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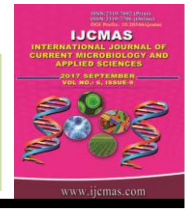

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Delineation and Characterization of Purvi Nayyar River Watershed in Mid-Himalayan Region of India Using Remote Sensing and GIS Techniques

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A B S T R A C T

Remote sensing and GIS techniques were used to delineate and characterize the Purvi Nayyar river watershed in Pauri Garhwal district of Uttarakhand, India pertaining to warm humid Himalayan ecosystem. Based on image characteristics and ground truth studies, four major physiographies *viz*., hill/ridge tops, side/reposed slopes, valleys and escarpments were delineated. They were further subdivided into ten physiographic units based on slopes and integrated with land use systems to delineate physiographic land units (PLU). Ten soils were identified occurring on different PLUs. Major soils occur on hill/ridge tops and side/reposed slopes and are very shallow to moderately shallow in depth, excessively drained, gravelly loamy sand and coarse sandy loam in texture and single grain to massive in structure. They have only A-C horizons underlain by indurated bed rock at 11 to 81 cm depth and belong to *Entisols*. Soils of valleys are deep to very deep, well drained, sandy loam to sandy clay loam in texture, medium, weak and moderate subangular blocky in structure having A-B-C horizons and belong to *Inceptisols.* Soils are acidic in nature with low to medium cation exchange capapcity and very low to low water holding capacity. Since, the watershed area is highly prone to various kinds of degradation, suitable soil and water conservation measures have been suggested to maintain soil health and integrated development of the area.

Keywords

Warm humid Himalayas, Pauri Garhwal, Watershed, Physiographic land unit, Entisols, Inceptisols and Land degradation.

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Introduction

Watershed is an area of land and water bounded by a drainage divide within which the surface runoff accumulates and flows out of the watershed through a single outlet into a large river or lake. The watershed programme is primarily a land based programme, which is increasingly being focused on water, with its main objective being to enhance agricultural productivity through increased moisture conservation and protective irrigation for socio-economic development of rural people. Integrated watershed management aims to alleviate poverty and improve living standards by improving sustainable livelihood opportunities for households and communities whose needs are met from a watershed's natural resources. It also improves the conservation and protection of forest areas that are important for preserving biodiversity and protecting water resources for sustainable economic productivity. The development of hill and mountain areas and protection of their ecology have become matters of national concern in recent years. These areas differ from the plains in topography, elevation, physiographic features, diversity of habitats for flora and fauna, ethnic diversity, land use systems and socio-economic conditions. In accessibility, fragility, marginality, heterogeneity, natural instability and human adaptation mechanism are the key factors to be focused for sustainable agricultural development in such areas. Thus, management of natural resources, specially soils has become imminent in this region. Soils are indispensable natural resources for any developmental planning in hilly region (Mahapatra *et al.*, 2005) but their indiscriminate use and over exploitation have adverse impact on the ecology (Blum, 1997 and Gorai *et al.*, 2013). Application of remote sensing and GIS techniques were found to be very useful in soil resource inventory (Dwivedi, 2001; Reddy *et al.*, 2008; Srivastava and Saxena, 2004). Mishra and Ghosh (1995) and Pai *et al.*, (2007) established soil-landform relationship and found it to be useful criteria for site specific management of soils. Some researchers have worked on some specific sites of hilly region (Kumar and Sharma 1987; Divakar *et al.*, 1989; Rawat *et al.*, 1994; Singh and Bhatnagar 1997; Ghosh and Singh 2002) but information on the soils of Garhwal region is still inadequate.

Agricultural production in the Garhwal region of warm humid Himalayas showed declining trend in the recent past. Soil losses were estimated to be high due to significant land use changes like construction of dams and other non-agricultural activities. Potential agricultural lands were lost along the river terraces. This caused stress on the available land for agricultural production in the region to meet the food demands. Therefore, a concern for watershed management through the soil resource inventory and spatial data generation was felt as the need for systematic assessment and agricultural planning.

Therefore, the present study was undertaken with an objective to delineate and characterize the Purvi Nayyar river watershed in mid Himalayan region using remote sensing and GIS techniques for the agricultural and overall development of the area (Fig. 1).

Materials and Methods

Study area

The study area belongs to Purvi Nayyar river watershed of Pauri Garhwal district of Uttarakhand state in India, spread over 29°53’45’’ to 29°58’50’’ N latitudes and 78°54’48’’ to 78°59’47’’E longitudes covering7,480 ha area. The area falls under warm humid lesser Himalayas, Agro-ecological sub region (AESR) 14.2 and is marked with rugged terrain having steep and high ridges. The elevation ranges from 1100to 2697 m above msl. The area is drained through Purvi Nayyar River and several drainage channels including *khads*. This river is merged into the main Nayyar River which ultimately merges into the river Ganga.

A 3 tier approach was adopted to assess the soil resources *i.e.*, image interpretation, ground truth verification and soil resource characterization.

Image interpretation and ground truth verification

The soil resource inventory was made by interpreting the Indian Remote Sensing satellite (IRS-ID LISS III) data FCC encoded imageries of bands 2, 3 and 4 and Survey of India toposheet (53 K/13) were interpreted 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). Landforms identified were further subdivided into physiographic units based on their elemental characteristics and slope functions of landforms. Physiographic land unit (PLU) map was generated by incorporating physiography with land use/land cover and corrected through ground truth verification. Different land use systems and parent materials were noted while traversing the area and during the ground truth observations.

Soil resource inventory and characterization

Soil survey was conducted using PLU map. Soils of different physiographic units and land use systems were studied in the field to determine morphological properties by digging mini pits and master pedons (Sehgal *et al.,* 1987; Bhattacharya *et al.,* 2009). Soil physiography relationship was established. Soil samples of each horizon of representative pedons were collected and characterised for important properties (Black 1965; Jackson 1966; Sharma *et al.,* 1987). Different soil series identified in different physiographic units were classified as per the soil taxonomy (Soil Survey Staff 2014).Soil and thematic maps were generated using GIS technique. Based on physiography, type of soils and their constraints and potentials, appropriate management practices and land use plans have been suggested for higher productivity.

