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Characterization and Suitability Evaluation of Soils of Chanavada Watershed in Aravalli Hills of Southern Rajasthan

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Abstract: A detailed soil survey was carried out to characterize and classify the soils of Chanavada micro-watershed in Girwa tehsil of Udaipur district, Rajasthan using cadastral map overlaid on IRS P6 LISS IV images of October 2007 and March 2008 as a base. Based on the visual interpretation of satellite data, other collateral data and local micro features six landforms units *viz.* Steeply sloping hills, Moderately steeply sloping hills, Moderately sloping foot slope, Inter hill valley, Narrow valley and Broad valley were delineated. Tentatively eight soil series were identified in the watershed and mapped into 15 soil mapping units at the level of phases of soil series on 1: 4000 scales after establishing soil landform relationship. These soils were classified as Entisols (Lithic Ustorthents, Typic Ustorthents) and Inceptisols (Typic Haplustepts, Fluventic Haplustepts). The soils of the steeply sloping and moderately steeply sloping hills are very shallow to moderately shallow, excessively drained, dark yellowish brown, gravelly loam to gravelly sandy loam (surface horizon) soils with very severe soil erosion. The soils of moderately sloping foot slope are moderately deep to deep, well-drained, dark brown (10 YR 3/3) to very dark greyish brown (10 YR 3/2) sandy clay loam soils with severe erosion. The soils of the valley are deep, well-drained, very dark greyish brown (10 YR 3/2) to dark yellowish-brown (10 YR 3/4), sandy clay loam to loam on the surface and dark grey (7.5YR3/1) silt loam in sub-surface horizons with severe erosion. The soils of the hills were slightly acidic to neutral in reaction whereas the soils of the valley were neutral to moderately alkaline in reaction. All these soil were very high in organic carbon content on the contrary the content of available nitrogen is low. Most of the soils are medium to high in available phosphorous and available potassium whereas the content of available micronutrients was adequate to high. The soils of the hills are not suitable for arable field crops and the soils of foot slope and narrow valley were marginal to moderately suitable for growing crops. The soils of the broad valley were good cultivable lands with minor soil problems such as gentle slope, fairly satisfactory texture and slight stoniness. All climatically adapted crops can be grown under irrigation.

Keywords: *soil survey, entisols, inceptisols, taxonomy, soil suitability*

Introduction

The watershed is considered to be the ideal unit for the analysis and management of natural resources planning. Watershed management aims at optimizing the use of land, water, vegetation, man, animal and environment to prevent soil erosion, moderate foods, alternate drought, improve water availability, increase food, fuel, fodder, fibre and timber production on a sustainable basis (Bhardwaj and Dogra 1997). Soils are considered an integral part of the landscape and their characteristics are largely governed by the landforms on

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which they have developed (Sharma *et al.* 1999). A landform comprises a geomorphological unit and is largely governed by its surface forms and location in the landscape. The importance of soil-physiographic relationship in soil survey and mapping provides a fair understanding of variability across the landscape needed for sustainable agricultural planning (Murthy *et al.* 1982). Soil resource inventory provides an insight into the potentialities and limitations of soils for their optimum utilization. It also provides adequate information in terms of landform, terrain, vegetation as well as characteristics of soils that can be utilized for land resources management and development (Manchanda *et al.* 2002).

In the recent past, the concept of the watershed is taken as a potential approach for a holistic development in the rainfed areas, which can lead to higher productivity and sustainability in agricultural production. Different measures are adopted and executed carefully in each of the toposequences according to their capability. The Girwa tehsil of Udaipur district in Mewar region of Rajasthan predominantly under rainfed farming with erratic rainfall distribution associated with low crop productivity, undulating terrain and needs site-specific information in terms of soil characteristics, their productivity potentials and limitations for land resources development and management. The present study was undertaken to characterize and evaluate the soils of Chanavada micro-watershed in Girwa tehsil of Udaipur district for land resource management and sustainable land use planning using remote sensing and GIS.

Materials and Methods

The Chanavada watershed is located in Girwa taluka ($24^0 15'$ to $24^0 16'$ N; $73^0 35'$ to $73^0 40'$E) of Udaipur district falls on toposheet no. 45H/11. The elevation in the area ranges from 485 to 666 m above mean sea level. The climate is tropical semi-arid characterized by dry hot summer and intense winter with mean annual rainfall of 650 mm and mean annual temperature of 26.9°C. The area qualifies for 'Hyperthermic' soil temperature and 'Ustic' soil moisture regime. Length of growing period ranges from 90-120 days in a year. The common rock type found in the area is quartzite, conglomerate, phyllites, dolomite, mica schist and meta volcanic rocks. Chanavada watershed is a part of Aravalli hills hence the dominant land use/ land cover is forest and cultivation of crops is confined along the stream and valley region. The natural vegetations of the watershed comprise of dry deciduous type mixed tree species and grasses. Commonly occurring species of trees are teak (*Tectona grandis*), babul (*Acacia spp*.), neem (*Azadiracta indica*), subabool (*Leucaena leucocephala*), palas (*Butea frondosa*) and grasses like kans (*Saccharum spontaneum*), doob (*Cynadon dactylon*), nut sledge (*Cyperus rotundus*), *etc.*

