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Characterization and Classification of the Soils of Bino-River Watershed in Almora District of Uttarakhand, India for Perspective Land Use Planning

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A B S T R A C T

Soils of Bino-river watershed in Almora district of Uttarakhand, India in north western Himalayas were characterised and classified for land categorisation and perspective land use planning. On the basis of interpretation of remote sensing data and ground truth verification three broad landforms *viz*., ridge tops, side slopes and valleys were identified and further sub-divided into seven landform units based on slope gradients. Nine types of soils (Pedons 1 to 9) were identified in the watershed area. Soils of valleys (Pedons 1 to 3) occur on gentle to moderates lopes and are moderately deep to very deep, well to somewhat excessively drained, sandy loam, gravelly sandy loam and loamy sand to sand in texture and slightly acidic to neutral (pH 6.11 to 6.98) in reaction. They haveA-B-C horizons in pedon 1, being classified as coarse loamy Dystric Eutrudepts and A-C horizons in pedons 2 and 3, being classified as loamy skeletal Typic Udorthents and Typic Udipsamments. They are evaluated as class III and V lands. Soils of side slopes (Pedons 4 to 7) occur on moderate to steep slopes and are shallow to moderately shallow in depth, well to excessively drained, sandy loam, gravelly sandy loam and gravelly loamy sand in texture and moderately acidic to slightly acidic (pH 5.52 to 6.49) in reaction. They have A-C horizons being classified as coarse loamy, sandy skeletal/loamy skeletal, Typic/Lithic Udorthents. They are assessed under class IV, V and VI land categories. Soils of ridge tops (Pedons 8 and 9) occur on moderately steep to steep slopes and are very shallow to shallow in depth, excessively drained, gravelly sandy loam in texture and moderately acidic (pH 5.64 to 5.95) in reaction. They have A-C and only Ahorizons and are classified as loamy skeletal Lithic Udorthents. They are evaluated as class VI and VII lands and not suitable for cultivation /plantations. The watershed area is prone to various kinds of degradation and hence proper soil and water conservation measures as well as good agronomic practices may be adopted to maintain soil health and increase productivity.

Introduction

Mountainous lands are at the risk of degradation and have serious impact on agricultural productivity and overall ecology. Thus, the development of the hilly region becomes a global concern for ecological balance and sustainable development of

agriculture (FAO, 2015). The watershed management is an important tool for the sustainable development of mountainous region. The watershed management lays emphasis on the water conservation practices for assured irrigation. In the hilly region the watershed development is the appropriate technique for improving the agricultural productivity, alleviation of poverty, economic and overall development of the community (Nagdev *et al.,* 2017a). For the development of any watershed area it is imperative to understand the inter-relationship among the landform, landuse and natural resources (Biswas, 1987; Mishra and Ghosh, 1995; Pai *et al.,* 2007; Nagdev *et al.,* 2018). Among the all natural resources, soil is the most prominent resource for developmental planning of any area (Mahapatra *et al.,* 2005; Nagdev *et al.,* 2017b). But its extensive use and continuous deterioration render serious threat to the ecology (Blum, 1997; Gorai *et al.,* 2013). The management of soil should be efficient and judicious for sustainable agricultural production. Most of the researchers worked on the development of soils in some specific sites (Kumar and Sharma, 1987; Divakar *et al.,* 1989; Rawat*et al.,* 1994; Singh and Bhatnagar, 1997; Ghosh and Singh, 2002) but the information of soils in remote areas of Himalayan region is limited. Therefore, a concern for development of any watershed area through the management of soil resources is required for enhancing agricultural productivity. Mahapatra *et al.,* (2018) reported that the Uttarakhand state is affected by moderate to severe soil erosion due to deforestation, human intervention, climatic instability and natural disasters and poses serious threat to agricultural productivity. Thus, the present study was undertaken to characterize and classify the soils of Bino-river watershed in Almora district of Uttarakhand in India for enhancing agricultural productivity and overall development of this hilly region.

Materials and Methods

Study area

The study area is Bino-river watershed which falls in warm humid Kumaon region of northwest Himalayas (Fig. 1). The area covers Chhani, Chachroti and Aphaukhala villages in Almora district of Uttarakhand. It represents agro-ecological sub region (AESR) No. 14.2 *i.e.* warm, moist dry sub-humid (Velayutham *et al.,* 1999) and marked with rugged terrain having steep and high ridges. It lays between 29°47.5' to 29°49.2' latitudes and 79°12.1' to 79°15' longitudes covering 1463 ha area. The elevation ranges from 1012 to 1495 m above MSL. The mean minimum and maximum temperatures are 2°C and 24°C and thus the area qualifies for *thermic* temperature regime (Walia *et al.,* 2013; Gorai *et al.,* 2013). The mean annual rainfall is about 1500 mm. The soil moisture control section (SMCS) does not remain dry for 90 cumulative days in a year or does not remain dry for 45 consecutive days after summer solstice, thus qualifying the area for *udic* soil moisture regime.

Delineation of landforms units

IRS 1D LISS III geo-coded false colour composite (FCC) on bands 2, 3 and 4 were visually interpreted with Survey of India toposheet for delineation of the watershed and landform units (Sahu *et al.,* 2016). The study area was traversed for ground truth verification of landform units and slopes in the field and base map was prepared for conducting soil survey work in the watershed area.

Soil sampling and analysis

Detailed soil survey was conducted using interpreted base map and soil pedons occurring on different landform units were studied in the field for their morphological

characteristics (Sehgal *et al.*, 1987; Bhattacharya *et al.*, 2009). Soil samples were collected from the different horizons of representative pedons. Soil samples were analysed for their physico-chemical parameters *viz.*, sand, silt, clay, soil reaction (pH), electrical conductivity (EC), organic carbon (OC), cation exchange capacity (CEC), exchangeable cations (Ca, Mg, Na and K) and base saturation (BS) using standard methods (Black 1965; Jackson 1966; Sharma *et al.*, 1987).