Results and Discussion

Delineation of physiographic land units (PLU)

Image interpretation resulted into delineation of four major physiographies *viz*., hill/ridge tops, side/reposed slopes, valleys and very steeply sloping escarpments. Based on the image elements and slope functions they were further divided into ten physiographic units *viz*., steeply sloping hill/ridge tops, moderately steeply sloping hill/ridge tops, moderately sloping hill/ridge tops, very steeply sloping side/reposed slopes, steeply sloping side/reposed slopes, moderately steeply sloping side/reposed slopes, moderately sloping side/reposed slopes, gently sloping narrow valleys, very gently sloping broad valleys and very steeply sloping escarpments. Different land use systems identified are barren and scrub land, thin forest and bushes, dense forest, medium forest, grazing land, cultivated land, cultivated land along with plantations, barren and denuded land, respectively. The physiographic land unit map generated by incorporating physiographic units and land use (Table 1) has been depicted in figure 2. The map contained ten PLUs and was used for soil resource inventory of the watershed area.

Soils and their properties

On the basis of ground truth study and soil resource characterization ten types of soil (P1 to P10) have been identified *viz*., *Phoolchatti, Umrda, Jollu, Mundai, Kainur, Maun, Bhandeli, Sigadi, Gularjhala and Chourikhal,* respectively. They have been mapped as phases of soil series (based on surface texture, slope and erosion) containing 18 soil mapping units. The soil map has been depicted in figure 3 and their properties have been described in table 2. *Phoolchatti* (P1) soils are very shallow in depth with only a horizon having abrupt smooth boundary, yellowish brown in colour, loamy sand in texture with strong coarse gravels, single grain in structure, underlain by indurated bedrock at 11 cm depth and developed on mica schist. *Umrda* (P2) soils are shallow in depth with A-C horizons having clear and abrupt smooth boundaries, yellowish brown in colour, sandy loam in texture with strong coarse gravels, massive and single grain in structure underlain by indurated bedrock at 27 cm depth and developed on sandstone. *Jollu* (P3) soils are moderately shallow in depth with A-AC-C horizons having clear, gradual and abrupt smooth boundaries underlain by indurated bedrock at 73 cm depth and developed on mica schist. They are dark yellowish brown to yellowish brown in colour, loamy sand in texture and single grain in structure. *Mundai* (P4) soils are moderately deep in depth with A-C horizons having gradual, clear and abrupt smooth boundaries underlain by indurated bedrock at 80 cm depth and developed on mica schist. They are grayish brown to dark grayish brown in colour, loamy sand in texture with strong gravels throughout the profile increasing downwards and single grain in structure. *Kainur* (P5) soils are very shallow in depth with only a horizon having abrupt smooth boundary, grayish brown in colour, loamy sand in texture with strong coarse gravels, single grain in structure, underlain by indurated bedrock at 22 cm depth and developed on mica schist. *Maun* (P6) soils are shallow in depth with A-C horizons having clear and abrupt smooth boundaries, brown in colour, sandy loam in texture with strong coarse gravels, disturbed and single grain in structure underlain by indurated bedrock at 32 cm depth and developed on sandstone. *Bhandeli* (P7) soils are moderately deep in depth with A-C horizons having clear, gradual and abrupt smooth boundaries underlain by indurated bedrock at 81 cm depth and developed on mica schist. They are dark grayish brown to grayish brown in colour, loamy sand in texture and single grain in structure. *Sigadi* (P8) soils are deep in depth with A-C horizons having clear, gradual and abrupt smooth boundaries underlain by indurated bedrock at 105 cm depth and developed on sandstone. They are dark yellowish brown to yellowish brown in colour, sandy loam in texture, disturbed and single grain in structure. *Gularjhala* (P9) soils are deep in depth with A-B-C horizons having clear, gradual and abrupt smooth boundaries underlain by unconsolidated bedrock at 115 cm depth and developed on colluvium/alluvium. They are dark yellowish brown to yellowish brown in colour, sandy loam in texture, disturbed and medium, weak, sub angular blocky in structure. *Chourikhal* (P10) soils are very deep in depth with A-B horizons having gradual and clear smooth boundaries developed on alluvium/colluvium. They are brown to dark yellowish brown in colour, sandy clay loam in texture and disturbed, fine and medium, weak and moderate sub angular blocky in structure. Thus, the study revealed that the physiography and parent materials played an important role in development and determination of types of soils.

The soils are acidic (pH varies from 5.3 to 6.2) in reaction (Fig. 4) with major soils belonging to slight (pH 6.1 - 6.5) to moderately acidic (pH 5.6 - 6.0) with patches of strongly acidic (pH 5.1 - 5.5) soils. The acidic nature of the soils is due to leaching of bases because of sloppy landscape and high intensity rainfall prevailing in the area. The electrical conductivity (Fig. 5) is very low to low (EC less than 0.50 dSm^{-1}) due to removal of soluble salts from the soil profiles at higher elevations as mentioned in soil reaction. The distribution of clay particles in the soils of the study area (Fig. 6) revealed that it is low to very low in hill/ridge tops and side/reposed slopes whereas, it is moderate to comparatively high in valleys due to removal of finer soil particles from the higher elevations along with runoff water during heavy rains and its deposition in lower areas. The cation exchange capacity (CEC) of the soils has been depicted in figure 7 which revealed that CEC is very low to low with medium value in patches. It is due to the reason that the soils are mainly coarse texture (loamy sand to coarse sandy loam) except *Chourikhal* soils which is sandy clay loam in texture. The values of CEC are controlled by organic matter, clay content and its constituent clay minerals (Sawhney *et al.*, 1996; Gorai *et al.*, 2013).