Geocoded Remote Sensing satellite data of IRS P6 LISS IV for the October 2007 and March, 2008 were procured from National Remote Sensing Centre (NRSC), Hyderabad. The satellite data was georeferenced to SOI toposheet using Arc GIS 10.2 software. Standard visual interpretation technique was used to prepare land use/land cover map of the area. Landforms and slope maps of the area were derived using contour information available on SOI toposheet. The detailed soil survey of the watershed was carried out using cadastral map as a base map on 1: 4000 scales. The soils of the watershed were studied in selected transects for their morphological properties as per Soil Survey Manual (IARI 1971) and field manual (Sehgal *et al.* 1987). Horizon wise soil samples collected from representative soil series and analyzed for various physical and chemical properties (Jackson 1973). Soils were classified according to Key to Soil Taxonomy (Soil Survey Staff 2010) and were evaluated for land capability using criteria of Klingbiel and Montgomerry (1961) and land irrigability sub-classes (AIS&LUS 1971)**.** The soil site suitability for maize, sorghum, wheat, barley, gram, groundnut and mustard was worked out as per the methodology given in the FAO framework on land evaluation (FAO 1976) modified by Sys *et al.* (1991).

Results and Discussion

Landform – soil relationship

The watershed represents typical Aravalli landscape. Based on the visual interpretation of the satellite data of IRSP6 LISSIV (March 2008 & October 2007), in conjunction with SOI Toposheet, Google image, Cadastral map and ground truth has brought out two major landform units *viz*. Hills & Valley. These major units were further subdivided into six sub units on the basis of slope, land use, topographical position & other micro features. The hills were subdivided into three subunits namely 1) Steeply sloping hills, these are the hills with slope > 30 %, 2) Moderately steeply sloping hills with the slope percentage ranging from 15-30 % and third one 3) Moderately sloping foot slope that is the lowest part of hill having slope percentage of 8-15 % at the lower topographical position. On the other hand valley was divided into three sub units namely i) Inter hill valley which formed at the base of the two or more hills and appears as bowl shaped landscape ii) Narrow valley which is formed along the stream but having the width of less than 500 meters and iii) Broad valley having an average width of more than 500 meters and it occurs on upper and lower reaches of the watershed. The different landforms, elevation, slope, land use, area, image characteristics and soil composition has been shown in table 1 and fig 5.1. However, moderately steeply sloping hills covers largest area *i.e.,* 32.31% of TGA of watershed and interhill valley covers least *i.e.* 5.18% of TGA area of the watershed.

After systematic study of soils in different landform units, the landform-soil relationship was established (Table 1). The landform soil relationship facilitates proper understanding of soil and other edaphic conditions having greater significance in detailed soil survey and land use planning. The landform-soil relationship indicated the changes in important soil properties *viz.* profile development (morphological), physical and chemical properties with the variation in landform unit. Recent studies (Srivastava and Saxena 2004; Patil *et al.* 2010; Borse *et al.* 2018) showed that landform soil relationship based on the image interpretation, ground truth and soil analysis for soil resource mapping at different scales level. Over all, eight soil series (Chanavada-1, Chanavada-2, Chanavada-3, Chanavada-4, Chanavada-5, Chanavada-6, Chanavada-7

Table 1. Soil-site and Morphometric characteristics of soils of Chanavada watershed

Series	Landform	Depth (cm)	Erosion	Drainage	Gravels (Vol %)	Texture	Matrix Colour	Reaction	Horizon Sequence
Chanavada -1	Steeply sloping hills	<25	Very severe	Excessively drained	50-60	loam	10 YR	Nil	A-C
Chanavada -2	Moderately steep sloping hills	50-75	Very severe	Excessively drained	40-50	loam	7.5 YR, 10 YR	Nil	A-C
Chanavada -3	Moderately sloping Foot slope	75-100	Very slow	Well drained	30-40	loam	10 YR	e	Ap-Bw-Cr
Chanavada -4	Interhill valley	100-150	Severe	Well drained	50-60	Silty loam	10 YR, 7.5 YR	e	Ap-Bw-Cr
Chanavada -5	Narrow Valley	>150	Severe	Well drained	30-40	loam	10 YR, 7.5 YR	e	Ap-Bw-BC
Chanavada -6	Broad Valley	>150	Severe	Well drained	50-60	Silty loam	10 YR	e	Ap-Bw-BC
Chanavada -7	Broad Valley	100-150	Very slow	Well drained	10-20	Silty loam	10 YR	es	Ap-Bw-Cr
Chanavada -8	Broad Valley	>150	Moderate	Well drained	10-20	Silty loam	10 YR	es	Ap-Bw-BC

and Chanavada-8) were tentatively identified in the different landforms and mapped in 14 mapping units as phases of soil series at 1:4000 scales after the establishing landform soil relationship.