Soil classification and land categorisation

Soils were classified as per Keys to Soil Taxonomy (Soil Survey Staff 2014) and the transect was prepared for establishment of soil-landscape relationship. The soils were evaluated for different land categories on the basis of site characteristics (climate, landform, slope and erosion) and limitation of soils based on properties *viz*., soil depth, texture, stoniness, rockiness and nutrient retention capacity (Sys, 1985; Sehgal, 1996). On the basis of land categories, ameliorative measures have been suggested for increasing productivity.

Results and Discussion

Site characteristics of the soils

On the basis of detailed soil survey conducted in the watershed area, nine soils (Pedons 1 to 9) have been identified. The site characteristics *viz*., landform, slope, parent material, erosion status and present land use of the soils are presented in Table 1. The broadland forms identified in the watershed are valleys, side slopes and ridge tops and further sub-divided into 7 landform units based on slope gradients. The transect showing all the soil pedons occurring on different landscapes (landform) has been depicted in figure 2. It is revealed that soils of pedons 1 and 2 occur on gently sloping valleys, developed on alluvium parent material and suffers from slight erosion problem. The present land use of both the soils is cultivation. Soils of pedon 3 occur on moderately slopping cultivated land in valleys, developed on mica schist/colluvium parent materials and are affected by moderate erosion. Pedon4 soils occur on moderately sloping cultivated side slopes, developed on quartzite parent material and suffer from moderate erosion problem. Pedon 5 soils occur on steep side slopes under forest, developed on mica schist parent material and suffer from severe erosion problem. Soils of pedon 6 occur on moderately steep side slopes under pasture land, developed on quartzite parent material and suffer from severe erosion. Soils of pedon 7 occur on moderately sloping hill sides under pastures, developed on mica schist and affected with moderate erosion problem. Pedon 8 soils occur on moderately steeply sloping ridge tops under forest, developed on quartzite parent material and suffer from severe soil erosion. Soils of pedon 9 occurs on steeply sloping ridge tops covered under shrubs and rocky land, developed on quartzite rock and suffer from very severe erosion problem.

Morphological characteristics of soils

The morphological characteristics of the soils of the watershed are described in Table 2. Soils of pedon 1 are very deep with Ap-A2-Bw1-Bw2-Bw3-Bw4-C horizons; well drained; brown in colour; sandy loam in texture; medium, weak, sub-angular blocky in structure; slightly hard, friable, slightly sticky and slightly plastic in consistency having clear smooth and gradual smooth horizon boundaries. Soils of pedon 2 are very deep with Ap-A2-A3-AC-C1-C2-C3 horizons; well drained; brown to yellowish brown in colour; sandy loam in texture with strong gravels throughout the profile increasing downwards;

massive in structure; slightly hard, friable, slightly sticky and non-plastic in consistency having clear smooth and gradual smooth horizon boundaries. Pedon 3 soils are moderately deep with Ap-A2-A3-C horizons; somewhat excessively drained; brown to yellowish brown in colour; loamy sand and sand in texture; single grain in structure; loose, very friable, non-sticky and non plastic in consistency having clear smooth, gradual smooth and abrupt smooth horizon boundaries underlain by unconsolidated bedrock at 85 cm depth. Soils of pedon4 are moderately shallow in depth with Ap-A2-A3-C horizons; well drained; brown to yellowish brown in colour; sandy loam in texture with gravels throughout the profile; massive in structure; loose, friable, slightly sticky and non-plastic in consistency having clear smooth, gradual smooth and abrupt smooth horizon boundaries underlain by unconsolidated bedrock at 72 cm depth. Pedon 5 soils are moderately shallow having A1-A2-C1-C2 horizons; excessively drained; brown to yellowish brown in colour; loamy sand in texture with strong gravels throughout the profile increasing downwards; single grain in structure; loose, very friable, non-sticky and non-plastic in consistency having clear smooth, gradual smooth and abrupt smooth horizon boundaries underlain by unconsolidated bedrock at 73 cm depth. Pedon 6 soils are moderately shallow with A1-A2-C horizons; somewhat excessively drained; brown to dark yellowish brown in colour; sandy loam in texture with strong gravels throughout the profile; massive in structure; slightly hard, friable, slightly sticky and non-plastic in consistency having clear smooth and abrupt smooth horizon boundaries underlain by indurated bedrock at 69 cm depth. Soils of pedon 7 are shallow with A1-A2-C horizons; excessively drained; brown to yellowish brown in colour; loamy sand in texture with strong gravels throughout the profile; single grain in structure; loose, very friable, non-sticky and non plastic in consistency having clear smooth and abrupt smooth horizon boundaries underlain by indurated bedrock at 48 cm depth. Pedon8 soils are shallow with A and C horizons; excessively drained; brown to yellowish brown in colour; sandy loam in texture with strong gravels in both horizons; massive in structure; slightly hard; friable, slightly sticky and non-plastic in consistency having clear smooth and abrupt smooth horizon boundaries underlain by indurated bedrock at 32 cm depth. Pedon 9 soils are very shallow with only one A horizon; excessively drained; brown in colour; sandy loam in texture with strong gravels (49%); granular in structure; loose, very friable, non sticky and non-plastic in consistency having abrupt smooth horizon boundary underlain by indurated bedrock at only 11 cm depth.