Taxonomy of soils

Soils of the watershed has 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 are*mixed* type. *Phoolchatti* soils are very shallow, excessively drained, loamy sand in texture with coarse gravels throughout the profile and have only a horizon underlain by indurated bedrock at 11 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 very shallow, mixed, thermic, sandy skeletal Lithic Udorthents. *Umrda*soils are shallow, excessively drained, sandy loam in texture with coarse gravels throughout the profile and have A-C horizons underlain by indurated bedrock at 27 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. *Jollu* soils are moderately shallow, excessively drained, loamy sand in texture and have A-AC-C horizons underlain by indurated bedrock at 73 cm depth. Hence, they belong to *Entisols* having sandy family textural class and are classified as moderately shallow, mixed, thermic, Typic Udipssaments. *Mundai* soils are moderately deep, excessively drained, loamy sand in texture with coarse gravels throughout the profile and have A-C horizons underlain by indurated bedrock at 80 cm depth. Hence, they belong to *Entisols* having sandy skeletal family textural class and are classified as moderately deep, mixed, thermic, sandy skeletal Typic Udorthents. *Kainur*soils are very shallow, excessively drained, loamy sand in texture with coarse gravels throughout the profile and have only a horizon underlain by indurated bedrock at 22 cm depth. Hence, they belong to *Entisols* having sandy skeletal family textural class and are classified as very shallow, mixed, thermic, sandy skeletal Lithic Udorthents. *Maun* soils are shallow, excessively drained, sandy loam in texture with coarse gravels throughout the profile and have A-C horizons underlain by indurated bedrock at 32 cm depth. Hence, they belong to *Entisols* having loamy skeletal family textural class and are classified as shallow, mixed, thermic, loamy skeletal Lithic Udorthents. *Bhandeli* soils are moderately deep, excessively drained, loamy sand in texture and have A-C horizons underlain by indurated bedrock at 81 cm depth. Hence, they belong to *Entisols* having sandy family textural class and are classified as moderately deep, mixed, thermic, Typic Udipssaments. *Sigadi* soils are deep, somewhat excessively drained, sandyloam in texture and have A-C horizons underlain by indurated bedrock at 105 cm depth. Hence, they belong to *Entisols* having coarse loamy family textural class and are classified as deep, mixed, thermic, coarse loamy, Typic Udorthents. *Gularjhala* soils are deep, sandy loam in texture, medium, weak subangular blocky in structure and have A-B-C horizons underlain by unconsolidated bed rock at 115 cm depth. These soils are comparatively well developed having cambic diagnostic (Bw) horizon and hence 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. *Chourikhal* soils are very deep, sandy clay loam in texture, fine to medium, weak and moderate, sub angular blocky in structure and have A-B horizons.

Table.1 Interpretation of remote sensing data

S. No.	Image Characteristics	Physiography	Land Use
1	Blackish tone with dark brown to reddish patches and rough texture	Steeply sloping hill/ridge tops	Mostly barren and scrub land
2	Dark brown tone with reddish patch and coarse texture	Moderately steeply sloping hill/ridge tops	Thin forest and bushes
3	Bright red tone, smooth texture with dense granular patches	Moderately sloping hill/ridge tops	Dense forest
4	Light bluish tone with light brownish patches, medium coarse texture	Very steeply sloping side/reposed slopes	Barren and scrub land
5	Bright bluish tone, medium coarse texture	Steeply sloping side/reposed slopes	Grazing land
6	Bluish tone, coarse texture and scattered grains	Moderately steeply sloping side/ reposed slopes	Mostly cultivated land
7	Whitish tone, smooth texture and fine scattered grains	Moderately sloping side/ reposed slopes	Medium forest
8	Light pinkish and brownish tone, scattered grains and mottled texture	Gently sloping narrow valleys	Mostly cultivated land
9	Light pinkish and whitish tone with smooth and diffused texture	Very gently sloping broad valleys	Cultivated land along with fruit plantations
10	Dark blackish brown tone, coarse texture and irregularly scattered grains	Very steeply sloping escarpments	Barren and denuded

