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Prioritisation and management needs of Kawal Khad Watershed based on sediment yield index in southern Himachal Pradesh using remotely sensed data and GIS techniques

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Abstract

Study was undertaken to ascertain the priority categories of sub-watersheds of Kawal Khad watershed based on sediment yield index (SYI) and to recommend/suggest suitable soil and water conservation measures. Landuse/Landcover, physiography cum soilscape maps obtained from visual interpretation of IRS-IC LISS-III imagery and terrain slope information obtained from topographic map were used to provide inputs to SYI model. Landuse, physiography cum soilscape and slope maps were integrated (two at a time) to generate composite erosion intensity units (CEIU). The CEIUs were assigned weightage values and delivery ratios to compute SYI. Priority classification of sub-watersheds based on SYI indicated that out of 12 sub-watersheds, only one sub-watershed (Ks12) covering 1046.6 ha area (6.3 %) registered very high SYI (1405.2) and qualified for the top priority treatment. The six sub-watersheds *viz.* Ks1, Ks2, Ks4, Ks8, Ks9 and Ks11 covering 50.2 per cent area exhibited high SYI (1205.4-1283.6) and fall in second priority category. The remaining five sub-watersheds *viz.* Ks3, Ks5, Ks6, Ks7 and Ks10 having medium SYI, i.e., 1150.0 to 1175.4 covering 51.0 per cent area qualified for third category of priority. On the basis of SYI suitable soil conservation measures have been suggested for different sub-watersheds and mapping units.

Additional keywords : Composite erosion intensity units, soil conservation measures

Introduction

For the formulation of proper watershed management programmes, the information on the existing or potential erosion prone areas is required as it helps in identifying the location and extent of the sediment sources in the watershed and in determining their relative importance. Satellite remote sensing offers scientific input for the formulation of proper watershed management programmes and also addresses some of the parameters related to watershed development. One such parameter is quantitative estimates of erosional soil loss and the priority classification of the sub-watersheds/micro-watersheds. This information is basic for integrated watershed management and development. Remote sensing and GIS techniques are useful in prioritisation of watersheds very accurately and efficiently and at the same time spatial database (maps) can be updated, stored and retrieved much faster than the conventional methods. With this in view, the Kawal Khad watershed was selected for detailed investigations.

The landscape characteristics of this watershed are hilly terrain with steep slopes, intensive cultivation, variable soils, different types of landuse/landcover, excessive monsoon rains and heavy biotic interference. The land of this watershed is subjected to different degrees of erosion resulting varied depth of soils. It is, therefore, desirable to prioritise the sub-watersheds of the *Kawal Khad* watershed and devise suitable conservation measures.

Materials and methods

Study Area: The Kawal Khad watershed, which forms a part of Giri river catchment, is located in Solan and Sirmour districts of Himachal Pradesh between 30° 45' 00" to 30° 54' 45" N latitudes and 77° 03' 15" to 77° 13' 35" E longitudes with elevation ranging from 900 to 2100 m above msl. It covers an area of 165.2 sq. km. and is situated on the right bank of Giri river, bounded by the high Himalayan mountains in north, the Shivalik ranges in south and lower Himalayas on south west. It has sub-humid sub-temperate climate with mean annual rainfall of 1300 mm and mean annual temperature of 20°C. The soil moisture and temperature regimes are characterised by "udic" and "thermic" types, respectively. The watershed is covered by the Survey of India topographical map 53 F/1 (1: 50,000).

IRS-IC LISS-III standard FCC (scale 1: 50,000) of February 6, 1997 was used for thematic mapping. Delineation of major landforms was done after studying hydro-geomorphological (Sharma 1999) and topographical maps (53 F/1, scale = 1: 50,000) of study area. Each landform was further sub-divided on the basis of image elements.

The fieldwork was undertaken to collect ground truth information. Different mapping units were delineated through visual interpretation of satellite imagery. The final legend was prepared after ground truth verification of prefield interpreted units (Table 1). The representative soil profiles were studied in different units and soil samples of dominant soils including surface soils were collected at different observation points. The soil samples were analysed in the laboratory for various physical and chemical properties and were classified according to the Soil Taxonomy (Soil Survey Staff 1975).