Physico-chemical properties of the soils

The physico-chemical properties of the soils have been presented in Table 3. The soils of pedons 4, 5 and 7 are very coarse textured having loamy sand and sand texture with clay content varying from 2.75 to 8.50% only. The low clay content and coarser texture are due to the fact that these soils were developed from mica schist parent material. Whereas, other soils are coarse textured having sandy loam texture with clay content ranging from 9.50 to 15.50 percent as these soils were developed from quartzite/colluvium/alluvium parent materials. The soils are acidic in nature as revealed from their pH values. Pedon 5, 8 and 9 soils are moderately acidic (pH ranges from 5.61 to 5.95) in reaction, whereas, pedons 3 and 6 soils are moderately to slightly acidic (pH ranges from 5.52 to 6.34) and pedons 1 and 2 are slightly acidic to neutral (pH ranges from 6.04 to 6.98) in reaction. The acidic nature of the soils is due to the leaching of bases from the soil profile as the landscape is sloppy. It is also revealed that pH is comperatively low in surface

horizon than sub-surface horizons. This is due to the reason that organic carbon is high in surface layer than sub-surface layers. The electrical conductivity (EC) of all the soils is very low to low (0.02 to 0.51dSm^{-1}). The lower value of EC is due to the reason that landscape is sloppy and the soluble salts are removed from the horizons of soil profiles during the high intensive rainfall. Organic carbon (OC) content of all the soils is high to very high (0.77 to 2.07%) in surface horizons except pedon3 which is medium (0.67%). The enrichment of organic carbon is due to vegetative cover and its decomposition as the area falls under warm humid climatic conditions. It has also been observed that the organic carbon content is high in surface horizon and decreases downwards, as also observed by earlier authors (Mahapatra *et al.*, 2000, 2005; Nagdev *et al.*, 2017c). This is due to continuous decomposition and enrichment of OC in surface layers and its leaching downwards along the lower horizons. In sub-surface horizons, the organic carbon content is mostly low (0.10 to 0.49%) except pedons4 and 6. In pedon4, OC content is high (0.82%) in second horizon and medium (0.52 to 0.61%) in lower horizons whereas in pedon 6 it is high (0.79 to 1.02%) in both sub-surface horizons. It is also revealed from the Table 3 that the nutrient holding capacity of all the soils are very low to low as reflected from their CEC values (0.68 to 5.31cmol(p+)kg^{-1}). It is low for pedons 1, 2, 4, 6, 8 and 9 (3.02 to 5.31cmol (p+)kg^{-1}), whereas it is very low (0.68 to 2.55cmol (p+)kg^{-1}) for pedons3 and 5 and 7, respectively. The lower CEC values of all the soils are due to the coarse to very coarse texture (sandy loam, loamy sand and sand) having less clay content (2.75 to 15.5%). The value of CEC is governed by finer soil particles *i.e.* clay and organic matter content of the soils (Nagdev *et al.*, 2017a). The base saturation (BS) of pedons4 to 9 is low (50.69 to 63.05%). This is due to the reason that these soils occur on higher elevations in hill slopes and bases are leached during high intensive rainfall prevailing in the area. The BS of pedons 1 to3 is medium (65.17 to 73.57%). The comparatively high value of BS of these soils is due to the reason that these soils occur on lower elevations (valleys) and deposition of bases leached from higher elevations.

Taxonomy of soils

The soils of the study area have been classified as per USDA soil classification system and presented in Table 4. The temperature regime of the watershed area is *thermic* and moisture regime is *udic*, respectively. The mineralogy of all the soils has been found to be mixed type as revealed from the CEC: clay ratio which ranged between 24.72 and 36.00 (Smith, 1986; Nagdev *et al.*, 2017c). Pedon 1 soils are very deep, well drained, sandy loam in texture with coarse gravels upto 11%, sub angular blocky in structure (cambicepipedon) and have A, B and C horizons. Hence, they belong to *Inceptisols* with coarse loamy family textural class as the clay percent is less than 18 percent. The base saturation of these soils are more than 60% throughout the profile and no free carbonates in any of the horizons. Hence they belong to "Eutrudepts" great group and "Dystric" sub-group and classified as very deep, mixed, thermic, coarse loamy, Dystric Eutrudepts. Pedon 2 soils are very deep, well drained, sandy loam in texture with clay content less than 18 % and strong coarse gravels upto 54% throughout the profile and have only A and C horizons. Hence these soils belong to *Entisols* with loamy skeletal family textural class and classified as very deep, mixed, thermic, loamy skeletal, Typic Udorthents. Soils of pedon 3 are moderately deep (upto85 cm depth), somewhat excessively drained, loamy sand and sand in texture with coarse gravels upto 19% and have only A and C horizons. Hence, these

soils belong to *Entisols* with sandy textural class and classified as moderately shallow, mixed, thermic, Typic Udipsamments. Pedon4 soils are moderately shallow (upto 72 cm depth), well drained, sandy loam in texture with clay content less than 18% and coarse gravels upto 24% and have only A and C horizons. Hence they belong to *Entisols* with coarse loamy family textural class and classified as moderately deep, mixed, thermic, coarse loamy, Typic Udorthents. Pedon 5 soils are moderately shallow (upto 73 cm depth), excessively drained, loamy sand in texture with strong gravels upto 47% throughout the profile and have only A and C horizons. Hence these soils belong to *Entisols* with sandy skeletal textural class and classified as moderately shallow, mixed, thermic, sandy skeletal Typic Udorthents. Pedon 6 soils are moderately shallow (upto 69 cm depth), somewhat excessively drained, sandy loam in texture with strong gravels upto 44% throughout the profile and have only A and C horizons. Hence they belong to *Entisols* having loamy skeletal textural class and classified as moderately shallow, mixed, thermic, loamy skeletal, Typic Udorthents. Soils of pedon 7 are shallow (upto 48 cm depth), somewhat excessively drained, sandy loam and loamy sand in texture with strong gravels upto 47% throughout the profile and have A and C horizons underlain by indurated bedrock at 48 cm depth. Hence these soils belong to *Entisols* having sandy skeletal textural class and classified as shallow, mixed, thermic, sandy skeletal, Lithic Udorthents. Pedon 8 soils are shallow (32 cm depth), excessively drained, sandy loam in texture with strong gravels upto 52% throughout the profile and have A and C horiozons underlain by indurated bedrock at 32 cm depth. Hence, they belong to *Entisols* having loamy skeletal family textural class and classified as shallow, mixed, thermic, loamy skeletal, Lithic Udorthents. Soils of pedon 9 are very shallow (upto 11 cm only), excessively drained, sandy loam in texture, with coarse gravels upto 49% and have only A horizon underlain by indurated bedrock at 11 cm depth. Hence, these soils belong to *Entisols* with loamy skeletal textural class and classified as shallow, mixed, thermic, loamy skeletal, Lithic Udorthents.