Soil morphological characteristic

The soils developed on steeply sloping and moderately steeply sloping hills are very shallow to shallow on the other hand soils occurring on foot slope, interhill valley, narrow valley and broad valleys are deep showing soil depth is a function of slope and erosion (Srivastava *et al.* 1991). The soils of the steeply sloping and moderately steeply sloping hills (Chanavada-1 and Chanavada-2 series) are very shallow to moderately shallow, excessively drained, dark yellowish brown (10 YR 3/4), gravelly loam to gravelly sandy loam (surface horizon) soils overlying weathered phyllitic material with very severe soil erosion. The soils of Chanavada-3 series found on moderately sloping foot slope are moderately deep to deep, well drained, dark brown (10 YR 3/3) to very dark greyish brown (10 YR 3/2) sandy clay loam soils with severe erosion. The soils of interhill valley Chanavada-4 are deep, well drained, dark brown (10 YR 3/3) to dark yellowish brown (10 YR 3/4) loam to silt loam soils with severe erosion. The soils occurring on narrow valley (Chanavada-5 series) are very deep, well drained, very dark greyish brown (10 YR 3/2) sandy clay loam in surface and dark gray (7.5YR3/1) silt loam in sub surface horizons with severe erosion whereas the soils Chanavada-6, Chanavada-7 and Chanavada-8 occurring along the broad valley associated with cultivation of maize and wheat having life saving irrigation are deep to very deep, well drained, brown (10 YR 3/4) to dark brown (10 YR 3/3) loam to silt loam in surface and very dark greyish brown (10 YR 3/2) to dark yellowish brown (10 YR 3/4), silty clay loam in sub surface with moderate to slight erosion.

Physical properties

The data on particle-size analysis (Table 2) indicated that sand forms major (9.9 to 58.9 percent) fraction of soil separates in all the soils. Similar findings were reported by Gill *et al.* (2012) in the Aravalli soils of Rajasthan. The silt content in the soils ranged from 34.0 to 68.8 percent and it increased with gentler slope and depth. That could be attributed due to the fact that the finer particles are washed away from the upper reaches and deposited to gentler slopes (Gill *et al.* 2012). In general the clay content increased with depth in all the soils and it ranged from 8.2 to 30.1 per cent. The higher clay was observed in soils of Chanavada-7 followed by Chanavada-8 and Chanavada-6 soil series whereas the lowest clay content was found in soils of Chanavada-4 series. The soil moisture retained at 33 kPa ranged from 18.7 to 37.1 per cent and 4.8 to 56.6 per cent at 1500 kPa. Clay content had positive effect on the amount of moisture retained at both extremes. The available water content (AWC) of soils varied from 11.3 to 25.9 percent.

Chemical properties

The pH of the soils (Table 2) is neutral to strongly alkaline in reaction with pH value ranging from 6.1 to 9.2 and it increased with depth in all the soils except in soils of Chanavada-4 series. In general the pH of the soils was higher in the soils occurring on gentler slopes in valleys compared to the soil on steeper slopes (Garhwal *et al.* 2013). The electrical conductivity varied from 0.01 to 0.34 dSm^{-1} indicating no salinity hazards. The soil organic carbon content ranged from 0.32 to 1.66 per cent in different horizons of pedons. Relatively the organic carbon content was higher in surface horizons as compared to the sub-surface horizons in all soils and it was decreased with depth in all the soils. The higher amount of accumulation of organic carbon in surface layers of hills and narrow valley soils might be due to addition of biomass and grass roots in the hill soils and further its erosion from the steep slopes and deposition in narrow valley resulted in high amount of organic carbon in these soils. The soils of Chanavada-1, Chanavada-2 and Chanavada-6 series were non-calcareous on the other hand remaining soils were calcareous and the calcium carbonate content varied from 0.9 to 10.7 per cent in different soils and it increased with depth in all soils. This could be attributed due to the downward movement of calcium ions and their precipitation in sub-surface layers.