Results and discussion

Sub-watershed Delineation : Based on visual interpretation of IRS-IC LISS III FCC, drainage pattern (dendritic type) in topographical map and Watershed Atlas of India (All India Soil and Land Use Survey 1990), the watershed was delineated into 12 sub-watersheds (Fig. 1). The code of the watershed is 2C6C5, where 2=water resource region, the Ganges; C=basin, the Yamuna; 6=catchment, the uppermost Yamuna; C=sub-catchment, the uppermost Yamuna in the Himalayan mountain and 5=watershed. As per the Watershed Atlas of India, this code is to be considered as a prefix while reading all sub-watershed codes.

Computation of Sediment Yield Index (SYI) : The All India Soil and Land Use Survey, Dept. of Agriculture and Co-operation, Ministry of Agriculture, Govt. of India has developed an empirical formula given below for computing SYI (Kulkarni *et al.* 1983).

Table 1. Soil-site characteristics of mapping units

Map-ping units	Land characteristics									
	D (d)	Texture (O.C.%)	Structure	e	s (%)	Fertility status			Dominant landuse	Soil Association
						N	P	K		
High Hills (H)										
H1	D5 (d4)	gsl, gsil (2.5-4.0)	I m2cr II m2abk	el & e2	>35	M	M	M	Dense forest	Coarse silty Typic Eutrochrepts/ Coarse sility Psammentic Udifluvents
H2	D3 (d3)	gl, gsl (1.5-2.5)	I m2cr II m2sbk	e2 & e3	>35	L	M	L	Scrubs	Coarse loamy Typic Arguidolls/ Coarse loamy Typic Eutrochrepts
Mid hill (M)										
M1	D5 (d4)	gl, gsil (2.5-4.0)	I m2cr II 2msbk	el	>35	L	L	L	Denser forests	Loamy skeletal Typic Eutrochrepts/ Loamy skeletal Psammentic Hapludalfs
M2	D4 (d4)	gl, gsl (2.0-3.0)	I m2cr II m2sbk	el & e2	>35	L	M	M	Moderately dense forests	Coarse loamy Typic Udorthents/ Coarse loamy Typic Hapludalfs
M3	D4 (d3)	gls, gsl (2.0-3.5)	I m2gr II m2sbk	e2 & e3	>35	L	L	L	Mixed forests	Coarse loamy Typic Eutrochrepts/ Coarse loamy Typic Udorthents
M4	D4 (d4)	gl, gsl. (2.0-3.0)	I m2gr II m2bsk	e2	5-35	L	L	L	Degraded forests	Loamy skeletal Typic Euthochrepts/ Loamy skletal Typic Hapludalfs
M5	D3 (d5)	gsl, gsil (2.0-3.0)	I mlgr II m2bsk	e2	5-35	M	H	M	Agro-horticultural plantation	Coarse loamy Typic Udorthents/ Fine loamy Typic Hapludalfs
M6	D3 (d5)	gsl, gsil (1.0-2.0)	I m2gr II m2sbk	e2 & e3	5-35	M	M	M	Crop land	Fine loamy Fluventic Eutrochrepts/ Fine loamy Typic Hapludalfs
M7	D4 (d3)	gsl, gls (1.0-1.5)	I sg II ma	e2	>35	L	L	L	Scrubs	Loamy skeletal Typic Eutrochrepts/ Loamy skeletal Lithic Udorthents
M8	D4 (d2)	gls, gsl 0.5-0.75	I sg II m2sbk	e3	>35	L	L	L	Barren lands	Coarse loamy Lithic Udorthents/ Coarse loamy Typic Udorthents
Low hills (L)										
L	D3 (ds)	gsil, gl (0.5-2.5)	I m2gr II m2sbk	e3	>35	M	M	L	Crop land	Coarse sility Fluventic Udifluvents

