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Assessment of Soil Degradation and Large Scale Soil Mapping Using GIS: A Case study of village Ramagarh from Purna Valley, Maharashtra

R.K. Naitam[1*], V.K. Kharche[2], V.V. Gabhane[3], T. Bhattacharyya[4], S.M. Taley[5], I.K. Ramteke[6], Preeti Deshmukh[7] and N.M. Konde[8]

[1]ICAR – National Bureau of Soil Survey and Land Use Planning, Regional Centre, Udaipur-313 001, India.
[2,8]Dept. of SSAC, PG Institute, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola- 444 104, India,
[3]AICRP for Dryland Agriculture, Dr Panjabrao Deshmukh Krishi Vidyapeeth, Akola- 444 104, India.
[4] Dr. BSKKV, Dapoli, Dist. Ratnagiri (M. S.), India
[5] Dept. of SWC Engineering, , Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola- 444 104, India
[6]Maharashtra State Remote Sensing Application Centre, Nagpur, India
[7] Vasantdada Sugar Institute, Manjri (Bk), Pune- 442 307, India

Abstract : The importance of soil-physiographic relationship in soil survey and mapping, provide a betterunderstanding of variability across the landscape needed for sustainable agricultural planning. Keeping this in view, soils of the Ramagarh village of Purna valley in Amravati district, Maharashtra (semi-arid region) were studied for their morphological, physical and chemical characteristics and soils were mapped at 1: 8000 scale using geographical information system. The soils of Ramagarh village are very deep, dark greyish brown to very dark greyish brown in colour, clay in texture and exhibits medium, moderate, subangular blocky structure in the surface layers and the subsoil horizons had medium, weak to strong angular blocky structure. Soils are alkaline in reaction, calcareous in nature and low to medium organic carbon content. The pH, CaCO3 and exchangeable sodium percentage (ESP) increase with depth in all the soils. Because of high smectitic clay content and ESP down the profile, these soils have impeded drainage and resulting in ponding of water during the rainy season. The soils of the uplands are classified as Sodic Haplusterts and low land soils belong to Typic Haplusterts category at sub group level. The study indicates that the soils had chemical degradation in terms of sodicity and 18.2% area of the TGA of the village had a severe problem of sodicity. The higher ESP related to corresponding decrease in exchangeable calcium and increase in exchangeable magnesium.

Keywords: Black soils, soil degradation, sodic soils

Introduction

Soil is the most precious natural resource of any nation and its judicious management is of paramount importance. Till now, the increasing demands of production were being met by putting more arable lands under cultivation. Besides reduction in land area, there is decline in soil quality, what we call soil degradation, either quantitatively/qualitatively or both as a result of processes such as soil erosion by water and wind, salinization, sodification, waterlogging, depletion of plant nutrients, depletion of soil structure, desertification and pollution. Soils are considered as an integral part of the landscape and thus their characteristics are largely governed by the landforms on which they have developed (Sharma *et al.,* 1999). The importance of soil-physiographic relationship in soil survey and mapping, provide a better understanding of variability across the landscape needed for sustainable agricultural planning (Murthy *et al*, 1982 Naitam *et al. 2016*). Systematic study of morphology and taxonomy of soils gives an idea about nature and type of soils, their constraints, potential capabilities and suitability for various uses (Sehgal 1996).

Vertisols and associated soils are the most widely distributed soils in the world and can be found under varied climatic condition. Shrink-swell soils are found mostly in the peninsular India and are developed on alluvium derived from the weathering of Deccan Basalt (Murthy *et al*. 1982). The Vertisols occupy about 26.62 m ha in India of which 5.6 m ha is in Maharashtra (Bhattacharyya *et al*. 2009). They are mainly confined to lower topographic positions, such as the river valleys. One such valley is the Purna valley, which

*Corresponding author (Email: ravindranaitam@gmail.com)

covers a large area of 1,900,000 ha in Amravati, Akola and Buldhana districts of Maharashtra, India. The earlier studies conducted in the region revealed that the soils of the Purna valley are prone to native salinity/sodicity, poor drainability and poor quality ground water. Thus these soils are deteriorated and that resulted in poor drainability and hence for the sustainable agricultural production it is essential to understand the spatial distribution of soil properties of these soils for better management options. Therefore, the present study has been undertaken with an objective to assess the kind of soil degradation and mapping the status of degradation on large scale 1:8000 in Ramagarh village of Amravati district of Maharashtra using geographical information system