Land categorisation for land use planning

The watershed area has been evaluated into different land category classes based on their limitations, potentials as well as site characteristics for suggesting measures for optimum productivity. Table 5 represents the different land categories of the nine soil pedons of the watershed and their suggestive measures. Pedon 1 soils occur on gently sloping valleys having limitations of coarse texture (sandy loam), low nutrient holding capacity (CEC varies from 3.50 to 5.31 cmol $(p+)kg^{-1}$)and slight erosion. They were evaluated as class III lands and can be cultivated for climatically adapted crops applying required doses of organic and inorganic fertilisers and land leveling. Pedon 2 soils also occur on gently sloping valleys and have limitations of coarse texture (sandy loam) with strong gravelliness, low nutrient holding capacity (CEC ranges from 3.33 to 4.35cmol$(p+)kg^{-1}$) and slight erosion. They are evaluated as class III lands and can be cultivated for crops adapted to climate and soil limitations applying recommended doses of organic and inorganic fertilisers. Pedon 3 soils occur on moderately sloping valleys having limitations of soil depth (upto85 cm), very coarse texture (sand and loamy sand), very low nutrient holding capacity (CEC ranges from 0.68 to 1.95 cmol $(p+)kg^{-1}$) and moderate erosion. They are categorised under class V lands and as such not suitable for cultivation of crops but suitable for pastures. However these lands can be utilised for cultivation adopting proper soil and water conservation measures like land leveling,

integrated nutrient management (INM) practices including recommended doses of organic and inorganic fertilisers and frequent timely irrigations. Soils of pedon4 occur on moderately sloping side slopes of hills and have limitations of limited soil depth (upto72cm), coarse texture (sandy loam), moderate stoniness, low nutrient holding capacity (CEC ranging from 3.75 to 4.66 cmol (p+)kg^{-1}) and moderate erosion. They were categorised under class IV lands and can be cultivated for crops adapted to limitation of soils and application of proper soil and water conservation measures and good agronomic practices. Soils of pedon5 occur on steeply sloping hills under forest and have severe limitations of soil depth (73 cm), very coarse soil texture (loamy sand), strong gravelliness, very low nutrient holding capacity (CEC ranges from 2.16 to 2.46 cmol(p+)kg^{-1}) and severe erosion. They are assessed as class VI lands and not suitable for cultivation but can be utilised for pastures/forestry adopting proper soil and water conservation practices to prevent erosion. Pedon6 soils occur on moderately steeply sloping pasture lands and have limitations of soil depth (upto 69 cm), coarse texture (sandy loam) with strong gravelliness, low nutrient holding capacity (CEC varies from 3.02 to 3.37 cmol(p+)kg^{-1}) and severe erosion. They are assessed as class V lands and as such not suitable for cultivation but can be brought under cultivation adopting conservation measures like construction of engineering structures to prevent erosion, application of good agronomic practices and selection of plants adapted to limitation of soils. Soils of pedon 7 occur on gently sloping hillsides under pastures having limitations of shallow soil depth (upto 48 cm), moderate erosion, very coarse soil texture (loamy sand) with strong gravelliness and very low nutrient holding capacity (CEC ranges from 1.30 to 2.55 cmol (p+)kg^{-1}). They are evaluated under class VI land category and not suitable for cultivation but can be utilised for pastures by adopting soil and water conservation measures. Pedon 8 soils occur on moderately steeply sloping hills under forest and have severe limitations of shallow soil depth (upto 32 cm), coarse texture (sandy loam) with strong gravelliness, low nutrient holding capacity (CEC ranges from 4.12 to 5.1 0 cmol(p+)kg^{-1}) and severe erosion. They are assessed as class VI lands and not suitable for cultivation but can be utilised for pastures/plantations with proper engineering structures to prevent erosion. Pedon 9 soils occur on steeply sloping hills under shrubs/rocky landscape and have very severe limitations of very shallow soil depth (upto 11 cm only), rockiness, coarse texture (sandy loam) with strong gravelliness, low nutrient holding capacity (CEC 3.52 cmol (p+)kg^{-1}) and very severe erosion. They are evaluated under class VII land category and are not suitable for cultivation or plantations but can be utilised for grazing/pastures after construction of proper engineering structures to prevent erosion.

Thus, it is revealed that the watershed area is prone to various kinds of degradation problems affecting productivity. The degradation is due to sloppy landscape, indiscriminate use and over exploitation of land resources due to pressure of increasing population, deforestation and eratic rainfall prevailing in the area.

Hence, suitable soil and water conservation measures should be adopted like construction of engineering structures *viz.,* contour trenching, bench terracing, staggered trenching, contour furrows, etc. to prevent erosion. Fallow lands may be covered with grasses/ shrubs as well as plantations to protect from degradations and improve soil quality (Dhayani *et al.,* 2005; Prasad and Dhayani, 2010; Nagdev *et al.,* 2017d). Besides, good agronomic practices may be adopted *viz.,* strip cropping, inter cropping

with legumes, mulching, INM practices with proper doses of organic and inorganic fertilizer, etc for maintenance of soil health and increasing productivity.