I = Surface, II = Sub-surface; O.C. = Organic carbon (%); e = Erosion hazard; D = Drinage class; s = Slope (%); d = Depth class
L = Low; M = Medium; H = High

$$SYI = \frac{\sum_{i=1}^{n} (Ai \times Wi \times Di)}{Aw} \times 100$$

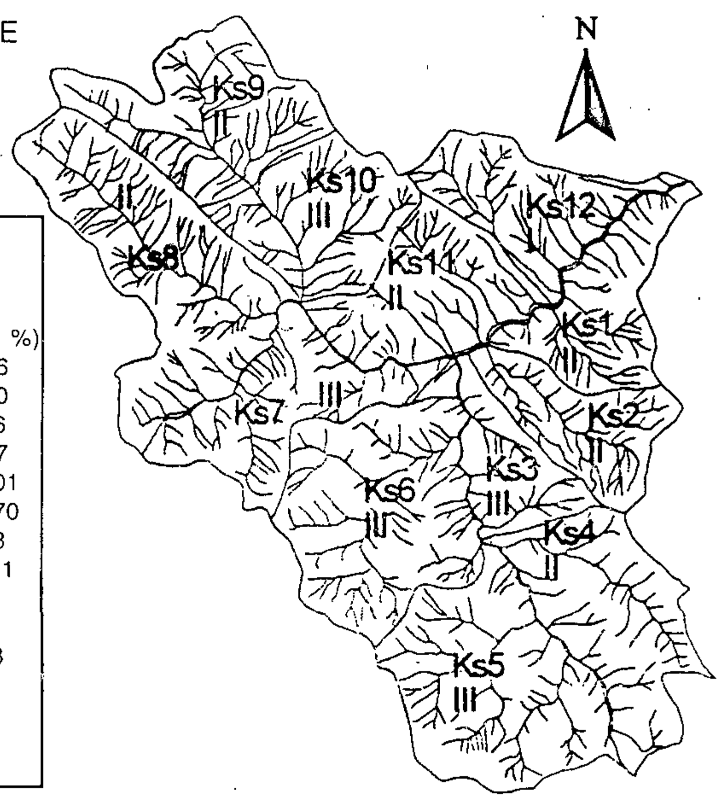
Where, i	=	1 to n
Ai	=	Area of ith composite erosion intensity unit (CEIU)
Wi	=	Weightage value of ith CEIU
Di	=	Adjusted delivery ratio assigned to ith CEIU
n	=	No. of mapping units
Aw	=	Total area of sub-watersheds

Sediment Yield Index for each sub-watershed was computed using this relation (Fig. 1)

Composite Erosion Intensity Units (CEIU) : The theme maps viz. landuse, physiography cum soil, slope, except the watershed, were integrated, two at a time, to generate a CEIU map using PC ARC/INFO GIS software package, version 3.4.2 of ESRI (Environmental

LOCATION
30^{o} 45' 00"-30^{o} 54' 45" N LATITUDE
77^{o} 03' 15"-77^{o} 13' 35" E LONGITUDE
Watershed Code : 2C6C5

I, II, III = Priority Categories



LEGEND
Drainage
Subwatershed Boundary

Subwatershed	SYI	Area	(ha, %)
Ks	1238.04	1016.66	6.16
Ks2	1280.56	891.26	5.40
Ks3	1151.04	971.15	4.06
Ks4	1283.62	1497.42	9.07
Ks5	1167.94	1982.85	12.01
Ks6	1150.03	2097.08	12.70
Ks7	1163.53	1243.14	7.53
Ks8	1217.76	2181.72	13.21
Ks9	1205.39	1453.51	8.80
Ks10	1175.39	1191.01	7.21
Ks11	1168.63	1243.97	7.53
Ks12	1405.16	1046.66	6.34

2 0 2 Km.

Fig. 1. Subwatershed delineation with drainage overlay and priority classes.