Table.2 Characteristics of the soils

Soil series	**Horizon**	**Depth (cm)**	**Boundary**	**Colour**	**Texture**	**Structure***
Phoolchatti (PI)	A	0-11	Abrupt, smooth	Yellowish brown	Gravelly loamy sand	Single grain
	R	11+	Indurated bedrock	-	-	-
Umrda (P2)	A	0-15	Clear, smooth	Yellowish brown	Gravelly sandy loam	Massive
	C	15-27	Abrupt, smooth	Yellowish brown	Gravelly sandy loam	Single grain
	R	27+	Indurated bedrock rock	-	-	-
Jollu (P3)	A1	0-16	Clear, smooth	Dark yellowish brown	Loamy sand	Single grain
	A2	16-35	Gradual, smooth	Yellowish brown	Loamy sand	Single grain
	AC	35-62	Clear, smooth	Yellowish brown	Loamy sand	Single grain
	C	62-73	Abrupt, smooth	Yellowish brown	Loamy sand	Single grain
	R	73+	Indurated bedrock	-	-	-
Mundai (P4)	A1	0-15	Gradual, smooth	Grayish brown	Gravelly loamy sand	Single grain
	A2	15-36	Clear, smooth	Grayish brown	Gravelly loamy sand	Single grain
	C	36-80	Abrupt, smooth	Dark grayish brown	Gravelly loamy sand	Single grain
	R	80+	Indurated bedrock	-	-	-
Kainur (P5)	A	0-22	Abrupt, smooth	Grayish brown	Gravelly loamy sand	Single grain
	R	22^{+}	Indurated bedrock	-	-	-
Maun (P6)	Ap	0-15	Clear, smooth	Brown	Gravelly sandy loam	Disturbed
	C	15-32	Abrupt, smooth	Brown	Gravelly sandy loam	Single grain
	R	32+	Indurated bedrock	-	-	-
Bhandeli (P7)	A1	0-14	Clear, smooth	Dark grayish brown	Sandy loam	Massive
	A2	14-36	Gradual, smooth	Grayish brown	Loamy sand	Single grain
	A3	36-55	Gradual, smooth	Grayish brown	Loamy sand	Single grain
	C	55-81	Abrupt, smooth	Dark grayish brown	Loamy sand	Single grain
	R	81+	Indurated bedrock	-	-	-
Sigadi (P8)	Ap	0-16	Clear, smooth	Dark yellowish brown	Sandy loam	Disturbed
	A2	16-38	Clear, smooth	Yellowish brown	Sandy loam	Disturbed
	A3	38-67	Gradual, smooth	Yellowish brown	Sandy loam	Single grain
	C	67-105	Abrupt, smooth	Yellowish brown	Loamy sand	Single grain
	R	105+	Indurated bedrock	-	-	-
Gularjhala (P9)	Ap	0-19	Clear smooth	Dark brown	Sandy loam	Disturbed
	Bw1	19-36	Gradual smooth	Dark yellowish brown	Sandy loam	m1sbk
	Bw2	36-61	Gradual smooth	Dark yellowish brown	Sandy loam	m1sbk
	Bw3	61-92	Clear smooth	Dark yellowish brown	Sandy loam	m1sbk
	C	92-115	Abrupt smooth	Dark yellowish brown	Sandy loam	f1sbk
	C_R	115+	Unconsolidated bedrock	-	-	-
Chourikhal (P10)	Ap	0-15	Gradual, smooth	Brown	Sandy clay loam	Disturbed
	A2	15-34	Clear, smooth	Brown	Sandy clay loam	Disturbed
	Bw1	34-50	Clear, smooth	Brown	Sandy clay loam	f1sbk
	Bw2	50-77	Gradual, smooth	Dark yellowish brown	Sandy clay loam	m1sbk
	Bw3	77-104	Gradual, smooth	Dark yellowish brown	Sandy clay loam	m2sbk
	Bw4	104-134	Gradual, smooth	Dark yellowish brown	Sandy clay loam	m2sbk
	Bw5	134-158	Clear, smooth	Dark yellowish brown	Sandy clay loam	m2sbk

* m 1 sbk: Medium, weak, sub angular blocky; f 1 sbk: fine weak sub angular blocky; m 2 sbk: medium, moderate, sub angular blocky.

Table.3 Taxonomy of soils

Soils	Description	Taxonomy
Phoolchatti (P1)	Very shallow, excessively drained, gravelly loamy sand soils of yellowish brown colour developed on mica schist	Lithic Udorthents
Umrda (P2)	Shallow, excessively drained, gravelly sandy loam soils of yellowish brown colour developed on sandstone	Lithic Udorthents
Jollu (P3)	Moderately shallow, excessively drained, loamy sand soils of yellowish brown colour, developed on mica schist	TypicUdipsamments
Mundai (P4)	Moderately deep, excessively drained, gravelly loamy sand soils of grayish brown colour developed on mica schist	TypicUdorthents
Kainur (P5)	Very shallow, excessively drained, gravelly loamy sand soils of grayish brown colour developed on mica schist	Lithic Udorthents
Maun (P6)	Shallow, excessively drained, gravelly sandy loam soils of brown colour developed on sandstone	Lithic Udorthents
Bhandeli (P7)	Moderately deep, excessively drained, loamy sand soils of grayish brown colour, developed on mica schist	TypicUdipsamments
Sigadi (P8)	Deep, somewhat excessively drained, sandy loam soils of yellowish brown colour developed on sandstone	TypicUdorthents
Gularjhala (P9)	Deep, well drained, sandy loam soils of dark yellowish brown colour, medium weak sub angular blocky structure, developed on colluvium/alluvium	TypicDystrudepts
Chourikhal (P10)	Very deep, well drained, sandy clay loam soils of brown to dark yellowish brown colour, medium moderate sub angular blocky structure, developed on alluvium/colluvium	DystricEutrudepts

