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Assessment of Agri-Environment in Garhwal Himalayas of India for Sustainable Productivity

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ABSTRACT

The agri-environment of Satpuli watershed in Garhwal Himalayan region of Uttarakhand state in India was assessed using remote sensing and GIS techniques. The study reveals that soil development depends mainly on landforms and parent materials. Seven landforms and ten types of soils (P1 to P10) have been identified. P1, P2 and P6 soils are developed on quartzite parent material whereas, P3 to P5 and P7 to P9 soils on sandstone and P10 soils on colluviums/alluvium, respectively. P1 and P2 soils occur on steep hill tops whereas P4 soils on very steep side slopes and are shallow (< 50 cm depth), coarse textured with strong gravelliness and susceptible to very severe erosion and droughtiness. They are evaluated as land capability (LC) subclass IV sew. P3 and P5 soils occur on steep hill tops and side slopes, respectively and are moderately shallow, coarse sandy loam to loam in texture, susceptible to severe erosion and are categorized under LC subclass IV esw. P6 and P7 soils occur on moderately steep side slopes and are moderately deep, gravelly sandy loam, susceptible to severe erosion and are rated as LC subclass IVes. P8 and P9 soils occur on moderately sloping side slopes and are rated as LC subclass IIIes. P10 soils occur on gently sloping valleys and are evaluated as LC subclass IIIe. Since the watershed area is highly prone to soil erosion, proper soil and water conservation practices must be adopted to arrest further erosion, to maintain soil health and for environmentally sustainable productivity. P1 to P5 soils are not suitable for cultivation but can be utilised for pasture and forestry development besides agroforestry and horticultural plantations whereas, P6 to P10 soils can be cultivated for agricultural crops with suitable integrated nutrient management practices for higher productivity.

Key Words: Pauri Garhwal; Watershed; Landform; Land Evaluation; Land Capability Class and Subclass

INTRODUCTION

Agri-environmental features are the key elements for sustainable agricultural land use planning. Sustainable agriculture implies the utilization of natural resources for food security of the present generation, without compromising the ability of future generations to ensure their food security. Climate, soil, water, landscape and hill slopes are the key constituents of the agri-environment which play vital role in the agricultural productivity. Mountainous lands are known for fragile ecosystem and hence requires careful management of natural resources for optimal land use planning. Several researchers (Kumar and Sharma 1987, Divakar et al. 1989, Rawat et al. 1994, Singh and Bhatnagar 1997, Ghosh and Singh 2002) have worked in hilly and mountainous region for research management of different locations but comprehensive information of Garhwal hills in Uttarakhand state is still scanty. The management of natural resources, specially soils has become imminent. Soil is the most important constituent of agri-environment that should be managed effectively, efficiently and optimally for sustainable agricultural production in these areas. But their multi-purpose use and continuous exploitation have serious impacts on the ecology. Information of the soil with respect to its genesis, characteristics, classification, location, extent and distribution, potentials and problems is imperative for any agricultural planning (Mahapatra et al. 2005, Gorai et al. 2013).

The watershed management is an important technique for sustainable mountain development of an area. It is a tool of managing human activities on an area by recognizing the inter-relationship among landform, land use, soil and water as well as linkage between uplands and adjoining lowlands (Biswas 1987, Mishra and Ghosh 1995, Pai et al. 2007). Information about soils are available at state level (Singh et al. 2004) which are in family level and cannot provide detailed soil information. The information about potential and problems of individual soils (soil series) can be available if those are studied at watershed/village/farm level surveys and may be useful for any kind of agricultural planning. Therefore, the present study has been undertaken to characterize and map the soils of Satpuli watershed in Garhwal hills of Uttarakhand, India using remote sensing and GIS techniques for promoting sustainable agriculture.

MATERIALS AND METHODS

Study Area

The study area is Satpuli watershed in Pauri Garhwal district of Uttarakhand state in India. It lies in between 29° 55' 23" to 30° 04' 49" N latitudes and 78° 40' 52" to 78° 45' 04" E longitudes covering 6730 ha area on Kotdwar -Pauri Road, with varied landforms and parent materials. The area falls in warm humid lesser Himalayas (Agro-ecological sub region 14.2) (Sehgal et al. 1992, Velayutham et al. 1999).The elevation ranges from 800-1900 m above MSL. The climate is moist to dry subhumid transitional ecosystem with warm summer and cool winters. The rainfall ranges from 1000 to 1300 mm. The soil moisture control section (SMCS) does not remain dry in any part of it for as long as 90 cumulative days in a year or any part of it does not remain dry for up to 45 consecutive days after summer solstice suggesting “udic” soil moisture regime in the area (Velayutham et al. 1999, Walia et al. 2013). During summer the average temperature is 20° C, varying between 13.6° C and 25.2° C, whereas, in winter the average mean temperature is 16.3 °C, varying between 11.1 °C and 19 °C. Thus, the area qualifies for “thermic” temperature regime (Walia et al. 2013, Gorai et al. 2013).

Image Interpretation and Ground Truth Verification

The Indian Remote Sensing satellite (IRS-ID LISS III) standard geocoded, false colour composite (FCC) on 1:50,000 scale (Figure 1) and Survey of India toposheet on same scale (53 K/13) were used to delineate the landform units. Geomorphic features were interpreted on the basis of key image elements such as shape, tone or colour, pattern, shadow, association and texture (Sahu et al. 2016). The landform units were checked and verified in the field before generating final landform map.