Materials and methods

Study area

The study area comprises central part of the Purna valley in Vidarbha region of central India. Ramagarh is located between $77^0$12'36″ to $77^0$13'50‴ E longitude and $20^0$52'46″ to $20^0$53'59″ N latitudes in Daryapur tehsil of Amravati district of Maharashtra covering an area of 324 ha (Fig 1). The mean elevation of the village ranges from 250 to 286 m above the mean sea level

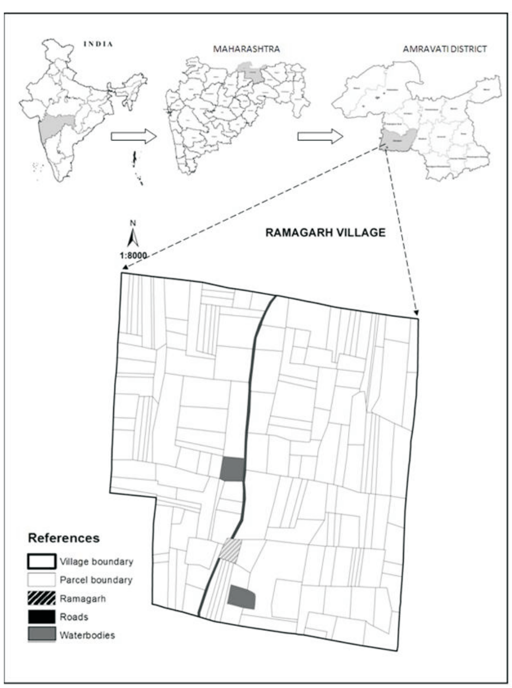

Fig 1. Location map of the area

The Purna valley is a faulted basin filled with sediments derived entirely from the Deccan basalt surrounding it. The total thickness of their deposit is upto 420 m (Adyalkar 1963). The area is characterized by hot summer and a dry weather conditions except, during the south west monsoon season and thus represents a tropical sub humid dry to semi-arid dry climate. The study area has monsoonal climate, beginning from June or July through September which receives 85-95% of the total annual rainfall of 700-975 mm. However, the district experiences an erratic rainfall pattern with low as 600 to as high as 1100 mm. This is followed by a dry season from October to May or June. April and May are the hottest months with mean monthly temperature of 32.5 and 35.2 ^oC respectively. December and January are the coolest months with monthly temperature of 22 ^oC. The length of growing period in the area is 152 days. The soils have a Typic Tropoustic moisture regime. The soil temperature regime is hyperthermic. Soybean (*Glycine max*), greengram (*Phaseolus aurens*) and cotton (*Gossypium spp.)* are the principal kharif crops. Pigeon pea (*Cajanous cajan*), black gram (*Phaseolus mungo*) and cowpea (*Vigna catiang*) are also grown. Chickpea (*Cicer arietinum*) is dominant *rabi* crop raised on residual soil moisture and/or with some protective irrigations. The natural vegetation of the area comprises of dry deciduous tree species and grasses. The dominant tree *Accacia arabica*, *Ziziphus jujube*, *Butea frondosa*, *Azadiracta indica*, *Calotropic gigantea*, *Saccharum spontaneum* and *Cynadon dactylon*.

Preparation of base maps, soil sampling, and their analysis

Survey of India (SOI) Toposheet No. 55 H/1 (1:50,000 scale) were used to collect topographic and location information. Google image and Cadastral map (1:8000 scale) of the village was used for identification of field boundaries traversing across the area. A detailed soil survey of the village area was carried out using the base map. Based on the variation in soil-site characteristics like slope and other micro features representative sites were selected for profile studies. Morphological characteristics of the pedon were studied in the field as per the procedures laid out in Soil Survey Manual (Soil Survey Staff, 1998). About 2 kg representative soil sample from each of the horizons were collected for laboratory characterization. The samples were initially air dried in the shade. The samples were ground using wooden mortar and pestle and passed through a 2 mm sieve. Sopecific estimations such as organic carbon, calcium carbonate, samples were further ground and passed through a 100 mesh sieve and stored in plastic bottles for further analysis.