Table.1 Site characteristics of the soil pedons

Soils	Landform	Slope (%)	Parent material	Erosion status	Present land use
Pedon 1	Valley	Gentle (3-5)	Alluvium	Slight	Cultivated
Pedon 2	Valley	Gentle (3-5)	Alluvium	Slight	Cultivated
Pedon 3	Valley	Moderate (5-10)	Mica schist /Colluvium	Moderate	Cultivated
Pedon 4	Side Slope	Moderate (5-10)	Quartzite	Moderate	Cultivated
Pedon 5	Side Slope	Steep (15-25)	Mica schist	Severe	Forest
Pedon 6	Side Slope	Moderately steep (10-15)	Quartzite	Severe	Pastures
Pedon 7	Side Slope	Moderate (5-10)	Mica schist	Moderate	Pastures
Pedon 8	Ridge top	Moderately steep (10-15)	Quartzite	Severe	Forest
Pedon 9	Ridge top	Steep (15-25)	Quartzite	Very severe	Shrubs and rocky land

Table.2 Morphological properties of the soils

Soils	Horizon	Depth (cm)	Colour (moist)	Texture*	Structure**	Consistence***			Boundary****		Coarse fragments (%)
						D	M	W	D	T	
Pedon 1	Ap	0-13	Brown (10YR 4/3 M)	sl	m	sh	fr	ss,ps	c	s	8
	A2	13-32	Yellowish Brown (10YR 5/4 M)	sl	f1sbk	-	fr	ss,ps	g	s	8
	Bw1	32-53	Brown (10YR 5/3 M)	sl	m1sbk	-	fr	ss,ps	g	s	9
	Bw2	53-75	Brown (10YR 5/3 M)	sl	m1sbk	-	fr	ss,ps	g	s	10
	Bw3	75-101	Brown (10YR 5/3 M)	sl	m1sbk	-	fr	ss,ps	g	s	9
	Bw4	101-125	Brown (10YR 5/3 M)	sl	m1sbk	-	fr	ss,ps	c	s	11
	C	125-157	Brown (10YR 5/3 M)	sl	-	-	fr	ss,ps	-	-	1
Pedon 2	Ap	0-14	Brown (10YR 5/3 M)	gsl	m	sh	fr	ss,po	c	s	30
	A2	14-37	Brown (10YR 5/3 M)	gsl	m	-	fr	ss,po	c	s	34
	A3	37-51	Yellowish Brown (10YR 5/4 M)	gsl	m	-	fr	ss,po	g	s	37
	AC	51-91	Yellowish Brown (10YR 5/4 M)	gsl	m	-	fr	ss,po	c	s	41
	C1	91-117	Brown (10YR 5/3 M)	gsl	m	-	fr	ss,po	g	s	44
	C2	117-139	Brown (10YR 5/3 M)	gsl	m	-	fr	ss,po	g	s	52
	C3	139-152	Brown (10YR 5/3 M)	gsl	m	-	fr	ss,po	a	s	54

Pedon 3	Ap	0-11	Brown (10YR 5/3 M)	ls	sg	l	vfr	so,po	c	s	13
	A2	11-33	Brown (10YR 5/3 M)	ls	sg	l	vfr	so,po	c	s	15
	A3	33-61	Yellowish Brown (10YR 5/4 M)	s	sg	-	vfr	so,po	g	s	18
	C	61-85	Yellowish Brown (10YR 5/4 M)	s	sg	-	vfr	so,po	a	s	19
	Cr	85+	-	-	-	-	-	-	Unconsolidated bedrock		-
Pedon 4	Ap	0-8	Brown (10YR 4/3 M)	sl	m	l	fr	ss,po	c	s	17
	A2	8-24	Brown (10YR 5/3 M)	sl	m	-	fr	ss,po	c	s	21
	A3	24-51	Yellowish Brown (10YR 5/4 M)	sl	m	-	fr	ss,po	g	s	20
	C	51-72	Yellowish Brown (10YR 5/4 M)	sl	m	-	fr	ss,po	a	s	24
	Cr	72+	-	-	-	-	-	-	Unconsolidated bedrock		-
Pedon 5	A1	0-13	Brown (10YR 5/3 M)	gls	sg	l	vfr	so,po	c	s	29
	A2	13-32	Brown (10YR 5/3 M)	gls	sg	-	vfr	so,po	c	s	37
	C1	32-52	Yellowish Brown (10YR 5/4 M)	gls	sg	-	vfr	so,po	g	s	41
	C2	52-73	Yellowish Brown (10YR 5/4 M)	gls	sg	-	vfr	so,po	a	s	47
	Cr	73+	-	-	-	-	-	-	Unconsolidated bedrock		-
Pedon 6	A1	0-16	Brown (10YR 4/3 M)	sl	m	sh	fr	ss,po	c	s	29
	A2	16-37	Brown (10YR 4/3 M)	gsl	m	-	fr	ss,po	c	s	38
	C	37-69	Dark Yellowish Brown (10YR 4/4 M)	gsl	m	-	fr	ss,po	a	s	44
	R	69+	-	-	-	-	-	-	Indurated bedrock		-
Pedon 7	A1	0-11	Brown (10YR 5/3 M)	ls	m	l	vfr	so,po	c	s	22
	A2	11-32	Brown (10YR 5/3 M)	gls	sg	-	vfr	so,po	c	s	38
	C	32-48	Yellowish Brown (10YR 5/4 M)	gls	sg	-	vfr	so,po	a	s	47
	R	48+	-	-	-	-	-	-	Indurated bedrock		-
Pedon 8	A	0-13	Brown (10YR 5/3 M)	gsl	m	sh	fr	ss,po	c	s	38
	C	13-32	Yellowish Brown (10YR 5/4 M)	gsl	m	-	fr	ss,po	a	s	52
	R	32+	-	-	-	-	-	-	Indurated bedrock		-