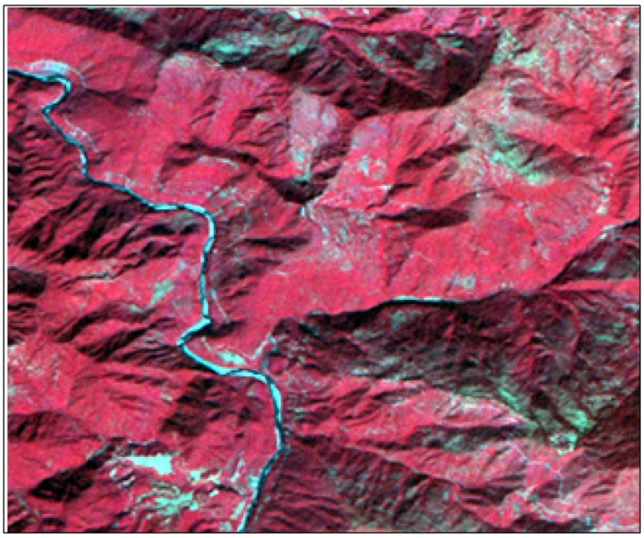

Figure 1. IRS-ID LISS IV imagery of the study area

Resource Characterization

The landform map was used for conducting soil survey to identify the soil types. Observations were studied in each landform unit and soil-landform relationship has been established. Different land use systems and parent materials were noted while traversing the area.

Soils of different landform units were studied in the field to determine their characteristics by digging minipits and master profiles following standard soil survey methods (Sehgal et al. 1987, Bhattacharya et al. 2009). Soils were classified as per soil taxonomy (Soil Survey Staff 2014) and the soil map has been prepared. The deteriorating environmental features viz. soil and land degradation, deforestation etc have been identified through traversing the study area and from available data sources.

The land capability classes (LCC) were determined as per the flow diagram depicted in Figure 2, on the basis of site characteristics (climate, landform, slope and erosion) and limitations of soils for plant growth based on soil depth, texture, stoniness, rockiness and permeability (Sys 1985, Sehgal 1996) and the land capability class (LCC) map has been generated.

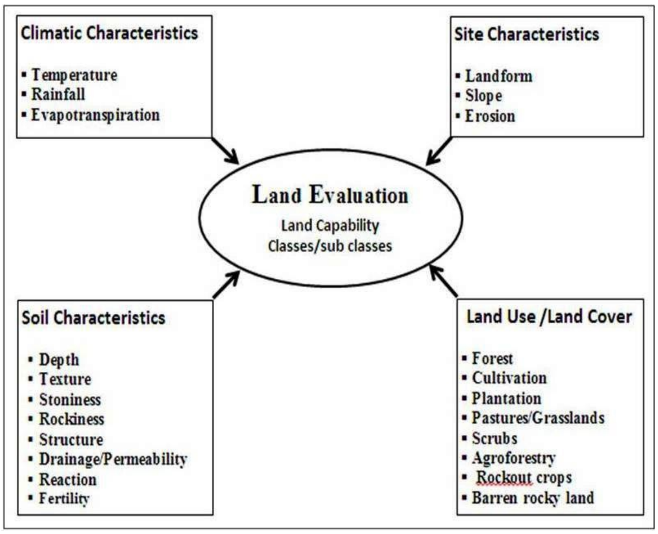

Figure 2. Flow diagram for Land Evaluation

RESULT AND DISCUSSION

Landform Analysis

The key elements of geomorphic features obtained from the image data viz., slope, tones of colour, pattern, shadow, association and texture were interpreted along with the terrain features viz., contours, land use, etc., obtained from the Survey of India toposheet to delineate hill slope, landforms and landuse and presented in Table 1. Seven landform units have been identified in the watershed (Figure 3). The study reveals that the major area belongs to moderately steeply sloping (15-30%) side/reposed slopes covering 2631 ha (39%) followed by very steeply sloping (> 50%) side/reposed slopes (1539 ha; 22.9%), steeply sloping (30-50%) hill/ridge tops (905 ha; 13.5%), moderately sloping (8-15%) side/reposed slopes (784 ha; 11.6%), very steeply sloping (>50%) escarpments (299 ha; 4.5%), gently sloping (3-8%) river valley (295 ha; 4.4%) and steeply sloping side/reposed slopes (277 ha; 4.1%), respectively. Major land uses are forest followed by cultivation, scrubs and barren/rocky lands, respectively.

Soil Characteristics

On the basis of field study and characterization of database, ten types of soils have been identified in the watershed area and described as P1 to P10. The characteristics of the soils have been presented in Table 2 and soil map has been depicted in Figure 4. P1 soils are very shallow in depth with only A horizon having abrupt smooth boundary, excessively drained, yellowish brown in colour, sandy loam in texture with strong coarse gravels, massive in structure, underlain by indurated bedrock at 18 cm depth and developed on quartzite. P2 soils are shallow in depth with A-AC-C horizons having clear smooth and abrupt smooth boundaries underlain by indurated bedrock at 46 cm depth and developed on quartzite. They are excessively drained, yellowish brown to light yellowish brown in colour, loamy sand in texture with strong coarse gravels throughout the profile increasing downwards and single grain in structure. P3 soils are moderately shallow in depth with A-AC-C horizons having clear smooth and abrupt smooth boundaries underlain by indurated bedrock at 71 cm depth and developed on sandstone. They are excessively drained, dark yellowish brown to yellowish brown in colour, sandy loam in texture with gravels throughout the profile increasing downwards and massive in structure. P4 soils are shallow in depth with A-AC-C horizons having clear smooth and abrupt smooth boundaries underlain by indurated bedrock at 47 cm depth and developed on sandstone. They are excessively drained, brown to yellowish brown in colour, sandy loam in texture with strong gravels throughout the profile increasing downwards and massive in structure. P5 soils are moderately shallow in depth with A-AC-C horizons having clear, gradual and abrupt smooth boundaries. They are developed on sandstone and are excessively drained, yellowish brown to dark yellowish brown in colour, loam in texture with gravels throughout the profile increasing downwards, massive in structure and underlain by indurated bedrock at 73 cm depth. P6 soils are developed on quartzite and are moderately deep in depth with A-AC-C horizons having clear, gradual and abrupt smooth boundaries. These soils are somewhat excessively drained, brown to yellowish brown in colour, sandy loam in texture with strong gravels throughout the profile increasing downwards, disturbed and massive in structure and underlain by indurated bed rock at 82 cm depth. P7 soils are moderately deep in depth with A-B-C horizons having clear, gradual and abrupt smooth boundaries; somewhat excessively drained and brown to