Fig.1 Study area, Purvi Nayyar River watershed, Pauri Garhwal

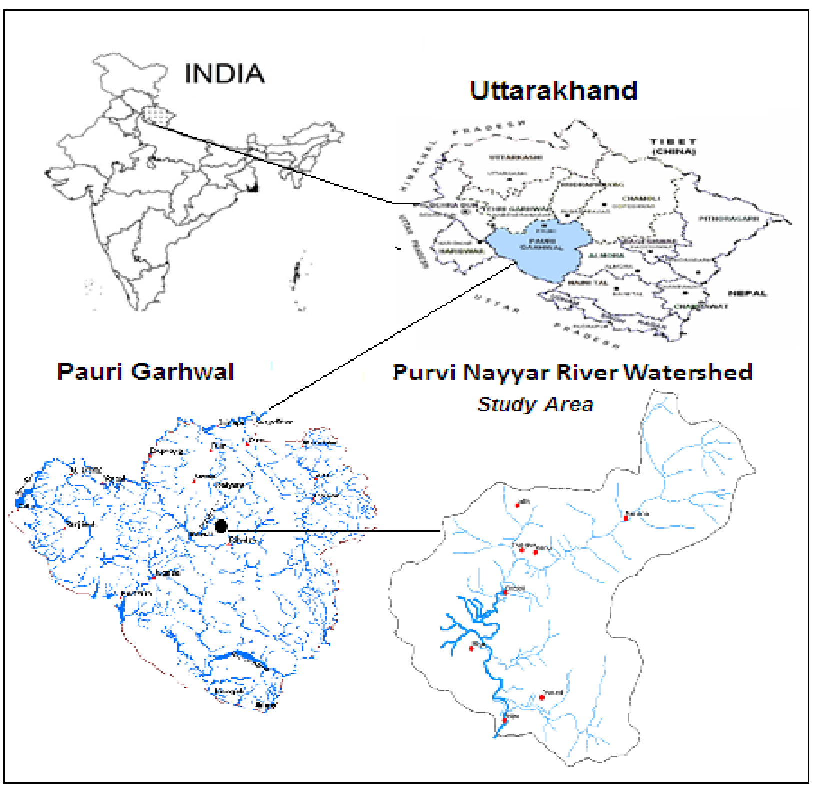

Fig.2 Physiographic land unit (PLU) map of Purvi Nayyar river watershed

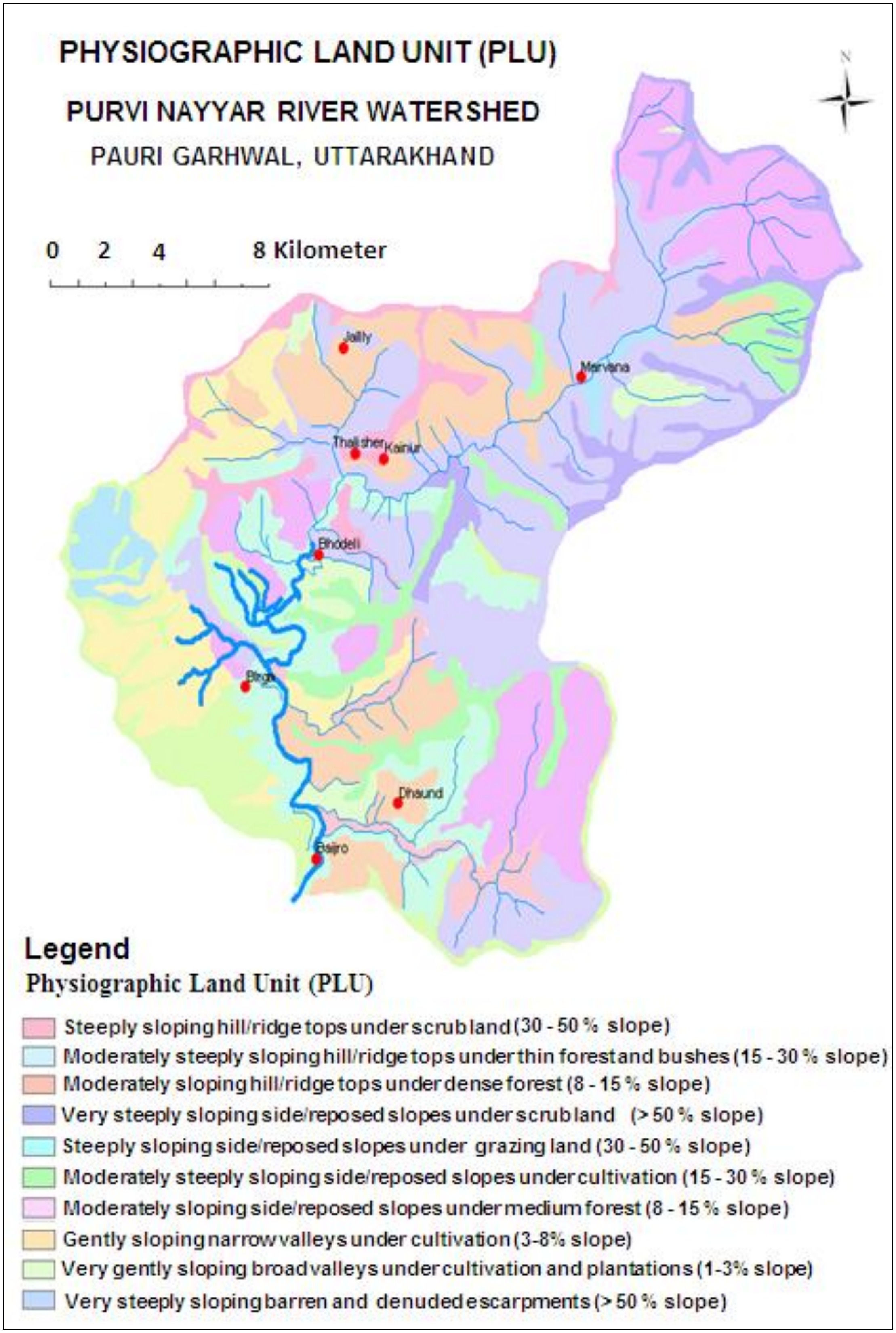

Fig.3 Soil map of Purvi Nayyar river watershed

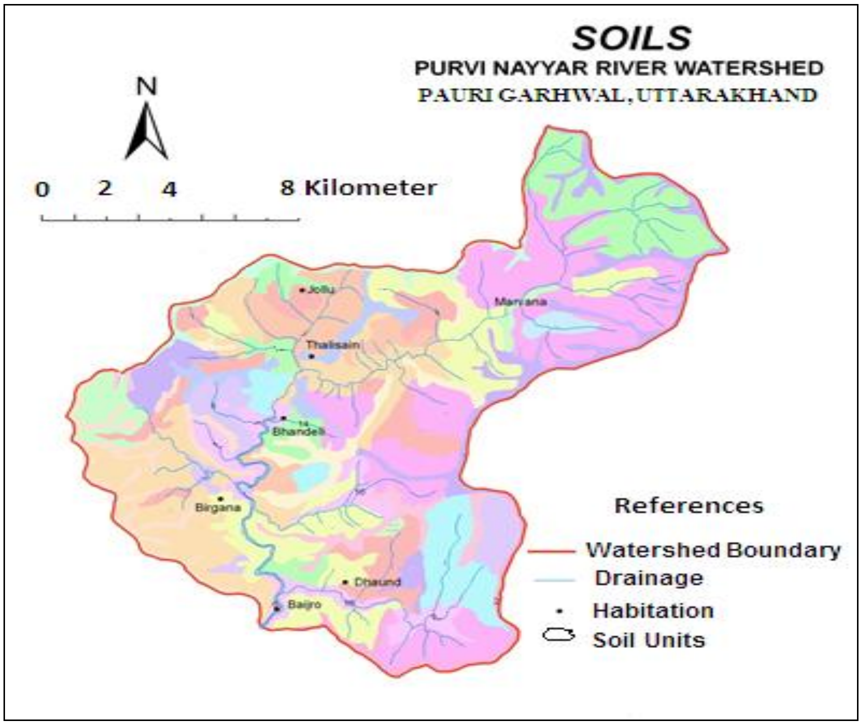

Fig.4 Soil reaction (pH) map of Purvi Nayyar river watershed

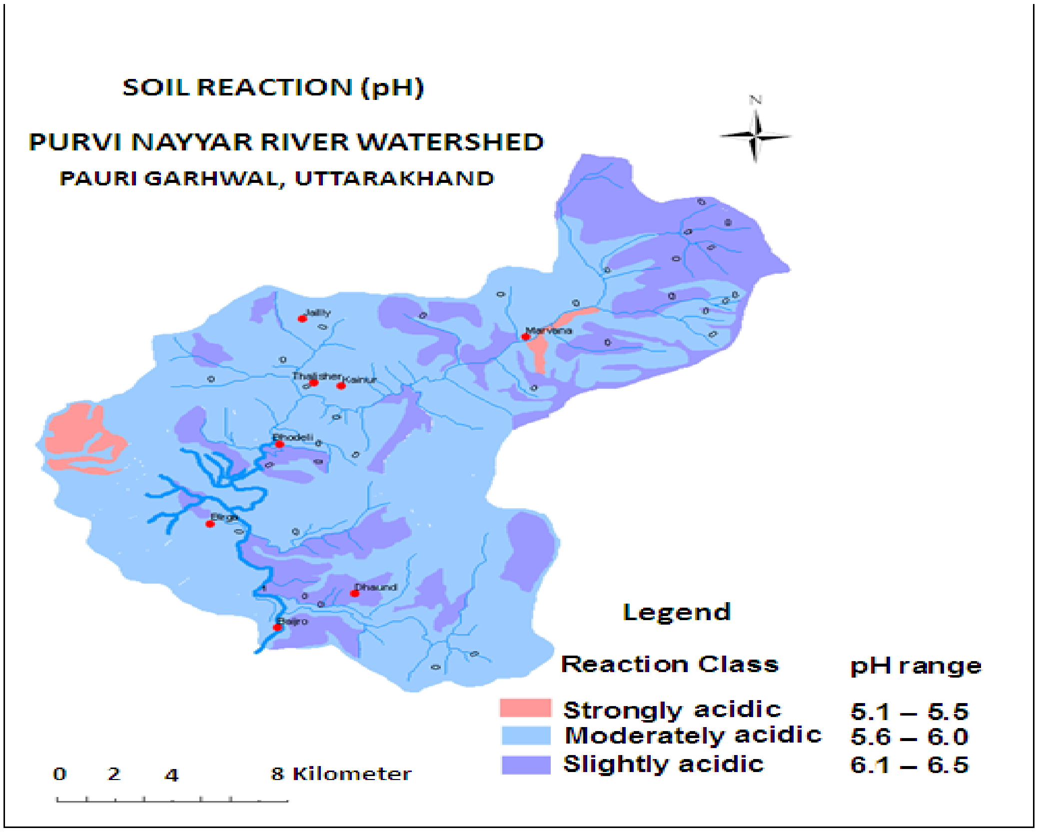

Fig.5 Electrical conductivity (EC) map of Purvi Nayyar river watershed

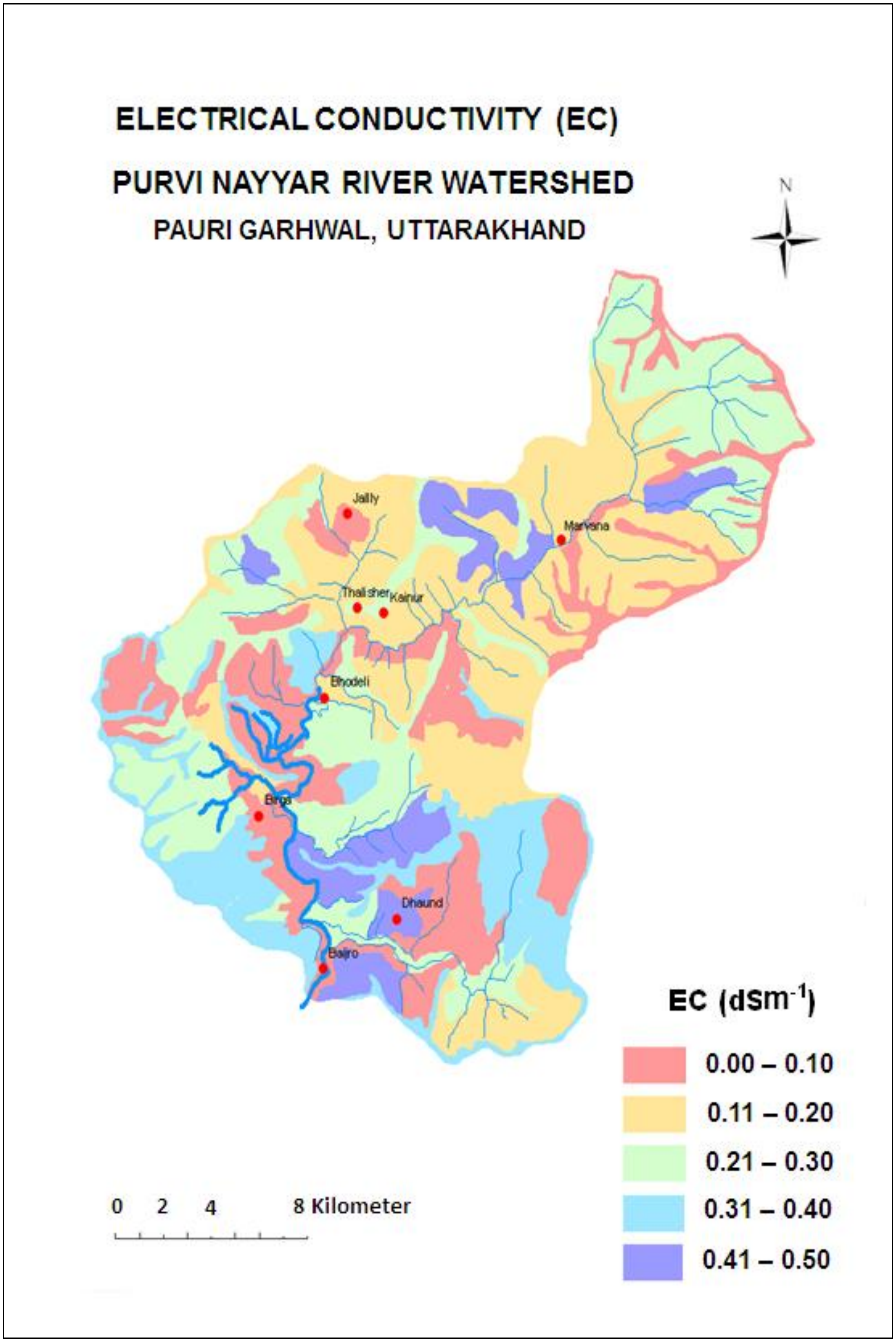

Fig.6 Clay content map of Purvi Nayyar river watershed

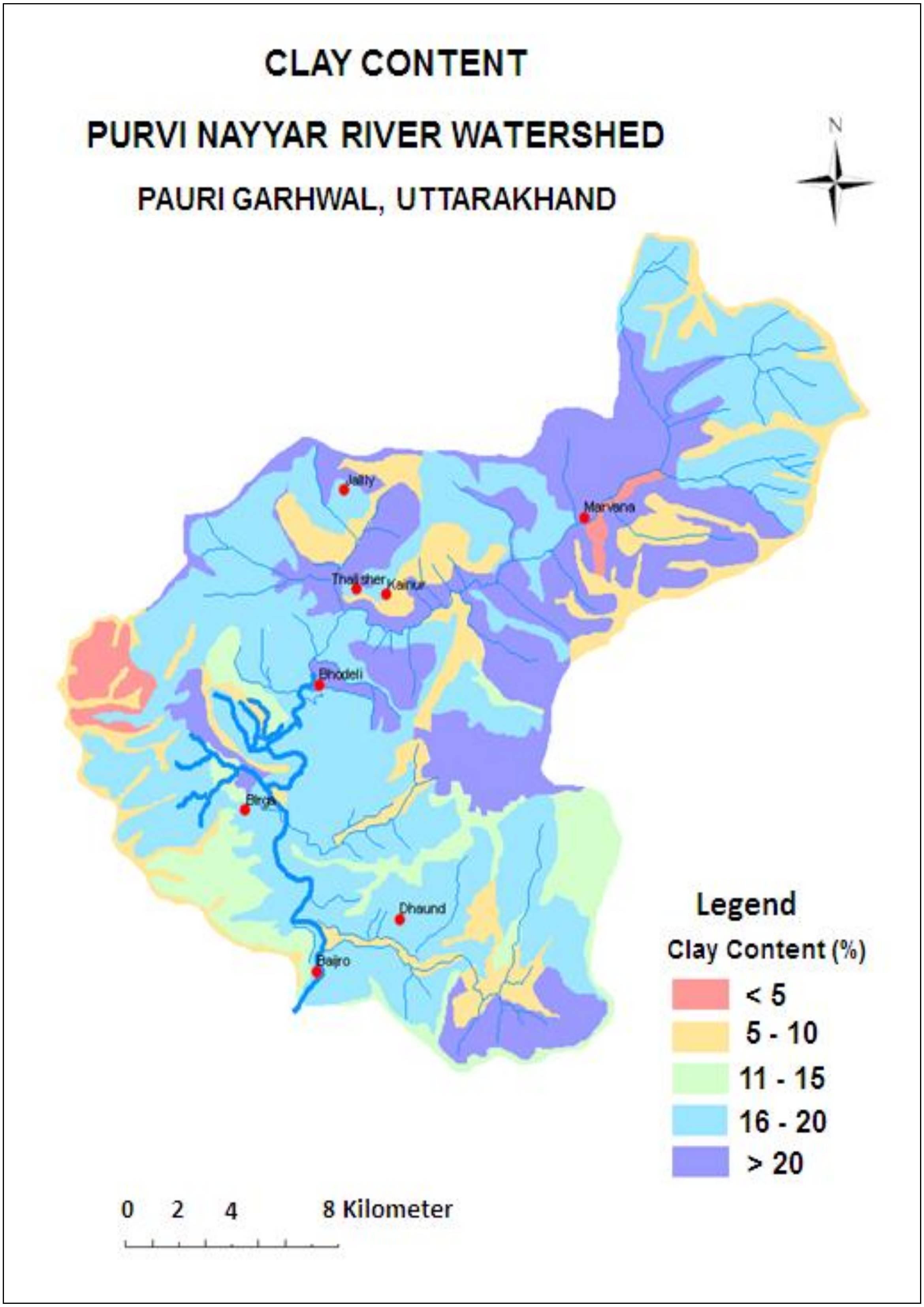

Fig.7 Cationexchange capacity (CEC) map of Purvi Nayyar river watershed

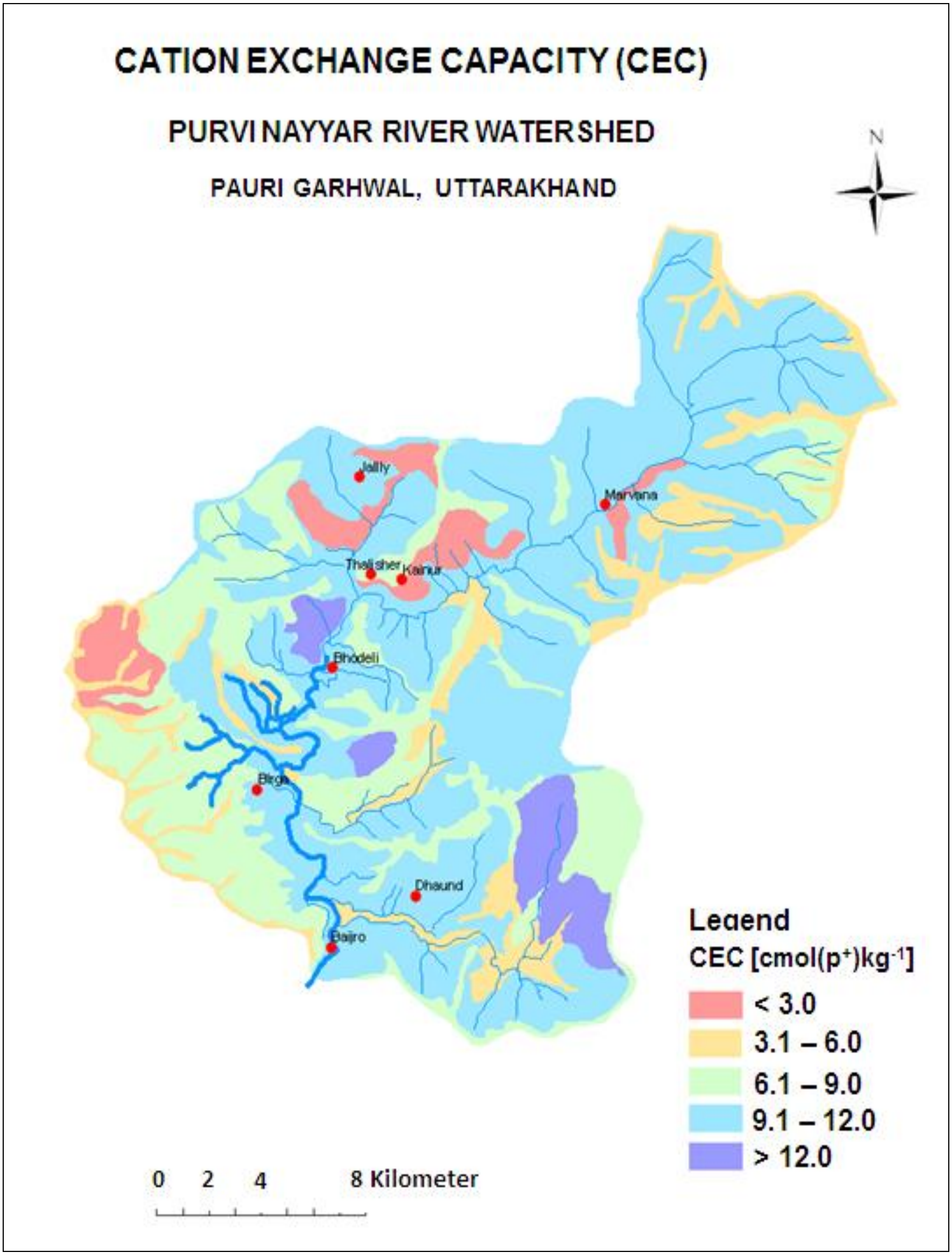

Fig.8 Soil erosion and deforestation in study area

They are the most developed soils in the study area having cambic diagnostic sub-surface horizon and belong to *Inceptisols* having fine loamy family textural class and base saturation more than 60%and no free carbonates throughout the profile. Hence they are classified as very deep, mixed, thermic, fine loamy, Dystric Eutrudepts.