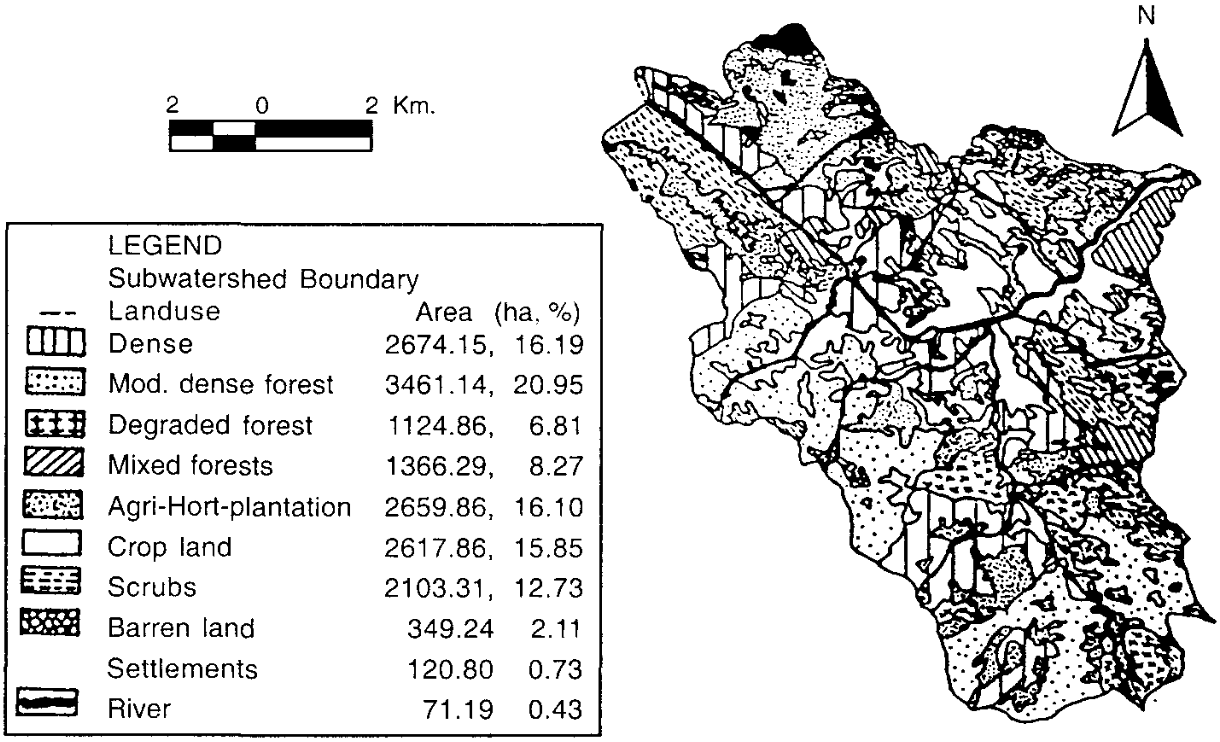


Fig. 2. Landuse map of Kawal Khad watershed.

System Research Institute, Redland, California, USA). The attribute table of this CEIU map was combination of attribute tables of the input maps. Each CEIU polygon was associated with particular set of physiography, soil, landuse and slope. As per the methodology, nineteen CEIU were identified and delineated in the watershed and have been described in table itself (Table 2). The CEIU viz. A, B, C and D occurred only in two sub-watersheds (Ks5 and Ks6) and occupied very small area. The remaining CEIU occupied appreciable area in different sub-watersheds.

Weightage value : The weightage values were assigned to different erosion intensity units representing approximately the relative proportions of sediment yield from different units. Parameters, like soil characteristics, slope (degree and length), agricultural practices, canopy coverage and existing conservation practices were considered in recognising these units. A basic factor K=10 was adopted in working out weightage values. The value 10 represents the geologic erosion indicating a static condition. Addition to the factor K suggests erosion in that proportion while subtraction from K indicates an active deposition. Weightage values assigned to various soilscape units of the watershed as per the methodology varied from 11 to 17 (Table 2).