Table 1. Interpretation of satellite image data

Image characteristics	Landform	Slope	Land Use
1. Brownish and mottled colour, medium to coarse texture with small, irregular and scattered grain	Hill/ridge top	Steep	Scrubs, thin forest
2. Medium brown with coarse mottled colour, smooth to medium coarse texture, evenly scattered fine grains	Side/reposed slope	Very steep	Thin forest
3. Reddish with medium brown colour, mottled and medium smooth texture and irregular, medium scattered grains	Side/reposed slope	Steep	Thin forest with patches of cultivation
4. Medium gray to light brown with medium smooth, light mottling	Side/reposed slope	Moderately steep	Cultivation
5. Yellowish to light green with smooth, fine mottled texture and irregular, fine scattered grains	Side/reposed slope	Moderate	Cultivation
6. Light bluish tone with scattered white patches in diffused and irregular grains	Valley	Gentle	Cultivation
7. Medium brown to dark grayish and mottled colour with coarse to rough texture and small irregular scattered grains	Escarpments	Very steep	Barren rocky land

yellowish brown in colour. They are developed on sandstone and are sandy loam in texture; medium, weak sub angular blocky in structure and underlain by indurated bedrock at 84 cm depth. P8 soils are deep in depth with A-B-C horizons having clear, gradual and abrupt smooth boundaries underlain by indurated bedrock at 130 cm depth. These soils are developed on sandstone and are well drained, yellowish brown to dark yellowish brown in colour, sandy loam in texture and fine to medium, weak subangular blocky in structure. P9 soils are deep with A-B-C horizons having clear, gradual and abrupt smooth boundaries underlain by bedrock at 140 cm depth and developed on sandstone. They are well drained, brown to yellowish brown in colour, sandy loam in texture and medium, weak to moderate, subangular blocky in structure. P10 soils are developed on colluvium/alluvium and are very deep with A-B horizons having clear, gradual and abrupt smooth boundaries, well drained, brown to dark yellowish brown in colour, loam in texture and fine to medium, weak to moderate, subangular blocky in structure. Thus, it is revealed from the data that the type of soils depends on landforms and parent materials.

Soil Classification

Soils of the watershed have been classified as per USDA soil taxonomy and presented in Table 3. The temperature and moisture regimes of the study area are thermic and udic, respectively. The mineralogy of all the soils is mixed type. P1 soils are very shallow, sandy loam in texture with coarse gravels throughout the profile and have only A horizon underlain by indurated bedrock at 18 cm depth. Hence, they belong to Entisols having loamy skeletal family textural class (as the texture is sandy loam with more than 35% coarse gravels) and are classified as very shallow, mixed, thermic, loamy skeletal Lithic Udorthents. P2 soils are shallow, loamy sand in texture with coarse gravels throughout the profile and have A-AC-C horizons underlain by indurated bedrock at 46 cm depth. Hence, they belong to Entisols having sandy skeletal family textural class (as the texture is loamy sand with more than 35% coarse gravels) and are classified as shallow, mixed, thermic, sandy skeletal Lithic Udorthents. P3 soils are moderately shallow, sandy loam in texture with coarse gravels throughout the profile and have only A-AC-C horizons underlain by indurated bedrock at 71 cm depth. Hence, they belong to Entisols having coarse loamy family textural class and are classified as moderately shallow, mixed, thermic, coarse loamy Typic Udorthents. P4 soils are shallow, sandy loam in texture with coarse gravels throughout the profile and have A-AC-C horizons underlain by indurated bedrock at 47 cm depth. Hence, they belong to Entisols having loamy skeletal family textural class (as the texture is sandy loam with more than 35% coarse gravels) and are classified as shallow, mixed, thermic, loamy skeletal Lithic Udorthents. P5 soils are moderately shallow, loam in texture with coarse gravels throughout the profile and have A-AC-C horizons underlain by indurated bedrock at 73 cm depth. Hence, they belong to Entisols having coarse loamy family textural class and are classified as moderately shallow, mixed, thermic, coarse loamy, Typic Udorthents. P6 soils are moderately