Thus, from the data it is revealed that major soils of the watershed belong to Entisols followed by Inceptisols. Among the Entisols, Lithic (very shallow to shallow in depth i.e. less than 50 cm) Udorthents cover more area than Typic Udorthents. Among the Inceptisols, Typic Dystrudepts occupy major area than Dystric Eutrudepts.

Soil erosion and its remedial measures

The study area is highly susceptible to various kinds of degradational constraints *viz*., severe to very severe soil erosion, deforestation, landslides, etc. (Fig. 8). The major causes of land degradation are sloppy landscape, human interventions (deforestation and overgrazing), high intense and low frequent rainfall and inappropriate agricultural activities. It leads to poor soil fertility, low productivity and poor soil quality besides environmental hazards (Blum, 1997). The present agriculture system in this region is under threat due to these degradational features and continuous exploitation of the natural resources. Thus, agricultural sustainability and food security have become a major concern in this hilly region. Hence, it is required to adopt the proper soil and water conservation measures to minimize the risk of natural resource degradation for enhancing crop productivity.

Proper engineering measures as well as soil and water conservation practices should be undertaken to protect the soils from further deteriorations. The conservation practices to be implemented are include contour trenching/staggered trenching/contour furrows, close spacing erosion resistant crops, inter-cropping or strip cropping. Soil management practices such as land leveling are required to improve organic matter and soil structure. Adoption of silvi-pastoral or horti-pastoral systems with emphasis on cover management, vegetation or plant cover, pasture and forest development, terraces and grass water ways be done to reduce the soil erosion. Development of proper engineering structures may be implemented for disposal of excess rain water to water harvesting bodies' *viz*., ponds, reservoirs, etc. to minimise the degradations caused by water erosion. Besides, afforestation may be encouraged on priority bases to arrest soil erosion (Nagdev *et al.*, 2017). The areas of shallow soils which are not suitable for agriculture and tree growth may be used for pasture development (Singh *et al.*, 1990; Sidhu *et al.*, 2010). The crops may be cultivated using good agronomic practices like contour farming, mulching, inter-cropping with legumes, application of high yielding seeds, manures, fertilizers, etc.

Thus, the study revealed that by using remote sensing and GIS techniques physiographic boundaries could be delineated in details and the information extracted from FCC could be extrapolated to inaccessible areas with similar image characteristics. Identification of landforms and soils as well as study of agri-environmental features are pre-requisites for conservation of natural resources and watershed development. Soil is the most indispensable natural resource and hence, it should be managed carefully for sustainable agricultural production and livelihood security of the people of this hilly region.

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