Table 2. Physico-chemical characteristics of soils of Chanavada watershed

Horizon	**Depth (cm)**	**Particle size distribution (%)**			**AWC (%)**	**pH (1:2.5)**	**EC (dSm^{-1})**	**OC ($g\ kg^{-1}$)**	**$CaCO_3$ (%)**	**Exchangeable bases [(cmol (p^+) kg^{-1}]**				CEC [(cmol (p^+) kg^{-1}]	ESP
		Sand	**Silt**	**Clay**						**Ca**	**Mg**	**Na**	K		
Chanavada 1- Very shallow loamy skeletal non calcareous Lithic Ustorthents (Hill top)															
A1	0-9	40.3	41.0	18.7	16.5	6.2	0.10	15.6	-	8.40	4.00	0.12	0.08	13.9	0.9
A2	9-17	35.0	43.0	22.0	15.6	6.1	0.04	9.8	-	10.80	2.40	0.10	0.04	12.6	0.8
Cr	17+	*Weathered saprolite*													
Chanavada 2 - Moderately shallow loamy skeletal non calcareous Typic Ustorthents (Hill side slope)															
A1	0-14	33.5	44.0	22.5	15.1	6.1	0.06	14.8	-	11.20	3.80	0.10	0.07	21.3	0.5
A2	14-44	28.7	47.7	23.6	15.1	6.5	0.03	9.2	-	9.60	3.60	0.10	0.03	14.3	0.7
Cr	44-70	24.9	56.6	18.5	15.4	6.8	0.03	3.4	-	8.80	3.60	0.18	0.01	17.0	1.1
Chanavada 3-Moderately deep loamy skeletal non calcareous Typic Haplustepts (Foot slope)															
Ap	0-14	48.4	34.0	17.6	13.4	7.1	0.19	14.3	0.9	9.40	3.60	0.09	0.21	13.0	0.7
Bw1	14-38	37.8	38.2	24.0	15.2	7.5	0.06	9.1	1.4	11.20	3.20	0.23	0.08	14.3	1.6
Bw2	38-56	36.8	39.0	24.2	11.8	8.4	0.09	8.2	1.2	11.60	4.00	0.59	0.14	16.5	3.6
Bw3	56-75	38.8	38.0	23.2	18.8	8.7	0.15	6.9	1.6	9.20	4.50	1.57	0.11	17.0	9.2
Cr	75-95	34.2	51.0	14.8	16.9	9.2	0.20	3.2	2.8	4.60	3.40	1.78	0.07	10.8	16.4
Chanavada 4 - Deep loamy skeletal non calcareous Typic Haplustepts (Inter hill Valley)															
Ap	0-18	40.0	51.8	8.2	15.3	7.5	0.42	17.4	1.3	8.80	1.20	0.10	0.60	14.8	0.7
A1	18-43	41.7	48.0	10.3	17.9	7.4	0.09	4.9	1.2	6.00	1.60	0.08	0.24	10.9	0.7
A2	43-67	38.1	50.3	11.6	18.6	7.2	0.01	3.8	0.9	6.80	1.20	0.06	0.16	11.7	0.5
Bw1	67-100	37.7	46.4	15.9	15.4	7.1	0.19	3.3	1.2	8.80	2.40	0.05	0.12	17.0	0.3
Bw2	100-135	33.2	48.0	18.8	17.5	7.1	0.18	3.6	1.3	10.40	6.00	0.08	0.09	18.3	0.4
Cr	135+	*Weathered saprolite*													
Chanavada 5 - Very deep fine non calcareous Typic Haplustepts (Narrow Valley)															
Ap	0-14	51.7	34.8	13.5	12.2	7.1	0.33	16.6	0.9	10.4	4.40	0.14	0.30	15.2	0.9
Bw1	14-34	48.3	38.5	13.2	11.6	7.3	0.12	12.6	1.2	9.60	5.60	0.21	0.15	16.1	1.3
Bw2	34-70	24.0	55.3	20.7	16.3	7.9	0.09	9.6	2.0	12.80	6.40	0.54	0.10	23.5	2.3
Bw3	70-105	25.8	56.0	18.2	17.2	8.0	0.12	8.3	1.6	14.0	7.20	0.75	0.11	23.9	3.1
Bw4	105-145	20.2	55.8	24.0	17.6	8.3	0.10	7.1	1.8	12.40	8.40	0.69	0.11	23.9	2.9
BC1	145-170	13.2	62.8	24.0	20.9	8.4	0.11	6.5	2.2	14.40	11.60	0.70	0.20	28.7	2.4
BC2	170-200	16.4	58.8	24.8	20.3	8.5	0.16	6.7	2.4	13.60	9.60	0.73	0.19	26.5	2.7