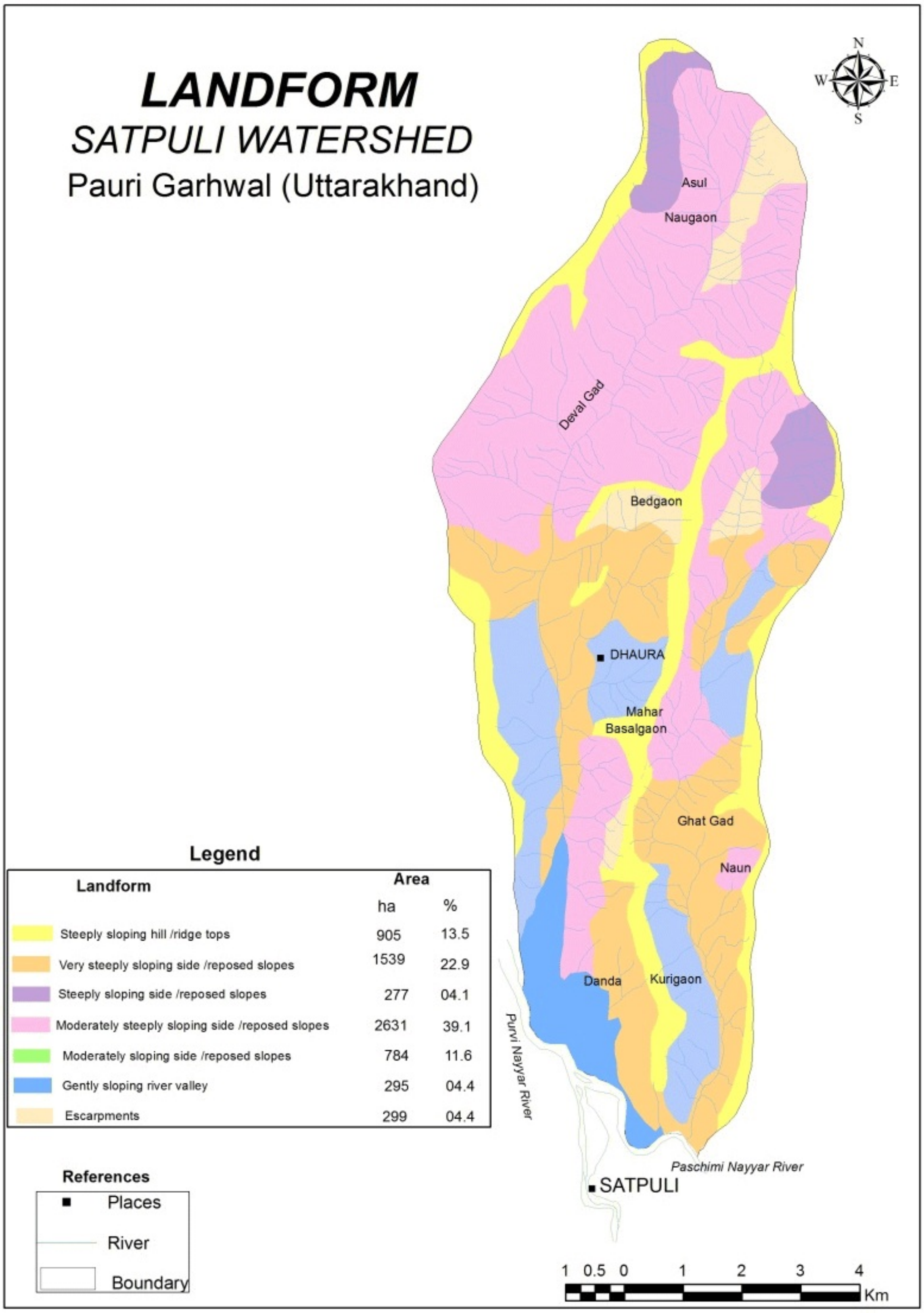

Figure 3. Landforms of the Satpuli watershed, Pauri Garhwal

Table 2. Characteristics of soils

Soils	Horizon	Depth	Boundary	Colour (moist)	Texture	Structure*	% Coarse gravel#
P1	A	0-18	Abrupt smooth	Yellowish brown	Sandy loam	m	45
	R	18+	Indurated bedrock	-	-	-	-
P2	A	0-16	Clear, smooth	Yellowish brown	Loamy sand	sg	38
	AC	16-33	Clear, smooth	Light yellowish brown	Loamy sand	sg	43
	C	33-46	Abrupt, smooth	Light yellowish brown	Loamy sand	sg	55
	R	46+	Indurated bedrock	-	-	-	-
P3	A1	0-17	Clear, smooth	Dark yellowish brown	Sandy loam	m	17
	A2	17-35	Clear, smooth	Yellowish brown	Sandy loam	m	20
	AC	35-52	Clear, smooth	Yellowish brown	Sandy loam	m	24
	C	52-71	Abrupt, smooth	Yellowish brown	Sandy loam	m	28
	R	71+	Indurated bedrock	-	-	-	-
P4	A	0-14	Clear, smooth	Brown	Sandy loam	m	40
	AC	14-29	Clear, smooth	Brown	Sandy loam	m	46
	C	29-47	Abrupt, smooth	Yellowish brown	Sandy loam	m	52
	R	47+	Indurated bedrock	-	-	-	-
P5	A1	0-18	Clear, smooth	Yellowish brown	Sandy loam	m	18
	A2	18-35	Gradual, smooth	Dark yellowish brown	Loam	m	23
	AC	35-53	Clear, smooth	Dark yellowish brown	Loam	m	26
	C	53-73	Abrupt, smooth	Yellowish brown	Loam	m	30
	R	73+	Indurated bedrock	-	-	-	-
P6	Ap	0-19	Clear, smooth	Brown	Sandy loam	d	30
	A2	19-37	Gradual, smooth	Yellowish brown	Sandy loam	d	38
	AC	37-57	Clear, smooth	Yellowish brown	Sandy loam	m	48
	C	57-82	Abrupt, smooth	Yellowish brown	Sandy loam	m	54
	R	82+	Indurated bedrock	-	-	-	-
P7	Ap	0-18	Clear, smooth	Brown	Sandy loam	d	12
	Bw1	18-35	Gradual, smooth	Yellowish brown	Sandy loam	m1sbk	15
	Bw2	35-57	Clear, smooth	Yellowish brown	Sandy loam	m1sbk	18
	C	57-84	Abrupt, smooth	Yellowish brown	Sandy loam	-	25
	R	84+	Indurated bedrock	-	-	-	-
P8	Ap	0-20	Clear, smooth	Yellowish brown	Sandy loam	d	10
	Bw1	20-45	Gradual, smooth	Dark yellowish brown	Sandy loam	f1sbk	12
	Bw2	45-74	Gradual, smooth	Dark yellowish brown	Sandy loam	m1sbk	14
	Bw3	74-102	Clear, smooth	Dark yellowish brown	Sandy loam	m1sbk	16
	C	102-130	Abrupt, smooth	Yellowish brown	Sandy loam	m	28
	R	130+	Indurated bedrock	-	-	-	-
P9	Ap	0-16	Clear, smooth	Brown	Sandy loam	d	8
	A2	16-35	Clear, smooth	Yellowish brown	Sandy loam	d	10
	Bw1	35-54	Gradual, smooth	Yellowish brown	Sandy loam	m1sbk	12
	Bw2	54-77	Gradual, smooth	Yellowish brown	Sandy loam	m2sbk	12
	Bw3	77-103	Clear, smooth	Yellowish brown	Sandy loam	m2sbk	15
	C	103-140	Abrupt, smooth	Yellowish brown	Sandy loam	m	22
	Cr	140+	Bedrock	-	-	-	-
P10	Ap	0-14	Clear, smooth	Brown	Sandy loam	f1sbk	8
	BA	14-32	Clear, smooth	Dark yellowish brown	Loam	f1sbk	10
	Bw1	32-51	Gradual, smooth	Dark yellowish brown	Loam	m1sbk	10
	Bw2	51-72	Gradual, smooth	Dark yellowish brown	Loam	m2sbk	13
	Bw3	72-93	Gradual, smooth	Dark yellowish brown	Loam	m2sbk	15
	Bw4	93-121	Gradual, smooth	Dark yellowish brown	Loam	m2sbk	15
	Bw5	121-150		Yellowish brown	Loam	m1sbk	18