Pedon 9	A	0-11	Brown (10YR 4/3 M)	gsl	m	l	vfr	ss,po	a	s	49
	R	11+	-		-	-	-	-	Indurated bedrock		-

*sl: sandy loam; gsl: gravelly sandy loam; ls: loamy sand; s: sand; gls: gravelly loamy sand
** m: massive; f 1 sbk: *fine weak subangular blocky*; m 1 sbk*: medium weak subangular blocky*; sg: *single grain;*
***D:dry; M: moist; W:wet; sh:slightly hard; l: loose; fr: friable; vfr: very friable; ss: slightly sticky; so: non-sticky; ps: slightly plastic: po: non-plastic
****D:distinctness; T:type; c: clear; g: gradual; a: abrupt; s: smooth

Table.3 Physico-chemical properties of the soils

Soils	Depth (cm)	Sand	Silt	Clay	pH (1:2.5)	EC (dS m^{-1})	OC (%)	Exchangeable cations [cmol(p+)kg^{-1}]				CEC [cmol(p+) kg^{-1}]	CEC/ clay ratio	Base Saturation (%)
		%						Ca	Mg	Na	K			
Pedon 1	0-13	57.75	27.50	14.75	06.11	0.12	1.26	1.90	1.12	0.34	0.18	05.31	36.00	66.67
	13-32	56.75	30.50	12.75	06.35	0.13	0.49	1.78	0.92	0.21	0.11	04.46	34.98	67.71
	32-53	64.50	24.25	11.25	06.55	0.17	0.27	1.69	0.94	0.20	0.11	04.16	36.97	70.67
	53-75	67.50	21.25	11.25	06.65	0.20	0.24	1.54	1.01	0.20	0.11	04.05	36.00	70.62
	75-101	62.75	26.50	10.75	06.84	0.21	0.18	1.73	0.60	0.18	0.10	03.65	33.95	71.51
	101-125	58.50	27.00	14.50	06.89	0.26	0.10	2.61	0.69	0.28	0.15	05.07	34.96	73.57
	125-157	63.00	27.00	10.00	06.98	0.36	0.10	1.43	0.62	0.27	0.25	03.50	35.00	73.43
Pedon 2	0-14	64.75	20.75	14.50	06.14	0.13	1.25	1.97	0.63	0.15	0.09	04.35	30.00	65.29
	14-37	69.75	18.75	11.50	06.22	0.17	0.29	1.46	0.55	0.08	0.08	03.33	28.95	65.17
	37-51	60.25	27.25	12.50	06.32	0.19	0.29	1.53	0.69	0.11	0.05	03.50	28.00	68..00
	51-91	58.25	27.75	14.00	06.39	0.33	0.29	1.49	0.78	0.24	0.10	03.78	27.00	69.05
	91-117	71.00	16.75	12.25	06.71	0.37	0.18	1.54	0.67	0.15	0.05	03.43	28.00	70.26
	117-139	70.25	14.25	15.50	06.77	0.49	0.14	1.57	1.05	0.28	0.09	04.18	26.96	71.53
	139-152	68.75	16.25	15.00	06.81	0.51	0.12	1.60	1.07	0.28	0.09	04.20	28.00	72.38
Pedon 3	0-11	89.75	02.75	07.50	06.21	0.11	0.67	0.90	0.16	0.09	0.13	01.95	26.00	65.64
	11-33	83.00	09.90	07.10	06.38	0.20	0.19	0.48	0.42	0.20	0.11	01.78	25.07	67.98
	33-61	92.20	04.80	03.00	06.43	0.29	0.15	0.25	0.12	0.10	0.07	00.78	26.00	69.23
	61-85	93.15	04.10	02.75	06.48	0.35	0.14	0.23	0.09	0.09	0.07	00.68	24.72	70.59
Pedon 4	0-8	58.10	27.40	14.50	05.66	0.10	2.07	1.83	0.58	0.16	0.19	04.64	32.07	59.48
	8-24	53.58	31.42	15.00	05.79	0.11	0.82	2.15	0.47	0.16	0.08	04.66	31.06	61.37
	24-51	54.25	30.25	15.50	06.15	0.13	0.61	1.78	0.44	0.19	0.10	04.03	26.00	62.28
	51-72	53.95	31.05	15.00	06.34	0.28	0. 52	1.67	0.36	0.15	0.16	03.75	25.00	62.40
Pedon 5	0-13	84.75	07.50	07.75	05.61	0.12	1.21	0.58	0.32	0.11	0.09	02. 17	28.00	50.69
	13-32	84.00	07.50	08.50	05.74	0.14	0.69	0.67	0.40	0.12	0.11	02.46	28.94	52.84
	32-52	83.75	08.50	07.75	05.82	0.19	0.15	0.59	0.34	0.11	0.11	02.17	28.00	52.99
	52-73	81.50	10.50	08.00	05.92	0.41	0.15	0.58	0.40	0.10	0.11	02.16	27.00	55.09
Pedon 6	0-16	54.75	35.50	09.75	05.52	0.16	1.86	0.82	0.48	0.16	0.15	03.02	30.97	53.31
	16-37	53.00	37.50	09.50	06.21	0.30	1.02	0.87	0.52	0.15	0.14	03.04	32.00	55.26
	37-69	52.50	36.25	11.25	06.34	0.36	0.79	1.21	0.52	0.14	0.05	03.37	29.95	56.97
Pedon 7	0-11	75.25	16.25	08.50	06.34	0.12	0.77	1.01	0.35	0.10	0.07	0 2.55	30.00	60.00
	11-32	83.50	08.50	08.00	06.43	0.14	0.38	0.86	0.40	0.16	0.01	02.32	29.00	61.64
	32-48	83.50	08.25	07.25	06.49	0.14	0.23	0.71	0.35	0.18	0.04	02.03	28.00	63.05
Pedon 8	0-13	53.15	31.85	15.00	05.64	0.02	1.48	2.22	0.29	0.09	0.13	05.10	34.00	53.53
	13-32	56.45	31.05	12.50	05.95	0.03	0.66	1.95	0.15	0.06	0.13	04.12	32.96	55.58
Pedon 9	0-11	65.35	22.90	11.75	05.86	0.02	1.23	1.57	0.09	0.07	0.08	03.52	29.96	51.42