Delivery ratio : The delivery ratio suggests the portion of eroded material that finally finds entry into the reservoir and this is expressed as percentage. The factors considered for the computation of delivery ratio include soil texture, slope, vegetation and proximity of the area to the main stream. Higher values were assigned to the CEIUs, which were nearer to

Table 2. Composite erosion intensity units (CEIU)

CEIU	Physiography	Dominant landuse	Slope (%)	Texture	Erosion status	WV	DR
A	High hills	Dense forests	5-10	gsl, gsil,	Slight	12	0.70
B	Mid hills	Dense, moderately dense & mixed forests	5-10	gsil, gl, gsl	Slight	11	0.75
C	Mid & high hills	Degraded forest, scrubs & barren lands	5-10	gsl, gl, gls	Slight to moderate	14	0.85
D	Mid hills	Agro-horticultural plantation & crop land	5-10	gl, gsil	Slight to moderate	13	0.75
E	High hills	Dense forests	10-15	gl, gsil, gls	Slight to moderate	14	0.80
F	Mid hills	Dense, moderately dense & mixed forests	10-15	gsil, gl, gsl	Slight	13	0.75
G	Mid & high hills	Degraded forest, scrubs & barren lands	10-15	gsl, gls, gl	Moderate to severe	15	0.85
H	Mid hills	Agro-horticultural plantation & crop land	10-15	gl, gsil	Moderate to severe	14	0.80
I	Low hills	Crop land	10-15	gl,gsil	Slight to moderate	12	0.75
J	High hills	Dense forests	15-35	gsl, gls, gsil	Moderate to severe	15	0.80
K	Mid hills	Dense, moderately dense & mixed forests	15-35	gsl, gsl	Slight to moderate	14	0.80
L	Mid & high hills	Degraded forest, scrubs & barren lands	15-35	gsl, gls	Severe	16	0.90
M	Mid hills	Agro-horticultural plantation & crop land	15-35	gl, gsl	Severe	15	0.80
N	Low hills	Crop land	15-35	gl, gsl	Moderate	13	0.85
O	High hills	Dense forests	>35	gsl, gls	Very severe	16	0.85
P	Mid hills	Dense, moderately dense & mixed forests	>35	gsl, gl, gls	Moderate to severe	15	0.80
Q	Mid & high hills	Degraded forest, scrubs & barren lands	>35	gsl, gls,	Very severe	17	0.95
R	Mid hills	Agro-horticultural plantation & crop land	>35	gsl, gl,	Very severe	16	0.85
S	Low hills	Crop land	>35	gsl, gls, gl	Severe	14	0.85

WV = Weightage value, DR = Delivery ratio

the main stream and lower values to those, which were far away from the main stream. Delivery ratio assigned to various soilscape units of the watershed varied from 0.70 to 0.95 (Table 2).

Prioritisation and categorisation of sub-watersheds on the basis of SYI : SYI was computed for each sub-watershed for prioritising them. The gradation and assignment of priority ratings to the sub-watersheds are based on the descending values of SYI and the priority categories used in the study are :

Priority category	**SYI Values**
Very high (I)	1300 and above
High (II)	1200-1299
Medium (III)	1100-1199
Low (IV)	1000-1099
Very Low (V)	<1000

Landuse/landcover : The major landuse categories found in the study area were chir pine forests (*Pinus roxburghii*), agro-horticultural plantation, crop land, scrubs, barren lands and settlements (Fig. 2). Larger area of the watershed i.e., about 50 per cent is under forests. Dense (canopy >40%), moderately dense (canopy 10-40%), degraded (canopy <10%) and mixed forests (*Quercus leucotrichophora, Pinus roxburghii, Acacia catechu*) covered 16.2, 20.9, 6.8 and 8.3 per cent watershed area, respectively. Agriculture (agro-horticultural plantation and crop land) covered 31.9 per cent, scrub lands and barren lands 14.8 per cent and settlements and river accounted only for 1.2 per cent area of the watershed.

Physiography and soils : There were 11 physiographic-soilscape units, in the watershed and the legend showing their soil associations and distribution are presented in figure 3 and table-1. In accordance with Soil Taxonomy (Soil Survey Staff 1975) the soils of the watershed belonged to four orders namely Entisols, Inceptisols, Alfisols and Mollisols. The high hills covering the mapping units H1 and H2 were mainly characterised by the presence of Inceptisol, Entisol, and Mollisol orders whereas the mid hills comprising the mapping units M1 to M8 exhibited the prevalence of Entisols, Inceptisols, and Alfisols. However, the low hills had only Entisols.