* m: massive; sg: single grain; d: disturbed; m1sbk: medium weak subangular blocky; m2sbk: medium moderate subangular blocky; f1sbk: fine weak subangular blocky; # : >2 mm

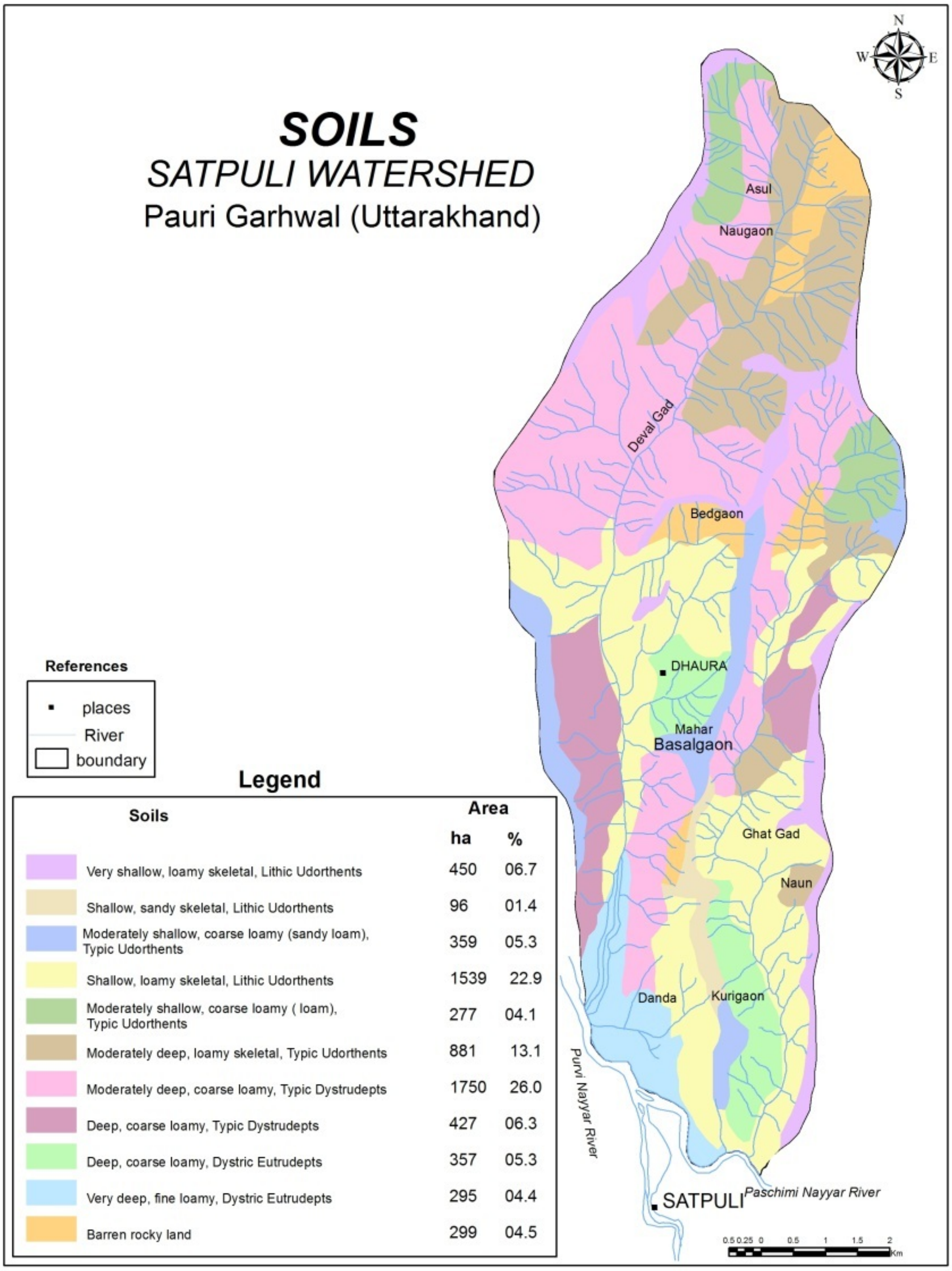

Figure 4. Soils of Satpuli watershed, Pauri Garhwal

Table 3. Taxonomy of soils

Soil	Description	Taxonomy	Area, ha	%
P1	Very shallow, excessively drained, gravelly sandy loam soils, yellowish brown in colour and developed on quartzite, Very shallow, mixed, thermic, loamy skeletal,	Lithic Udorthents	450	6.7
P2	Shallow, excessively drained, gravelly loamy sand soils, yellowish brown to light yellowish brown in colour and developed on quartzite, Shallow, mixed, thermic, sandy skeletal,	Lithic Udorthents	96	1.4
P3	Moderately shallow, excessively drained, sandy loam soils, dark yellowish brown to yellowish brown in colour and developed on sandstone, Moderately shallow, mixed, thermic, coarse loamy,	Typic Udorthents	359	5.3
P4	Shallow, excessively drained, gravelly sandy loam soils, brown to yellowish brown in colour and developed on sandstone, Shallow, mixed, thermic loamy skeletal,	Lithic Udorthents	1539	22.9
P5	Moderately shallow, excessively drained, loam soils, yellowish brown to dark yellowish brown in colour and developed on sandstone, Moderately shallow, mixed, thermic, coarse loamy,	Typic Udorthents	277	4.1
P6	Moderately deep, somewhat excessively drained, gravelly sandy loam soils, brown to yellowish brown in colour and developed on quartzite; Moderately deep, mixed, thermic, loamy skeletal,	Typic Udorthents	881	13.1
P7	Moderately deep, somewhat excessively drained, sandy loam soils, brown to yellowish brown in colour, medium, weak subangular blocky in structure and developed on sandstone, Moderately deep, mixed, thermic, coarse loamy,	Typic Dystrudepts	1750	26.0
P8	Deep, well drained, sandy loam soils, yellowish brown to dark yellowish brown colour, fine to medium, weak subangular blocky in structure and developed on sandstone, Deep, mixed, thermic, coarse loamy,	Typic Dystrudepts	427	6.3
P9	Deep, well drained, sandy loam soils, brown to yellowish brown in colour, medium, weak to moderate, subangular blocky in structure and developed on sandstone, Deep, mixed, thermic, coarse loamy,	Dystric Eutrudepts	357	5.3
P10	Very deep, well drained, loam soils of brown to dark yellowish brown colour, fine to medium, weak to moderate, subangular blocky in structure and developed on colluvium/alluvium, Very deep, mixed, thermic, coarse loamy,	Dystric Eutrudepts	295	4.4
	Barren rocky land	Barren rocky land	299	4.5