Chanavada 6 - Very deep loamy skeletal calcareous Typic Haplustepts (Broad Valley)															
Ap	0-17	29.2	53.8	17.0	16.3	5.7	0.34	8.3	-	8.40	4.00	0.14	0.25	21.7	0.6
Bw1	17-40	16.8	62.2	21.0	21.7	6.6	0.03	8.6	-	10.40	3.60	0.15	0.16	23.5	0.6
Bw2	40-70	24.2	53.6	22.2	19.1	7.0	0.02	9.4	-	10.80	4.40	0.17	0.18	27.8	0.6
Bw3	70-120	22.8	52.8	24.4	15.9	7.0	0.05	8.5	-	12.00	4.80	0.12	0.24	29.1	0.4
BC1	120-160	22.4	51.6	26.0	25.9	7.6	0.04	6.4	-	10.80	4.40	0.19	0.20	15.6	1.2
BC2	160-175+	21.7	54.8	23.5	11.3	7.4	0.06	3.3	-	6.80	3.20	0.17	0.15	12.6	1.3
Chanavada 7 - Deep fine calcareous Typic Haplustepts (Broad Valley)															
Ap	0-19	32.5	50.5	17.0	18.4	7.9	0.33	9.8	2.2	12.00	4.40	0.56	0.39	18.7	3.0
Bw1	19-41	10.0	63.0	27.0	18.9	8.3	0.17	6.0	3.4	16.40	7.60	0.74	0.23	25.2	2.9
Bw2	41-69	8.8	68.8	22.4	19.7	8.3	0.20	5.5	3.4	16.00	6.00	0.70	0.15	24.3	2.9
Bw3	69-105	11.3	66.7	22.0	20.9	8.4	0.18	4.9	6.8	14.00	7.60	0.78	0.11	21.7	3.6
Bw4	105-147	14.2	55.7	30.1	22.5	8.7	0.15	4.9	8.0	17.20	3.60	1.96	0.25	22.2	8.8
BC	147+	58.9	27.9	13.2	12.0	8.7	0.14	4.6	4.9	10.40	2.40	0.67	0.07	13.0	5.1
Chanavada 8 - Very deep fine calcareous Typic Haplustepts (Broad Valley)															
Ap	0-17	20.7	64.6	14.7	19.9	7.7	0.19	9.2	1.8	12.00	6.00	0.54	0.23	18.7	2.9
Bw1	17-46	19.8	54.6	25.6	18.9	8.2	0.12	7.2	2.1	16.00	6.80	0.59	0.09	22.2	2.7
Bw2	46-87	12.8	57.7	29.5	20.3	8.3	0.15	7.1	2.6	15.20	6.80	0.51	0.06	28.3	1.3
Bw3	87-107	31.3	47.0	21.7	14.6	8.4	0.15	5.1	2.5	15.20	1.20	0.78	0.06	23.0	3.4
Bw4	107-150	9.9	63.8	26.3	18.1	8.5	0.14	5.2	6.7	20.80	3.20	0.96	0.19	26.9	3.0
BC	150-190	16.3	55.7	28.0	16.8	8.6	0.15	5.3	10.7	14.00	8.00	1.22	0.16	26.9	4.5

Similar results have been reported by Gill *et al.* (2012) and Chaudhary (1992). Among the exchangeable cations, Ca^{2+} is the dominant cation followed by Mg^{2+}, Na^{+} and K^{+} on the exchange complex. The exchangeable Ca^{2+}, Mg^{2+}, Na^{+} and K^{+} ranged between 4.6 to 20.8, 1.2 to 11.6, 0.05 to 1.96 and 0.01 to 0.6 c mol (p^{+}) kg^{-1} respectively. It was observed that soils occurring on broad valley had the highest exchangeable Ca^{2+} content than the soils of steeply sloping hills. In general the exchangeable Ca^{2+}, Mg^{2+} and Na^{+} content increased with depth in all the soils except in soils of Chanavada-1 series however exchangeable K^{+} showed reverse trend that decreased with depth in all the soils. Cation exchange capacity (CEC) of soils ranged from 10.9 to 29.1 c mol (p^{+}) kg^{-1} soils and the highest CEC was observed in soils of Chanavada-6 series developed on broad valley. CEC increased with depth in all soils with exceptions in soils of Chanavada-1 and Chanavada-2 series. Gill *et al.* (2012) also reported similar findings in soils of Phalasia block in Udaipur district, Rajasthan. The increase in depth wise CEC in valley region might be due to deposition of sedimentation in gentle slopes. The base saturation ranged from 58.8 to 105.9 per cent.