Salient characteristics of the mapping units : The soils of the watershed were characterised by the presence of abundant gravels throughout the profile depth (Table 1). These were slightly to moderately eroded and well-drained with moderate permeability. Three dominant soil textural classes *viz.* loamy sand, sandy loam and silty loam were observed in different mapping units. The soil structure was well developed except in few mapping units *viz.* M7 and M8. These soils were moderately deep to very deep with moderate moisture availability. The high organic carbon content (0.5-4.0 %) in these soils may be because of coniferous vegetation and sub-temperate climate of the area. The available N and K status was low to medium whereas that of P was low to high.

Slope information : The slope information was obtained from contour data of SOI topographical map following IMSD (Integrated Mission for Sustainable Development

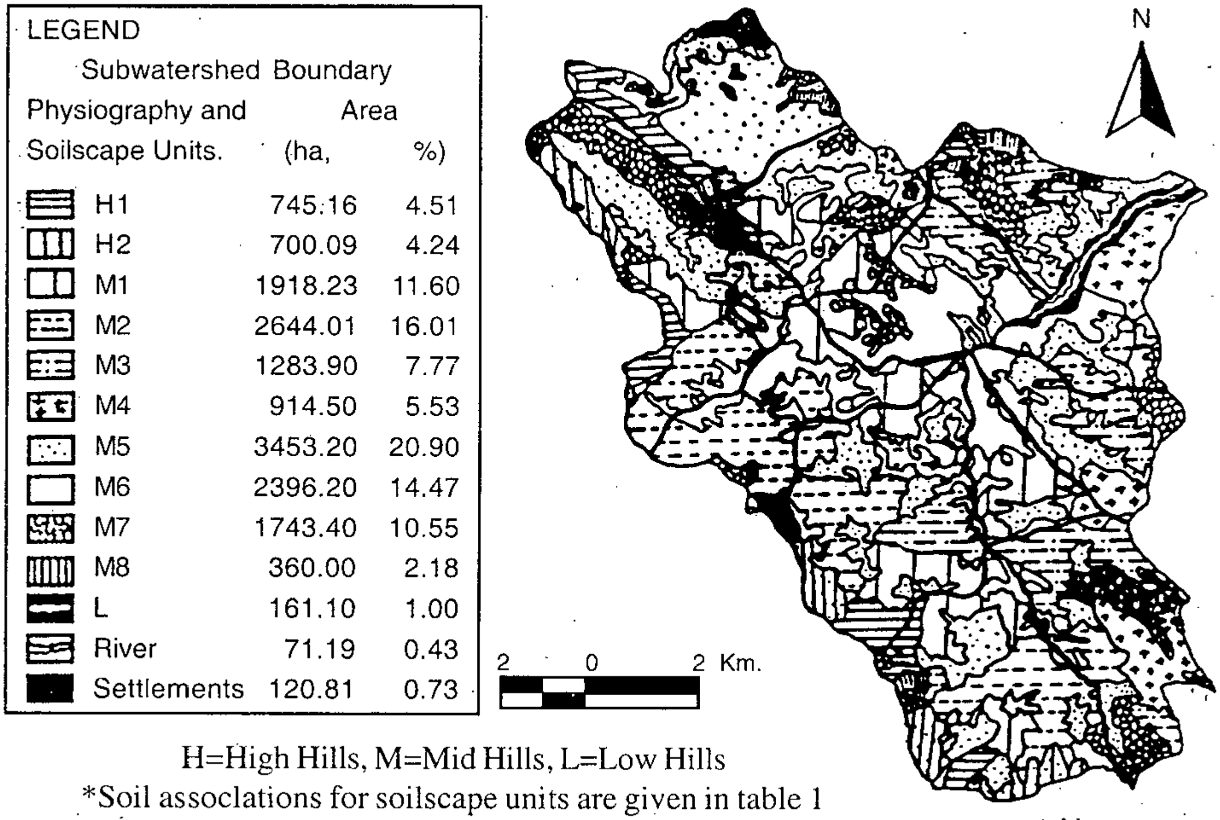


Fig. 3. Physiography and soilscape of Kawal Khad watershed.