Table.4 Soil classification

Soils	Description	Taxonomy
Pedon 1	Very deep with A, B and C horizons, well drained, sandy loam soils of brown colour developed on Alluvium.	Very deep, mixed, thermic, coarse loamy, DystricEutrudepts.
Pedon 2	Very deep with A and C horizons, well drained, sandy loam soils of brown to yellowish brown colour developed on Alluvium.	Very deep, mixed, thermic, loamy, skeletal, TypicUdorthents.
Pedon 3	Moderately shallow with A-C horizons, somewhat excessively drained, sandy soils of brown to yellowish brown in colour developed on Alluvium/Colluvium.	Moderately shallow, mixed, thermic, TypicUdipsamments.
Pedon 4	Moderately deep with A and C horizons, well drained, sandy loam soils of brown to yellowish brown in colour developed on Mica schist.	Moderately deep, mixed, thermic, coarse loamy, TypicUdorthents.
Pedon 5	Moderately shallow with A-C horizons, excessively drained, loamy sand soils of brown to yellowish brown in colour developed on Mica schist.	Moderately shallow, mixed, thermic, sandy skeletal, TypicUdorthents.
Pedon 6	Moderately shallow with A-C horizons, somewhat excessively drained, sandy loam soils of brown to dark yellowish brown in colour developed on Quartzite.	Moderately shallow, mixed, thermic, loamy skeletal, TypicUdorthents.
Pedon 7	Shallow with A-C horizons, somewhat excessively drained, loamy sand soils of brown to yellowish brown colour developed on Alluvium.	Shallow, mixed, thermic, sandy skeletal, Lithic Udorthents.
Pedon 8	Shallow with A-C horizons, excessively drained, sandy loam soils of brown to yellowish brown in colour developed on Alluvium.	Shallow, mixed, thermic, loamy skeletal, Lithic Udorthents.
Pedon 9	Very shallow with A-C horizons, excessively drained, sandy loam soils of brown colour developed on Quartzite.	Very shallow, mixed, thermic, loamy skeletal, Lithic Udorthents.

Table.5 Land categorisation and suggested measures

Soils	Limitations	Land Categories	Suggested measures
Pedon 1	Undulating land, coarser texture, slight erosion and low nutrient holding capacity	Class III	Land leveling, adoption of integrated nutrient management (INM) practices including required doses of organic and inorganic manures and fertilisers.
Pedon 2	Undulating land, coarser texture with strong gravels, slight erosion and low nutrient holding capacity	Class III	Land leveling, adoption of INM practices including recommended doses of organic and inorganic manures and fertilisers, selection of crops adapted to limitations of soils.
Pedon 3	Limited soil depth, sandy texture moderate slope with moderate erosion and very low nutrient holding capacity	Class V	Not suitable for cultivation but suitable for pastures, can be utilised for cultivation with proper soil and water conservation measures including high doses of organic and inorganic fertilizers, timely and sufficient irrigations and selection of crops adapted to limitation of soils.
Pedon 4	Limited soil depth, coarser texture, moderate slope with moderate erosion, moderate stoniness and low nutrient holding capacity	Class IV	Adoption of proper soil and water conservation practices to prevent erosion and selection of plants adopted to limitation of soils.
Pedon 5	Limited soil depth, very coarser texture with strong gravels, steep slopes and severe erosion and very low nutrient holding capacity	Class VI	Not suitable for cultivation, but can be utilised for grazing/pastures/forestry with proper engineering structures to prevent erosion.
Pedon 6	Limited soil depth, coarser texture with strong gravels, moderate steep slopes and severe erosion and low nutrient holding capacity	Class V	Not suitable for cultivation but suitable for pastures, can be brought under cultivation, adopting conservation measures like construction of engineering structures to prevent erosion, good agronomic practices and selection of plants adapted to limitation of soils.
Pedon 7	Sloppy landscape, shallow soil depth, very coarser soil texture with strong gravels and very low nutrient holding capacity	Class VI	Not suitable for cultivation, but can be utilised for pastures, adoption of proper soil and water conservation measures to prevent erosion.
Pedon 8	Shallow soil depth, coarser texture with strong gravels, moderately steep slopes with severe erosion and low nutrient holding capacity	Class VI	Not suitable for cultivation, but can be utilised for grazing/plantations after construction of proper engineering structures to prevent erosion.
Pedon 9	Very shallow soil depth, coarser texture with strong gravels, steep slopes with very severe erosion and low nutrient holding capacity	Class VII	Not suitable for cultivation and plantations, can be utilised for grazing/pastures after construction of proper engineering structures to prevent erosion.