Available NPK

The available soil nitrogen was rated as very low (<140 kg ha^{-1}), low (141-280 kg ha^{-1}), medium (281-420 kg ha^{-1}), moderately high (421-560 kg ha^{-1}), high (561-700 kg ha^{-1}) and very high (>700 kg ha^{-1}) (Table 3). The available soil nitrogen content in the soils of Chanavada watershed varied from 44.0 to 155.0 kg ha^{-1}. Soils of Chanavada-1, Chanavada-3, Chanavada-4 and Chanavada-5 are very low (102.0-130.0 kg ha^{-1}) and soils of other series are low (141.0-155.0 kg ha^{-1}) in available nitrogen content (Table 4). The available phosphorus content of the surface soils (Table 4) indicated that soils of Chanavada-1 and Chanavada-3 series are low (9.4 to 10.0 kg P ha^{-1}), soils of Chanavada-2, Chanavada-6 and Chanavada-8 are medium (15.0 to 22.9 kg P ha^{-1}), soils of Chanavada-5 and Chanavada-7 are high (30.0 to 31.1 kg P ha^{-1}) whereas the soils of Chanavada-4 are very high (142.5 kg P ha^{-1}) in available phosphorus. The data (Table 4) indicated that soils of Chanavada-1, Chanavada-2 and Chanavada-3 series are low (49.0 to 104.0 kg K ha^{-1}) on the other hand soils of Chanavada-4, Chanavada-5, Chanavada-6, Chanavada-7 and Chanavada-8 are medium (129.0 to 280.0 kg K ha^{-1}) in available potassium.

Available micronutrients

The DTPA-Fe ranged from 7.3 to 101.4 mg kg^{-1} (Table 3) and found to be much higher than the critical level of 4.5 mg kg^{-1} (Lindsey and Norvell 1978) in all the soils. DTPA-Mn varied from 4.7 to 39.2 mg kg^{-1} (Table 4) and found to be much higher than the critical level of 3.0 mg kg^{-1} (Takkar *et al.* 1989) in all the soils. DTPA-Cu of the soils ranged from 0.3 to 18.6 mg kg^{-1} (Table 4) and decreased with depth but higher than the critical value of 0.2 mg kg^{-1} (Katyal and Randhawa 1983) in all the soils. Zn content of the soils varied from 0.01 to 2.2 mg kg^{-1} (Table 4) and the surface layers of all the series is sufficient in Zn as Zn content is higher than the critical level of 0.6 mg $kg^{-1}$and decreases with depth in all the soils.

Soil classification

The soils of the Chanavada watershed possess Ustic soil moisture regime, hyperthermic soil temperature regime and mixed mineralogy class. The soils of Chanavada-1 series were formed on steeply sloping hills having > 30 per cent slope, due to this most of the fine earth particles are lost by erosion and leaving behind coarser particles as coarse fragments at the place. By virtue of having lithic contact within the first 50 cm soil depth and absence of any sub-surface diagnostic horizons underlain by Ochricepipedon and presence of 50 to 60 per cent coarse fragments compel them to be classify as Loamy-skeletal, mixed, hyperthermic, Lithic Ustorthents. The soils of the Chanavada-2 series were found on moderately steeply sloping hills with 15-30 per cent slope and 40-50 per cent coarse fragments. The absence of lithic contact within 50 cm soil depth and no sign of profile development below the Ochricepipedon compel to put these soils under Loamy-skeletal, mixed,

Table 3. Available major and micronutrient status of soils of Chanavada watershed