Particle-size distribution were determined by the International Pipette Method (Klute, 1986). The bulk density was determined by clod coating method (Black and Hartge, 1986). The hydraulic conductivity was measured by constant head method as described by Klute and Dirksen (1986). The coefficient of linear extensibility (COLE) was estimated by following the method of Schaffer and Signer (1976). The moisture retention and release behavior within the available range of 33 kPa to 1500 kPa were measured using pressure plate membrane apparatus as per method outlined by Richards (1954). Chemical properties like pH and EC of the soil suspension (1:2 soil : water ratio) was determined by the methodology described by Jackson (1973). For the determination of soil organic carbon (SOC), the modified Walkley and Black wet oxidation method was used (Walkley and Black, 1934; Jackson, 1973). The free calcium carbonate was determined by rapid titration method (Piper, 1966). The exchangeable cations, cation exchange capacity of soils were determined by methods outlined by Richards (1954).

Results and Discussion

Morphological properties of soils

All the soils were very deep (>150 cm), clayey in texture and dark brown (10YR 3/3) to dark grayish brown (10 YR 3/2) in colour (Table 1). Soils exhibit a hue of 10YR, a value of 3 and chroma ranging from 1 to 6 corresponding to very dark gray to dark yellowish brown coloured soils. The subsurface horizons in all pedons are very dark grayish brown (10 YR 3/2) to very dark gray (10 YR 3/1) in colour except Bss3 horizon of pedon 8, which is dark yellowish brown (10 YR 3/6) in colour. This may be due to presence of more $CaCO_3$ in diffused form with the depth. The dark colour of these soils may be attributed to humus and minerals like titaniferous magnetite (Zonn, 1986). All the soils in the Ramagarh village exhibit medium, moderate, sub angular blocky structure in the surface layers and hard (dry) and friable (moist) consistence. However, the subsoil horizons had medium, weak to strong angular blocky structure consisting of intersecting slickensides, forming parallelepipeds with their long axes at 30-45 degrees from the horizontal. These separate into strong, coarse angular blocks with shiny pressure faces and firm (moist) and very sticky and very plastic (moist) consistence. Common, many, few fine and very fine sized roots were observed in the surface layers. The number of roots decreased with depth. Below 100 cm depth there are only very few to few, fine and medium roots. The soils of Ramagarh village are calcareous in nature and showed strong effervescence (with 10% HCl) in the surface horizons and it was violent in rest of the profile which is attributed to the presence of diffuse powdery form of $CaCO_3$ (Balpande,1993). Calcium carbonate concretions are observed throughout the depth in all the soils.

The slickensides were commonly found in the soils of Ramagarh village. The slickensides appear first at the depth of 43 to 74 cm from the surface and extend beyond 155 cm if there are no restricting layers like Ck horizons. These slickensides form an angle of about 35^o to 70^o with the horizon. All the soils exhibit cracks measuring more than 2 cm wide at the surface during dry season. These cracks separate soil mass into number of polyhedrons. These cracks were extended up to slickensides zone in pedon 2, 3 4 and 8. On the other hand the cracks were extended through whole of the slickensides zone in pedon 1, 5, 6 and 7 (Table 1).