	Total		6730	100

deep, sandy loam in texture with coarse gravels throughout the profile and have A-AC-C horizons underlain by indurated bedrock at 82 cm depth. Hence, they belong to Entisols having loamy skeletal family textural class (as the texture is sandy loam with more than 35% coarse gravels) and are classified as moderately deep, mixed, thermic, loamy skeletal Typic Udorthents. P7 soils are moderately deep; sandy loam in texture; medium, weak subangular blocky in structure and have A-B-C horizons underlain by indurated bedrock at 84 cm depth. These soils are comparatively well developed having cambic diagnostic horizon and hence belong to Inceptisols. They have base saturation less than 60% and no free carbonates throughout the profile and are classified as moderately deep, mixed, thermic, coarse loamy, Typic Dystrudepts. P8 soils are deep; sandy loam in texture; fine to medium, weak subangular blocky in structure and have A-B-C horizons underlain by indurated bedrock at 130 cm depth and developed on sandstone. These soils are also well developed having cambic diagnostic horizon and belong to Inceptisols having base saturation less than 60% and no free carbonates throughout the profile and hence are classified as deep, mixed, thermic, coarse loamy, Typic Dystrudepts. P9 soils are deep; sandy loam in texture; medium, weak and moderate subangular blocky in structure and have A-B-C horizons underlain by bedrock at 140 cm depth. These soils are also well developed having cambic diagnostic horizon and hence belong to Inceptisols being classified as deep, mixed, thermic, coarse loamy, Dystric Eutrudepts. P10 soils are very deep; loam in texture; fine to medium, weak and moderate, subangular blocky in structure and have A-B horizons. They are the most developed soil in the study area having cambic diagnostic sub-surface horizon and belong to Inceptisols having fine loamy family textural class. Hence, they are classified as very deep, mixed, thermic, fine loamy, Dystric Eutrudepts.

Thus the study reveals that major soils of the watershed belong to Entisols covering 3602 ha (53.5%) area followed by Inceptisols occupying 2829 ha (42.0%) and barren rocky lands covering 299 ha (4.5%) area, respectively. Among the Entisols, Lithic (very shallow to shallow in depth i.e. less than 50 cm) Udorthents covers more area (2085 ha, 31.0 %) whereas, Typic Udorthents cover 1517 ha (22.5%) area. Among the Inceptisols, Typic Dystrudepts cover major area (2177 ha, 32.3 %) followed by Dystric Eutrudepts occupying 652 ha (9.7%) area, respectively.