Horizon	Depth (cm)	Av. N	Av. P	Av. K	Fe	Mn	Zn	C
		kg ha^{-1}			ppm			
Chanavada 1- Very shallow loamy skeletal non calcareous Lithic Ustorthents (Hill top)								
A1	0-9	113	9.4	76	16.74	19.86	1.36	2.34
A2	9-17	143	7.6	27	40.40	14.54	0.34	1.58
Cr	17+							
Chanavada 2 - Moderately shallow loamy skeletal non calcareous Typic Ustorthents (Hill side slope)								
A1	0-14	155	15.0	49	38.24	15.48	0.64	1.20
A2	14-44	127	18.5	30	26.27	11.18	0.43	0.84
Cr	44-70	127	15.1	17	19.64	5.26	0.39	0.33
Chanavada 3-Moderately deep loamy skeletal non calcareous Typic Haplustepts (Foot slope)								
Ap	0-14	105	10.0	104	18.02	26.40	1.08	2.80
Bw1	14-38	103	9.8	30	11.06	24.84	0.95	3.62
Bw2	38-56	120	12.0	59	16.72	24.58	1.04	3.82
Bw3	56-75	106	8.0	29	15.44	17.64	0.24	2.70
Cr	75-95	60	12.8	39	7.26	4.72	0.02	1.32
Chanavada 4 - Deep loamy skeletal non calcareous Typic Haplustepts (Inter hill Valle y)								
Ap	0-18	130	142.5	280	25.82	5.76	2.22	0.96
A1	18-43	99	93.9	116.6	38.02	11.82	2.20	2.16
A2	43-67	101	23.1	67.8	30.21	14.36	1.92	1.82
Bw1	67-100	102	11.6	51.9	19.46	13.1	2.76	1.64
Bw2	100-135	88	21.6	41.8	17.4	11.4	1.48	1.12
Cr	135+	*Weathered sapro lite*						
Chanavada 5 - Very deep fine non calcareous Typic Haplustepts (Narrow Valley)								
Ap	0-14	102	31.1	167	17.86	25.40	1.34	1.36
Bw1	14-34	114	13.8	86	21.42	27.00	0.64	1.86
Bw2	34-70	135	12.0	64	14.68	25.48	0.01	1.60
Bw3	70-105	87	11.6	61	17.84	20.08	0.02	2.24
Bw4	105-145	62	13.7	70	13.36	19.40	0.16	2.08
BC1	145-170	75	8.1	134	16.68	17.42	0.40	2.68
BC2	170-200	75	16.1	122.57	16.14	14.54	0.68	2.64
Chanavada 6 - Very deep loamy skeletal calcareous Typic Haplustepts (Broad Valley)								
Ap	0-17	141	22.9	156	101.42	19.82	1.86	3.18
Bw1	17-40	123	9.0	90	101.13	39.20	1.08	3.64
Bw2	40-70	124	8.3	103	84.62	18.12	0.84	0.02
Bw3	70-120	45	9.2	115	78.83	16.26	0.64	0.02
BC1	120-160	93	16.5	92	21.84	20.30	0.07	2.94
BC2	160-175+	93	9.1	78	15.44	11.22	0.09	1.64
Chanavada 7 - Deep fine calcareous Typic Haplustepts (Broad Valley)								
Ap	0-19	141	30.0	211	30.84	18.03	1.48	18.58
Bw1	19-41	105	19.8	69	41.16	18.80	0.43	13.10
Bw2	41-69	92	12.2	61	17.20	16.08	0.36	6.30
Bw3	69-105	76	8.14	59	22.54	11.80	0.35	6.28
Bw4	105-147	79	12.3	148	26.32	9.84	0.42	4.27
BC	147+	44	15.7	58	30.40	10.44	0.36	1.44
Chanavada 8 - Very deep fine calcareous Typic Haplustepts (Broad Valley)								
Ap	0-17	152	16.2	129	27.32	16.58	1.72	2.38
Bw1	17-46	117	11.7	45	19.44	15.00	0.83	2.48
Bw2	46-87	105	10.0	40	21.08	15.86	0.31	1.82
Bw3	87-107	75	11.6	36	17.34	12.02	0.32	1.66
Bw4	107-150	49	16.9	105	34.40	14.62	0.34	2.83
BC	150-190	49	30.2	118	24.10	11.64	0.68	2.54

hyperthermic, Typic Ustorthents. The soils of Chanavada-3, 4, 5, 7 and 8 series were formed on moderately sloping foot slope to broad valley type landforms with the slope ranging from 1 to 15 per cent. These soils did not have lithic contact within 50 cm soil depth from the surface hence these were grouped under Ustept at sub-order level due to *ustic* soil moisture regime and Haplustepts at great group level as these soils possess cambic sub-surface horizon underlain by Ochricepipedon and qualified for Typic Haplustepts at sub group level. Similarly the soils of Chanavada-6 series were developed on broad valley with 3-8 per cent slope showing the presence of cambic B sub-surface horizon under lained by the ochricepipedon but the irregular distribution of soil organic carbon down the profile depth qualifies it to classify for Fluventic Haplustepts.

Land capability, irrigability and suitability of soils for crops

As per land capability classification criteria, soils of the Chanavada watershed is grouped into five capability classes *viz*. II, III, IV, V, VI and VII (Table 4). The dominant LCC class covering largest area is V with the limitation of soil erosion, which covers 32.3% area of total geographical area of the watershed followed by land capability class II with the limitation of soils comprising 25% of total geographical area of the watershed. The soils of the watershed are grouped into five land irrigability classes *viz.* 2,3,4,5 & 6 and the dominant land irrigability class occurring in the watershed is 5 occupying an area of 32.31% of total geographical area of the watershed which are classed as the lands that are temporarily not suitable for sustained use under irrigation because of severe limitation of soil and topography. Following the class 5 another dominant land irrigability class in the watershed is 2s which are, the lands with moderate limitation of soils for sustained use under irrigation, covering an area of 25.0% of total geographical area of the watershed. The soils under land irrigability class 6 are the lands not suitable for sustained use under irrigation or not susceptible to delivery of irrigation water.