Fig.1 Study Area: Bino-river watershed, Almora District, Uttarakhand, India

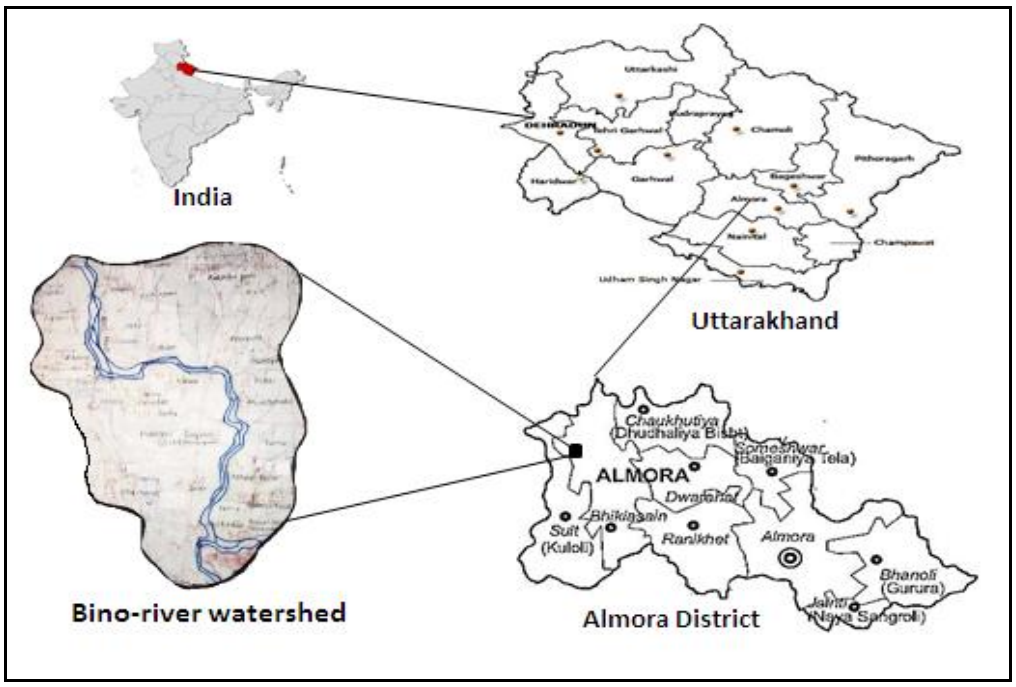
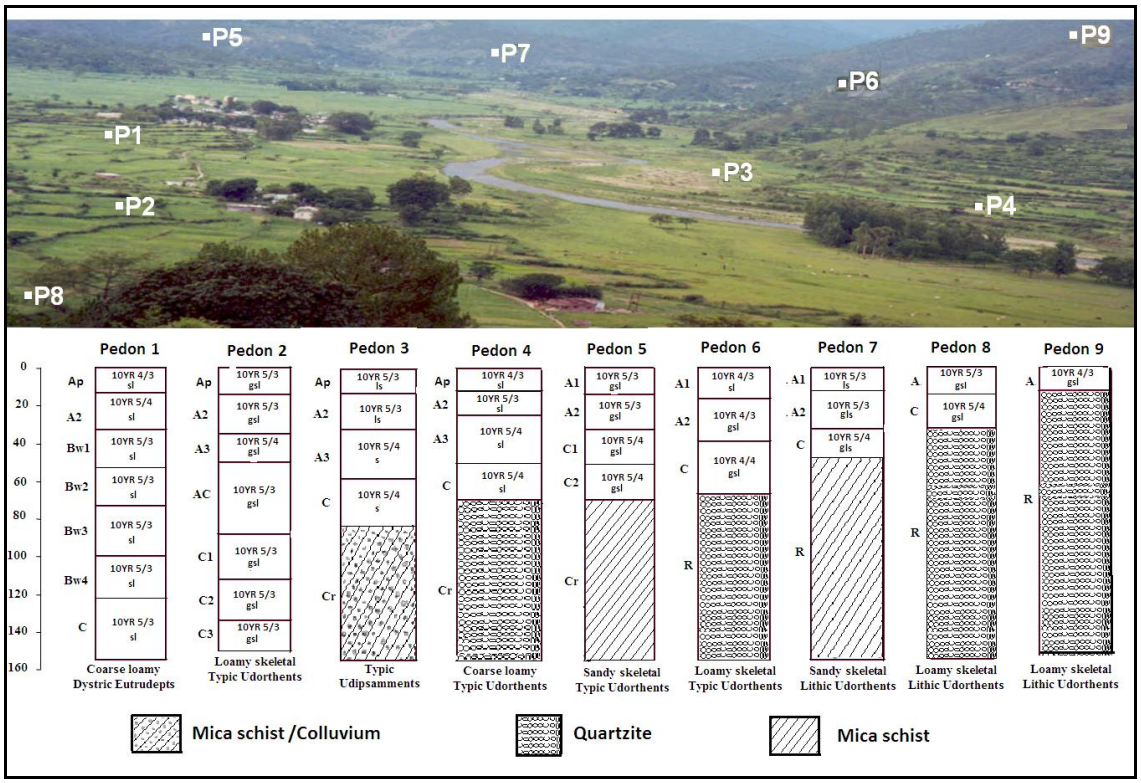


Fig.2 Soil Landscape Relationship of Bino-River Watershed



Soils of the Bino-river watershed in Almora district of Uttarakhand in India have been characterised and classified for land evaluation and conservation of natural resources. Nine types of soils have been found occurring on three major landforms *viz*., moderately steep to steeply sloping ridge tops, moderate to steep side slopes and gentle to moderately sloping valleys. Eight soils belong to Entisols having only A and C horizons whereas only one soil occurring on fluvial valleys belongs to Inceptisols having A-B-C horizons. The major limitations of the watershed are sloppy landscape, limited soil depth, moderate to severe erosion, strong gravelliness and low to very low nutrient holding capacity. Soils are evaluated as class III land on fluvial valleys, class IV and VI lands on side slopes and class VI and VII lands on ridge tops, respectively. Proper soil and water conservation measures as well as good agronomic practices may be adopted for enhancing productivity and overall development of this hilly area.

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