Land Evaluation and Land Use Planning

The present land use systems of different landforms of the watershed area has been presented in Table 1. In order to recommend sustainable land use plans of the watershed area for attaining optimal productivity, the evaluation of lands by considering their potential and limitation are essential. Therefore, the soils of the watershed have been evaluated into land capability classes and subclasses based on their characteristics, limitations and potentials (Figure 5 and Table 4). P1 and P2 soils occur on steeply sloping hill/ridge tops whereas P4 soils occur on very steeply sloping side/reposed slopes. They are very shallow to shallow in depth, coarse textured (loamy sand to coarse sandy loam) with strong gravelliness and susceptible to very severe erosion and droughtiness. They are evaluated as class IV lands under land capability classification and subclass IV sew. They are very low in water holding capacity, poor in fertility status and have very low productivity potential. Construction of engineering structures are recommended in these areas to arrest soil erosion and selection of plants for pasture and forestry development adapted to limitation of soils and climate. P3 and P5 soils occur on steeply sloping hill/ridge tops and side/reposed slopes, respectively. They are moderately shallow in depth with gravels throughout the profile and susceptible to severe erosion and droughtiness. They are evaluated as land capability class IV lands and subclass IV esw. They are low in water holding capacity, poor in fertility status and have low productivity potential. Adoption of soil and water conservation practices are recommended with selection of plants for pasture and forestry development adapted to limitation of soils and climate. Horticultural plantations may be encouraged besides agroforestry development. P6 and P7 soils occur on moderately steeply sloping side/reposed slopes and are moderately deep, coarse textured (sandy loam) with moderate to strong gravels throughout the profile and susceptible to severe erosion. They are rated as land capability class IV and subclass IVes. They are low in water holding capacity, poor in fertility status and have low productivity potential. Development of engineering structures are recommended to arrest soil erosion and integrated nutrient management (INM) practices involving recommended doses of organic and inorganic fertilizers and selection of crops adapted to limitation of soils and climate. P8 and P9 soils occur on moderately sloping side/reposed slopes and are deep, coarse textured (sandy loam) with gravels throughout the profile and susceptible to moderate erosion. They are evaluated as land capability class III and subclass III es. They are low in water holding capacity, fertility status and productivity potential. Agricultural crops adapted to climate can be grown by adoption of soil and water conservation practices and INM practices involving recommended doses of organic and inorganic fertilizers, besides horticultural plantations. P10 soils occur on gently sloping river valleys and are very deep in depth and loam in texture with gravels throughout the profile. They are evaluated as land capability class III and subclass IIIe. They are medium in water holding capacity, fertility status and productivity potential. They are recommended for cultivation of crops adapted to climate under proper soil and water management practices. The barren and rocky lands which occur on very steep slopes and susceptible to very severe erosion, are not fit for cultivation but may be used for pasture development with construction of proper engineering structures.

Deteriorating Agri-Environmental Features

The soils of the study area are highly prone to degradation problems (Figure 6). The agri-environment is affected by several factors viz., steep slopes, soil erosion, landslides, deforestation, overgrazing, indiscriminate human interventions, etc., as well as high intensity low frequency rainfall prevailing in the area. The process of soil erosion involves detachment, transport and subsequent deposition (Meyer and Wischmeier 1969). Soil particles are removed from the particular hill