Table 1. Morphological properties of soils of village Ramagarh Purna valley

Horizon	Depth (cm)	Boundary		Matrix colour	Texture	Structure	Consistence			Nodules		Roots		Effervescence with dil. HCl	Other features	
		D	T				D	M	W	S	Q	S	Q		SS/Pf	Cracks
Pedon:1 Fine, smectitic, hyperthermic Typic Haplusterts																
Ap	0-16	c	s	10YR3/2	C	m2sbk	h	Fr	vsvp	F	m	vf,f	m	es	-	2 to 3 cm wide cracks
Bw1	16-40	c	s	10YR3/2	C	m2sbk	h	Fr	vsvp	f,m	m,c	vf,f	m	ev	-	extending up to 45 cm
Bw2	40-64	g	w	10YR3/2	C	m2abk	h	Fi	vsvp	m	c	f	f	ev	Pf	depth.
Bss1	64-99	g	w	10YR3/2	C	m3abk	-	Fi	vsvp	m	c	f	f	ev	SS	1.5 to1 cm wide cracks
Bss2	99-130	c	s	10YR3/1	C	m3abk	-	Fi	vsvp	m	c	c	f	ev	SS	extending up to 100 cm
Bss3	130-160	-	-	10YR3/1	C	m3abk	-	Fi	vsvp	m,c	c	-	-	ev	SS	depth
Pedon:2 *Very fine, smectitic, hyperthermic* *Typic* Haplusterts																
Ap	0-18	c	s	10YR3/2	C	m2sbk	h	Fr	vsvp	vf,f	m	vf,f	m,c	es	-	2 to 3 cm wide cracks
Bw1	18-46	g	w	10YR3/2	C	m2sbk	h	Fr	vsvp	vf,f	m	vf,f	m	es	-	extending up to 20 cm
Bw2	46-70	g	w	10YR3/2	C	m2abk	h	Fi	vsvp	F	m	f	m	ev	Pf	depth.
Bss1	70-99	g	s	10YR3/1	C	m3abk	-	Fi	vsvp	F	m	f	m	ev	SS	1.5 to1 cm wide cracks
Bss2	99-128	g	s	10YR3/1	C	m3abk	-	Fi	vsvp	F	m	f	f	ev	SS	extending up to 90 cm
Bss3	128-157	-	-	10YR3/1	C	m2abk	-	Fi	vsvp	m	m	-	-	ev	SS	depth.
Pedon:3 *Very fine, smectitic, hyperthermic* *Typic* Haplusterts																
Ap	0-19	c	s	10YR3/3	C	m2sbk	h	Fr	vsvp	vf,f	m	vf,f	m	es	-	2 to 3 cm wide cracks
Bw1	19-49	g	w	10YR3/2	C	m2sbk	h	Fr	vsvp	F	m	vf	m	es	-	extending up to 40 cm
Bw2	49-82	g	w	10YR3/2	C	m2abk	vh	Fr	vsvp	m	c	vf	m	es	Pf	depth
Bss1	82-109	g	w	10YR3/1	C	m3abk	-	Fi	vsvp	m	c	f	m	ev	SS	1.5 to1 cm wide cracks
Bss2	109-135	g	s	10YR3/1	C	m3abk	-	Fi	vsvp	m	c	m	f	ev	SS	extending up to 90 cm
Bss3	135-160	-	-	10YR3/2	C	m2abk	-	Fi	vsvp	C	c	-	-	ev	SS	depth.
Pedon:4 *Fine, smectitic, hyperthermic* *Sodic* Haplusterts																
Ap	0-18	c	s	10YR3/2	C	m2sbk	h	Fr	vsvp	vf,f	m	vf,f	m	es	-	1.5 to 2 cm wide cracks
Bw1	18-45	c	s	10YR3/2	C	m2sbk	h	Fr	vsvp	vf,f	m	vf,f	m	ev	-	extending up to 80 cm
Bw2	45-90	g	w	10YR3/1	C	m2abk	h	Fr	vsvp	m	c	f	m	ev	Pf	depth
Bss1	90-121	g	w	10YR3/1	C	m2abk	-	Fi	vsvp	m	c	c	f	ev	SS	
Bss2	121-140	g	w	10YR3/1	C	m3abk	-	Fi	vsvp	m	c	c	f	ev	SS	
Bss3	140-160	-	-	10YR3/1	C	m3abk	-	Fi	vsvp	m	c			ev	SS	
Pedon:5 *Fine, smectitic, hyperthermic* *Typic* Haplusterts																
Ap	0-18	C	s	10YR3/2	c	m2sbk	h	fr	vsvp	vf,f	m	vf,f	m	es	-	2 to 3 cm wide cracks
Bw1	18-39	C	s	10YR3/2	c	m2sbk	h	fr	vsvp	vf,f	m	vf,f	m	es	-	extending up to 40 cm
Bw2	39-74	G	w	10YR3/1	c	m2abk	h	fr	vsvp	vf,f	m	f	m	es	Pf	depth.
Bss1	74-100	C	s	10YR3/1	c	m3abk	vh	fi	vsvp	vf,f	m	m	f	ev	SS	1.0 to 0.5 cm wide
Bss2	100-131	G	w	10YR3/1	c	m3abk	vh	fi	vsvp	m	m	vf,f	f	ev	SS	cracks extending up to
Bss3	131-162	-	-	10YR3/3	c	m1abk	-	fi	vsvp	c	c	-	-	ev	Pf	100 cm depth.

