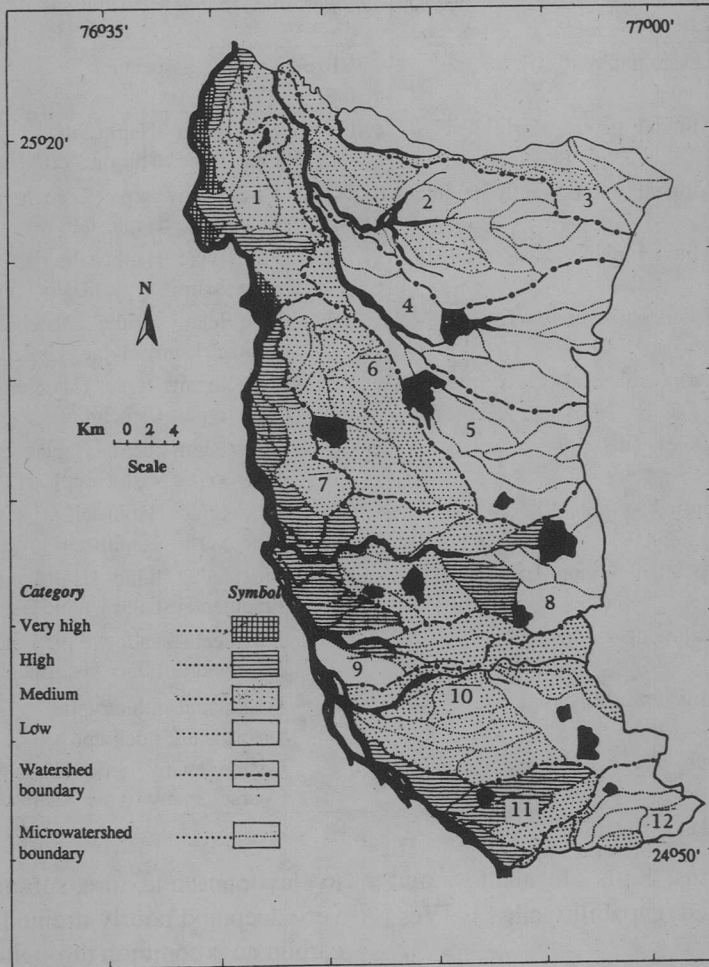


Fig. 5. Priority watershed.

high priority category (where SYI > 990), covering only 3.2% area of the tehsil (Table 3). These watersheds are located around Parbati river and north-western part of the tehsil in gently sloping alluvial area where the land is mostly single cropped. These watersheds need immediate attention. Twenty four micro-watersheds are under high priority category (where SYI is 740 to 990) and centered around the river along

the western boundary of the tehsil. Landuse of the micro-watersheds in this category is mostly agriculture, or moderately dense forest, covering 19.2% area. Medium priority watersheds are 48 in number, having SYI value of 480 to 740 and covering 38.4% area. These occur along western half of the tehsil and have degraded moderately dense forest. The dominant units are shallow buried pediment and hence,

Table 3. Prioritisation of the micro-watersheds according to the need of soil and water conservation in Parbati river basin

Watershed No.	V. High (>991)	High (741-990)	Medium (481-740)	Low (<480)
1	b,c,i,m	a,j,k	d,e,f,g,h,l,n	-
2	-	-	a,b,j,k,n	c,d,e,f,g,h,i,l,m
3	-	-	b	a,c,d,e,f,g,h,i
4	-	-	-	a,b,c,d,e,f,g,h,i
5	-	a	b,c,d	e,f,g,h,i,j,k,l,m
6	-	-	b,c,d,e,f,g,h,i	a
7	-	a,b,c,e,f,g	d	-
8	-	a,b,o,p,q,r	c,d,l,m,n	e,f,g,h,i,j,k
9	-	a,b,c,g	d,e,f	h
10	-	-	a,b,c,d,f,g,h,i,j,l	e
11	-	a,b,d	c	-
12	-	-	a,b,f	c,d,e,g
13	-	a	-	-
SA	-	-	SA	-
125*	4*	24*	48*	49*

SA=sandy area within the river; a,b,c,d ... refer to micro-watersheds.