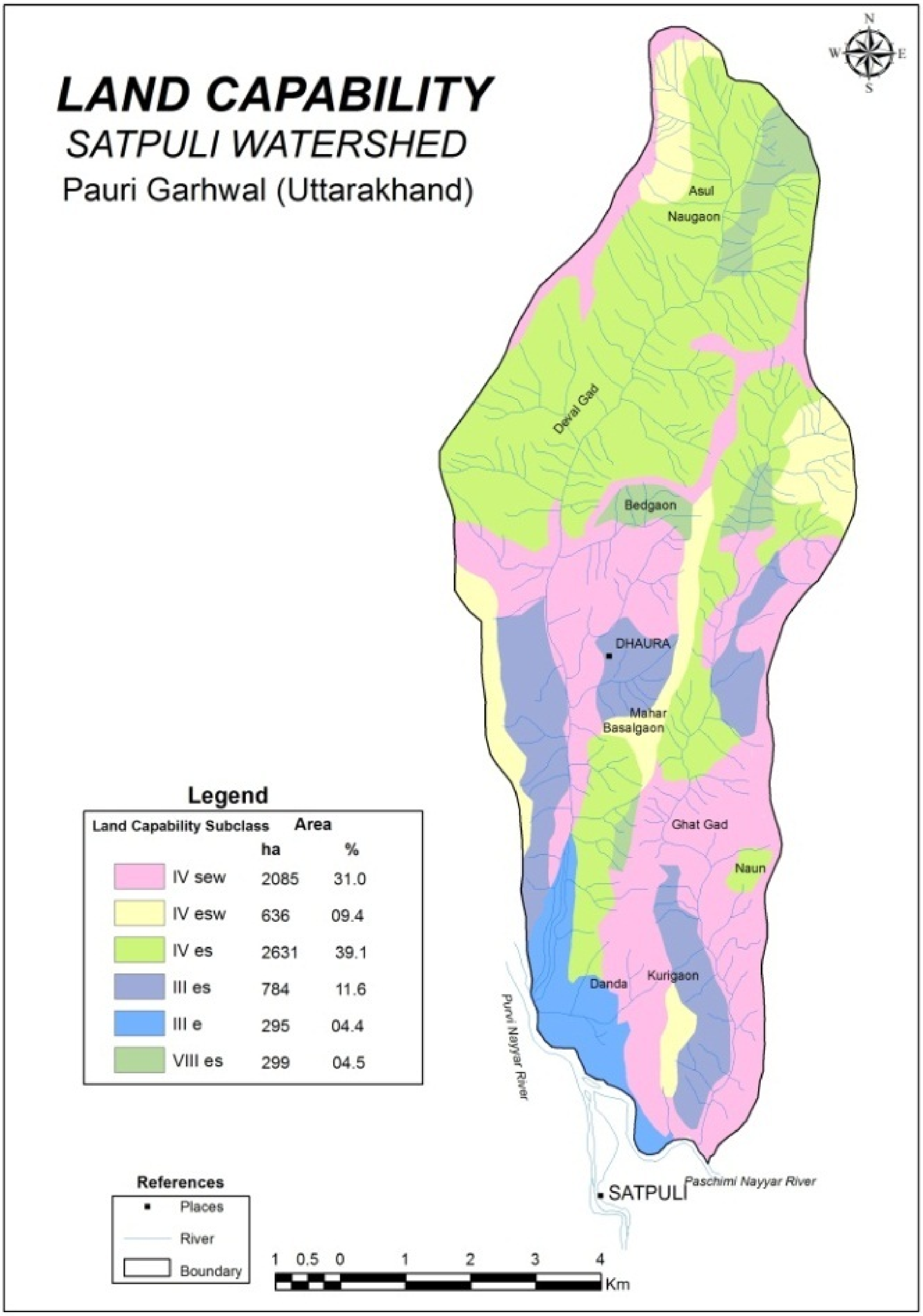

Figure 5. Land capability subclasses of Satpuli watershed, Pauri Garhwal

Table 4. Land capability classes and subclasses

Soils	Limitations	Land capability class and subclass	Area, ha (%)	Management recommendation
1. P1, P2, P4	Very shallow to shallow soil depth, steep to very steep slope, coarse soil texture (loamy sand), strong gravelliness, very severe erosion and droghtiness	IV sew	2085 (31)	Construction of engineering structures, selection of plants adapted to limitation of soils and climate
2. P3, P5	Steep slope, very severe erosion, limited soil depth, (moderately shallow), coarse texture (sandy loam), gravelliness and droughtiness	IV esw	636 (9.4)	Adoption of soil and water conservation practices, selection of plants adapted to limitation of soils and climate. Horti-cultural plantations may be encouraged, besides agro forestry.
3. P6, P7	Moderate steep slopes, severe erosion, limited soil depth (moderately deep) coarse texture (sandy loam), moderate to strong gravelliness	IV es	2631 (39.1)	Development of engineering structures to arrest soil erosion, INM practices involving recommended doses of organic and inorganic fertilizers, selection of crops adapted to limitation of soils and climate.
4. P8, P9	Moderately slopping lands, moderate erosion, coarse texture (sandy loam), gravelliness	III es	784 (11.6)	Adoption of soil and water conservation practices, INM practices involving recommended doses of organic and inorganic fertilizers, selection of climatically adopted cereal crops and horticultural plantations.
5. P10	Sloppy landscape, moderate erosion	III e	295 (4.4)	Cultivation of cereal crops adaptable to the climate with proper soil and water management practices.
6.	Barren rocky land; Very steeply sloping rocky lands, very severe erosion	VIII es	299 (4.5)	Not fit for cultivation, may be used for pasture development with construction of proper engineering structures.

slope or slope segment (Toy and Renard 1998). Inappropriate agricultural practices, overgrazing and indiscriminate deforestation cause soil degradation which results decline in soil fertility, productivity and soil quality besides environmental hazards (Blum 1997).

Due to degradation features occurring in the area viz., soil erosion, landslides, climatic hazards, etc, agriculture is under stress affecting its sustainability and threatening the food security. Hence, proper engineering measures as well as soil and water conservation practices should be adopted to arrest further degradation and sustainable management of agri-environment to maintain soil health and enhance crop productivity.

Soil and Water Conservation Measures

Since the soils of the watershed are highly prone to degradation problems, proper engineering measures, mainly the soil and water conservation practices, need to be undertaken. The soil and water conservation practices to be adopted in moderate erosion areas are crop diversification with emphasis on erosion resistant crops and cropping patterns viz. inter cropping, strip cropping etc., safe disposal of excess runoff to water harvesting bodies viz. ponds, dams, etc., introduction of silvi-pastoral and horti-pastoral systems on degraded lands, appropriate engineering measures like land levelling, terracing in agricultural fields and contour trenching in other land uses, contour farming to check soil erosion and conserve soil moisture in soil profile. The conservation measures to be applied in severe erosion areas include combination of biotic and abiotic measures such as integrated watershed management with emphasis on catchments to reduce sediment flow, in-situ soil

A. Erosion due to landslides

B. Erosion due to sheet detachment

C. Erosion due to deforestation

D. Erosion due to overgrazing

Figure 6. Soil erosion and deforestation, Pauri Garhwal

moisture conservation for establishment and growth of forest ecosystem, diversion of excess runoff in monsoon season to water harvesting structures for supplemental irrigations to plants, establishment of permanent cover on the current fallows for proper resource utilization, adoption of silvi-pastoral or horti-pastoral systems with emphasis on cover management and ensuring people participation in hill development and sharing of forest resources through suitable legislations. Vegetation or plant cover reduces the soil erosion, its effectiveness depending upon the height and continuity of canopy, density of ground cover and root density. Roots play an important role in reducing erosion rate by binding the soil mass to increase its resistance to flow. Generally forests are most effective in reducing erosion because of their canopy; dense grass is equally effective. Hence, afforestation and plantation may be encouraged in non-cultivable areas to arrest erosion of soils. The areas which are not suitable for agriculture and tree growth may be used for pasture development (Singh et al. 1990, Sidhu et al. 2010).

Identification of landforms and soils as well as study of agri-environment are thus very much essential for conservation of natural resources and watershed development. Soil is the most precious natural resource and hence, it should be managed effectively and optimally for sustainable agricultural production and livelihood security of hilly people.

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