Pedon:6 *Very fine, smectitic, hyperthermic Typic* Haplusterts																
Ap	0-16	C	s	10YR3/2	c	m2sbk	h	fr	vsvp	vf,f	m	vf,f	m	es	-	2 to 3 cm wide cracks
Bw1	16-47	G	w	10YR3/2	c	m2sbk	h	fr	vsvp	vf,f	m	vf,f	m	es	-	extending up to 18 cm
Bw2	47-80	G	w	10YR3/2	c	m2sbk	h	fr	vsvp	m	c	f	c	ev	Pf	depth.
Bss1	80-110	G	w	10YR3/1	c	m2abk	-	fi	vsvp	m	c	f	c	ev	SS	1.5 to1 cm wide cracks
Bss2	110-135	G	s	10YR3/1	c	m3abk	-	fi	vsvp	m	c	f	c	ev	SS	extending up to 110 cm
Bss3	135-170	-	-	10YR3/2	c	m3abk	-	fi	vsvp	m	c	-	-	ev	SS	depth.
Pedon:7 *Very fine, smectitic, hyperthermic Typic* Haplusterts																
Ap	0-16	C	s	10YR3/2	c	m2sbk	h	fr	vsvp	vf,f	m	vf,m	f,c	es	-	2 to 3 cm wide cracks
Bw	16-43	C	w	10YR3/2	c	m2sbk	h	fr	vsvp	f,m	m	vf,f	m	ev	Pf	extending up to 40 cm
Bss1	43-80	C	w	10YR3/2	c	m2abk	h	fi	vsvp	f,m	m	f	c	ev	SS	depth
Bss2	80-103	C	w	10YR3/1	c	m3abk	-	fi	vsvp	f,m	m	f	c	ev	SS	1.5 to1 cm wide cracks
Bss3	103-132	G	s	10YR3/1	c	m3abk	-	fi	vsvp	f,m	m	f	c	ev	SS	extending up to 100 cm
Bss4	132-157	-	-	10YR3/3	c	m2abk	-	fi	vsvp	m,c	m	-	-	ev	SS	depth.
Pedon:8 *Very fine, smectitic, hyperthermia c Typic* Haplusterts																
Ap	0-18	C	s	10YR3/2	c	m2sbk	h	fr	vsvp	f,m	m	vf,f	m	es	-	2 to 3 cm wide cracks
Bw1	18-41	C	s	10YR3/2	c	m2sbk	h	fr	vsvp	f,m	m	f	m	es	-	extending up to 40 cm
Bw2	41-57	G	w	10YR3/3	c	m2abk	vh	fi	vsvp	m,c	c	f	m	es	Pf	depth
Bss1	57-86	G	w	10YR3/3	c	m2abk	-	fi	vsvp	m	c	m	m	ev	SS	1.0 to 0.5 cm wide
Bss2	86-117	C	w	10YR3/2	c	m3abk	-	fi	vsvp	m	c	f	m	ev	SS	cracks extending up to
Bss3	117-154	-	-	10YR3/6	c	m1abk	-	fi	vsvp	C	m			ev	Pf	80 cm depth