*Total.

depth of soil is less. The watersheds in the eastern half are mostly under degraded, moderately dense forest. The fallow areas of flat and cultivated sandstone pediments have low priority watersheds. A total of 49 watersheds are under this category, covering 39.2% area (Fig. 6). These watersheds have good vegetation cover and gentle to moderate slope. No immediate soil and water conservation measure is necessary.

Conclusions

This study demonstrates that the terrain physiography and soil, coupled with watershed information obtained from interpretation and analysis of remotely sensed data, SOI toposheets and aerial photographs, and dovetailed with ARC/INFO GIS, could be effectively utilized for qualitative assessment of soil erosion hazard while ad-

ressing integrated land resources development vis-a-vis retrieval of data for developing suitable model or for change detection in the future. The mapping of potential erosion hazard in 125 micro-watersheds indicates that only 4 micro-watersheds are under very high priority category, 24 are high, 48 are medium and 49 are low priority category, constituting 3.2%, 19.2%, 38.4%, and 39.2% area of the tehsil, respectively. Such categorization has relevance for soil and water conservation at district level planning and under Integrated Rural Development Programme.

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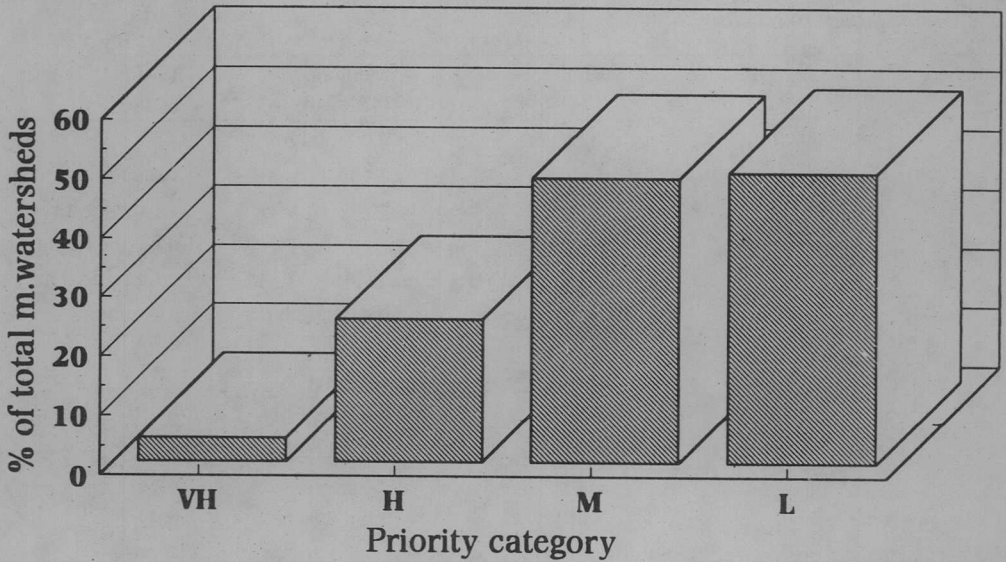


Fig. 6. Distribution of different priority watersheds.

Jodhpur, for providing information on watersheds.

References

- AIS & LUS and SAC, 1987. *Application of Remote Sensing Techniques for Watershed Characterization in a part of Ukai Catchment*. Report No. SAC/RSA/RSAG/SN/02/87.
- Anonymous 1988. *Watershed Atlas of India*. All India Soil and Landuse Survey, Dept. of Agriculture and Cooperation, Ministry of Agriculture, GOI, New Delhi.
- Bali, Y.P. and Karale, R.L. 1977. A sediment yield index for choosing priority basins. *IAHS-AISH Publ.* 222, p.180.
- Karale, R.L., Bali, Y.P. and Narula, K.K. 1977. Priority watersheds for soil conservation work in Matatilla catchment. *Journal of Indian Society of Soil Science* 25(3): 331-336.
- NBSS & LUP 1989. *Soil Resources Mapping of Different States in India*. Technical Bulletin No.13, Nagpur.