Soil site suitability studies provide information on the choice of crops to be grown on best suited soil unit for maximizing crop production per unit of land, labour and inputs. Land suitability for defined use and the impact of use on environment is determined by land condition and land qualities. Generally crops are grown as per choice, tradition of the farmers and market needs, ignoring the suitability of soil and climatic conditions. Increase in production can only be attained through scientific use of resources and by the selection of specific crops completely adaptable to the agro-climate. Each plant species requires definite soil, site and climatic conditions for its optimum growth. The suitability of soils was evaluated for the commonly grown crops *viz.* for maize, rice, sorghum, wheat, barley, gram, mustard and cluster bean in the region and is presented in table 4. The data indicates that the soils of Chanavada-1 and Chanavada-2 series are not suitable (N) for cultivation of any arable crops due to their severe limitations of hilly topography, steep slope; severe erosion, very shallow depth and their skeletal nature impose great problems in the watershed. Soils of Chanavada-3 are marginally suitable (S3) for maize, sorghum and cluster bean cultivation as these soils are well drained and favourable soil texture for luxuriant growth of maize however the severity of slope, erosion and graveliness make these soils not suitable (N) for crops like rice, wheat, barley, gram and mustard. Soils of Chanavada-4 series are moderately suitable for sorghum and cluster bean (S2) whereas marginally suitable (S3) for maize, wheat, barley, gram, mustard and not suitable for rice (N) due to the severe limitations of slope, very severe erosion and very strong stoniness. Soils of Chanavada-5 series were situated on gently sloping narrow valley showed moderate suitability (S2) maize, sorghum, gram and cluster bean with slight limitations of slope, erosion and soil characteristics on the other hand same soils were marginally suitable (S3) for rice, wheat, barley due to minor limitation of soil texture and severe limitations of slope, erosion, undulating topography and graveliness. The Chanavada-6 soils were formed on the upper reaches of broad valley were moderately suitable (S2) for sorghum and cluster bean whereas due to the severe limitations of erosion, graveliness and soil constraints

Table 4. Land capability, land irrigability and soil-site suitability for major crops grown in the region

Series	Land capability sub-class	Land irrigability sub-class	Soil suitability rating							
			Maize	Rice	Sorghum	Wheat	Barley	Gram	Mustard	Cluster bean
Chanavada -1	VIes	6st	N	N	N	N	N	N	N	N
Chanavada -2	Ves	5st	N	N	N	N	N	N	N	N
Chanavada -3	IVes	4st	S3	N	S3	N	N	N	N	S3
Chanavada -4	IIIes	3st	S3	N	S2	S3	S3	S3	S3	S2
Chanavada -5	IIes	2s	S2	S3	S2	S3	S3	S2	S2	S2
Chanavada -6	IIIes	3s	S3	S3	S2	S3	S3	S3	S3	S2
Chanavada -7	IIs	2s	S2	S2	S2	S2	S2	S1	S1	S2
Chanavada -8	IIs	2s	S1	S2	S1	S2	S1	S1	S1	S1

compelled these soils to classify under marginal suitable (S3) class for maize, rice, wheat, barley, gram and mustard crops. Chanavada-7 soils are highly suitable (S1) for gram and mustard whereas these soils are moderately suitable (S2) for maize, sorghum, rice, wheat, barley and cluster bean due to slight limitations of soils, slope and erosion. The soils of Chanavada-8 series are situated on the broad valley floor in the lower reaches of the watershed and due to continuous deposition of sediment *via* good soil health and life saving irrigation facility makes these soils highly suitable (S1) for maize, sorghum, barley, gram, mustard and cluster bean and moderately suitable (S2) for rice and wheat with slight limitations of soils.

Conclusion

The study showed that the soils of the hills are very shallow to moderately shallow soils belongs to Entisols soil order and the soils of the valley region are deep to very deep Inceptisols. The formation of diverse group of soils could be attributed to the effect of topography, vegetation and climate leading to various pedogenic processes. The major constraints for agricultural productivity in the watershed is more than half of the area is under steeply sloping land, severe erosion, shallow soil depth, strong soil stoniness and acute shortage of irrigation facilities. The soils of the hills are not suitable for arable field crops and the soils of foot slope and narrow valley were marginal to moderately suitable for growing crops. The soils of the broad valley were the good cultivable lands with minor soil problem such as gentle slope, fairly satisfactory texture and slight stoniness. All climatically adapted crops can be grown under irrigation. The study showed the immense need of application of scientific approach in terms of soil and water conservation measures with proper land use planning for land resource management and to improve livelihood of local peoples and sustained the agricultural productivity of watershed.

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