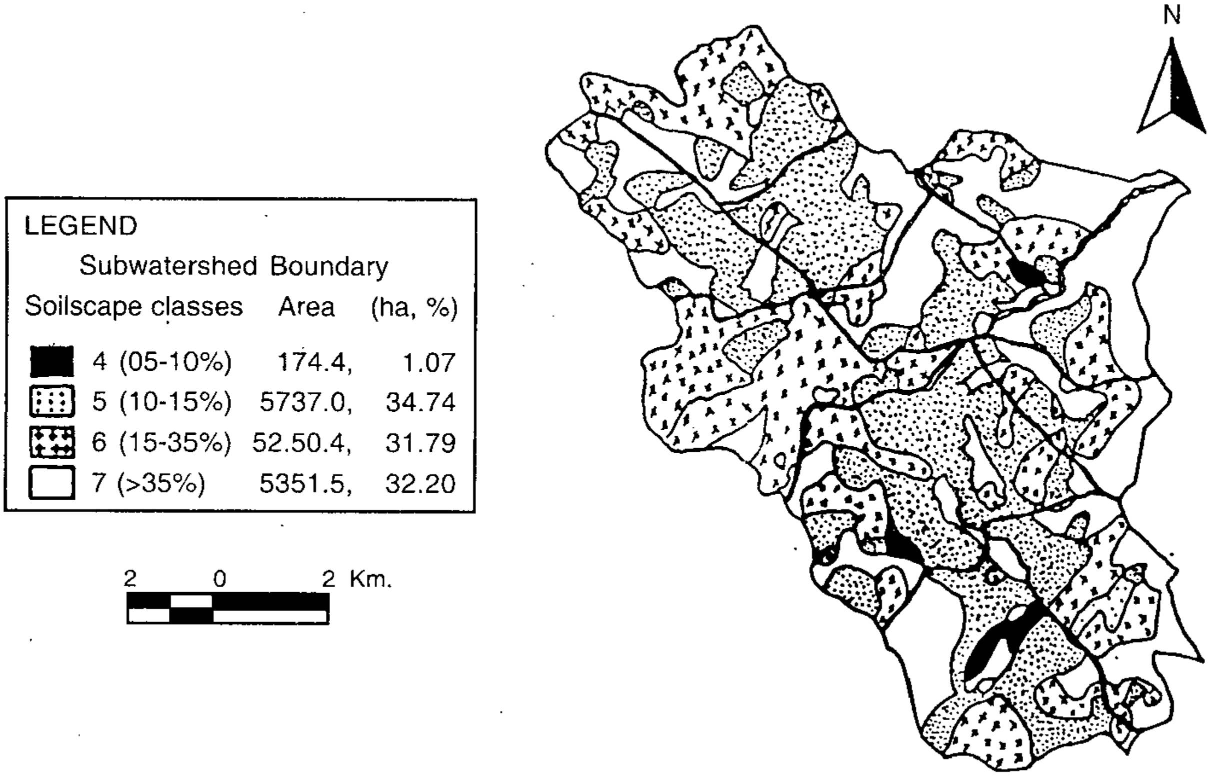


Fig. 4. Slope map of Kawal Khad watershed.

Project of NRSA, Dept. of Space, Govt. of India) guidelines. Only four slope classes viz. 5-10 (4), 10-15 (5), 15-35 (6) and >35 (7) per cent slope were found in the area (Fig. 4). These slope classes covered 34.7, 31.8 and 32.4 per cent watershed areas, respectively. The physiographic cum soilscape units *viz.* H1, M1, M2, M4, M5 and M6 had all the four slope classes, however, 15-35, and >35 per cent slopes dominated in these mapping units. Barren lands (M8) were maximum on the slope of >35 per cent followed by 15-35 per cent. In mapping units having agro-horticultural and intensive cultivation (M5 and M6) practices, more than 75 per cent of the area had 10-35 per cent slope.

Sediment Yield Index (SYI) : SYI was computed for each sub-watershed based on encountered CEIU and weightage values assigned to them in corroboration with delivery ratio. The status of sub-watersheds categorised into priority categories on the basis of SYI, presented in figure 1, is given below:

Priority-I : Out of 12 sub-watersheds, only one *viz.* Ks12 covering an area of 1046.6 ha (6.34 %), exhibited very high SYI (1405.2) and thus qualified for the top priority treatment. This is due to poor land cover, i.e., dominant land use is scrubs followed by agro-horticultural plantations and barren lands. In addition to this, the soils are coarser in texture with weak structure. This sub-watershed is also dominated by excessively steep slopes i.e. 15-35 per cent and >35 per cent. The landuse/landcover and the slope play an important role with reference to the susceptibility of an area to soil erosion (Morgan 1979; Sharma *et al.* 1985). This model has also been used earlier for the prioritisation of sub-watersheds by various workers and indicated that steep slopes increase the susceptibility of land to soil erosion (Chaudhary *et al.* 1992; Saha *et al.* 1992; Rao *et al.* 1994).

Priority-II : Six sub-watersheds viz. Ks1, Ks2, Ks4, Ks8, Ks9 and Ks11 covering 50.2 per cent area exhibited SYI from 1205.4-1283.6 and thus qualified for this priority category. The dominant landuse under these sub-watersheds is mixed and degraded forests, crop lands, scrubs and barren lands. About 60 to 80 per cent of the area is characterised by steep slopes (> 35 %) resulting in high erosive velocity of runoff water. The high rate of sediment yield in the sub-watershed of this priority category could be attributed to poor landcover and steeper slopes (Morgan 1979; Sharma *et al.* 1985).

Priority-III : Five sub-watersheds *viz.* Ks3, Ks5, Ks6, Ks7 and Ks10 having medium SYI i.e. 1150.0 to 1175.4 covered 43.5 per cent area and have been placed in third category of priority. Medium SYI in these sub-watersheds could be due to greater percentage of the area (50-60 %) under luxuriant vegetative cover and remaining area under well managed crop lands. Sharma *et al.* (1985) has also recorded minimum soil loss under forested areas followed by row crops and wasteland. Vegetation protects the soil against impact of falling rain drops, increases the roughness of the soil surface, reduces the speed of surface runoff, binds the soil mechanically and improves the physical, chemical and biological properties of the soil (Zacher 1982).

Table 3. Physiographic conditions and management recommendations

Mapping units	Per cent area classes	Physiography	Dominant landuse	Dominant slope	Erosion status	Management recommendation
H1 & M1	16.1	High & mid hills	Dense forests	5, 6 & 7	Very low	Regular monitoring of vegetation status and low biotic interference.
M2	16.0	Mid hills	Moderately dense forests	5, & 6,	Very low	Regular monitoring of vegetation status and biotic interference and gap filling.
M3	7.4	Mid hills	Degraded forests	5 & 7	Low	Complete closure of the area, gap filling, gully plugging and plantation of site specific species.
M4	5.5	Mid hills	Mixed forests	7	Very low	Regular monitoring of bio-diversity, gap filling and checking of biotic interference.
M5	4.0	Mid hills	Agro-horticultural plantation	5, 6 & 7	Very low	Bunding, terracing, land levelling, improvement of existing terraces, and soil binding grasses.
M6 & L	15.5	Low and mid hills	Crop land	5, 6 & 7	Very high	Improved cropping pattern, use of mulches, growing of soil binding grasses, and nitrogen fixing trees on bunds.
H2, M7 & M8	17.0	Mid hills	Scrubs and barren lands	6 & 7	Low to very high	Gully plugging, small check dams, runoff management, gradient control structures, afforestation with suitable site-specific species and silvi-pastoral development.

IMSD slope classes: 5 = 10-15 %; 6 = 15-35 %; 7 = >35 %

Soil conservation measures : It is evident from the sediment yield index that there is an urgent need for adoption of suitable location specific soil conservation measures to arrest the alarming soil erosion problems in different sub-watersheds. The soil conservation measures suggested/ recommended for different sub-watersheds and mapping units for controlling the serious problem of soil erosion and land degradation are given in table 3. According to relative priority grading, soil conservation measures should be taken up immediately in sub-watersheds falling in priority categories-I (Ks12) and II (Ks1, Ks3 & Ks11) covering 56.5 per cent area and then in sub-watersheds falling in category-III (Ks2, Ks4, Ks5, Ks6, Ks7, Ks8, Ks9 & Ks10) covering 43.5 per cent area.

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