Physical properties of soils

The soils are clay in texture and the clay content varies from 57.0 to 67.3% and it increasesd with depth in all the pedons which might be due to downward translocation of finer particles from the surface layers (Kadu 1991; Balpande, 1993;). Very high clay content of these soils can be attributed to their formation from basaltic parent material (Pal and Deshpande 1987). The bulk density was variable in different horizons and varied from 1.44 to 2.07 Mg m^{-3}. Similar observations were recorded by Nimkar (1990) and Padekar (2014) while studying the soils of Purna valley. It was relatively lower in the surface horizons and increased with depth in all the soils that may be due to comparatively more organic matter in the surface horizons and higher swelling pressure and compaction caused due to smectitic clay content in the subsoil (Ahuja *et al*., 1988). The saturated hydraulic conductivity of the soils of village varied from 0.20 to 7.56 mm hr^{-1} and rapidly decreased with depth in all the pedons except P5 and P8. The data (Table 2) indicated imperfect to poor internal drainage condition of these soils. This might be due to the compactness of the sub-surface layers and due to high exchangeable sodium percentage (ESP) in the sub-surface horizons. Considerable decrease in SHC with increasing depth was also observed in deep black soils by Bharambe *et al*. (1986), Kadu (1991), Nimkar *et al*. (1992) and Balpande (1993). It is generally observed that the soils which have ESP ≥ 5 have low SHC value (Pal *et al*., 2000) indicating poor internal drainage condition. The COLE varies from 0.19 to 0.26 and fall into very high shrink-swell soils category (Nayak *et al*. 2006). The mean weight diameter varied from 0.42 to 0.98 mm in different horizons of the pedon except P1 and P2. The downward decrease in mean weight diameter can be attributed to sub-soil sodicity in these soils (Table 2). The gravimetric water retention at 33 kPa and 1500 kPa tension indicated that of AWC ranged from 5.0 to 35.1% and increased with depth in all the soils. The moisture retention and release functions in the soils of Purna valley indicated that sub-soil retained more moisture than the surface soils at the given tensions. This effect may be due to higher Na^{+} saturation in the subsurface layers (Balpande 1993).

Table 2. Physical Properties of soils of village Ramagarh (Purna valley)

Horizon	Depth	Sand	Silt	Clay	BD	SHC	MWD	COLE	Water retention (%)		
	(cm)		%		($Mg\ m^{-3}$)	($mm\ hr^{-1}$)	(mm)	($cm\ cm^{-1}$)	33 kPa	1500 kPa	AWC
Pedon:1 Very Fine, smectitic, hyperthermic (calc.), Typic Haplusterts											
Ap	0-16	5.6	37.4	57.0	1.66	3.18	0.74	0.19	32.7	22.3	10.4
Bw1	16-40	7.1	34.5	58.5	1.71	0.97	0.42	0.21	37.0	18.5	18.6
Bw2	40-64	6.2	35.4	58.5	1.72	0.79	0.84	0.20	37.2	21.7	15.5
Bss1	64-99	6.4	34.4	59.3	1.88	0.73	0.78	0.19	39.1	22.2	16.9
Bss2	99-130	5.0	35.5	59.6	1.85	0.50	0.96	0.22	38.5	22.7	15.8
Bss3	130-160	5.6	33.8	60.6	1.87	0.42	0.98	0.25	40.7	23.1	17.6
Pedon:2 *Very Fine, smectitic, hyperthermic (calc.), Typic Haplusterts*											
Ap	0-18	4.6	30.8	64.6	1.52	3.18	0.83	0.22	52.5	22.9	29.6
Bw1	18-46	5.4	29.5	65.1	1.56	1.41	0.85	0.22	40.3	23.6	16.7
Bw2	46-70	2.5	34.5	63.1	1.61	0.91	0.88	0.23	41.4	25.0	16.4
Bss1	70-99	3.4	29.4	67.3	1.59	0.91	0.87	0.25	60.9	25.8	35.1
Bss2	99-128	3.1	32.2	64.7	1.68	0.79	0.90	0.24	45.0	26.3	18.7
Bss3	128-157	2.3	36.6	61.1	1.64	0.60	0.88	0.23	51.2	26.2	25.0
Pedon:3 *Very Fine, smectitic, hyperthermic (calc.), Typic Haplusterts*											
Ap	0-19	6.9	33.8	59.4	1.67	5.77	0.67	0.24	35.6	23.8	11.8
Bw1	19-49	9.8	28.7	61.5	1.63	2.51	0.89	0.24	34.8	22.9	11.9
Bw2	49-82	7.5	32.0	60.6	1.68	1.42	0.75	0.25	35.4	23.9	11.5
Bss1	82-109	5.5	31.5	63.1	1.68	0.91	0.63	0.26	37.6	24.4	13.2
Bss2	109-135	3.0	32.5	64.6	1.95	0.68	0.58	0.25	39.3	26.0	13.3
Bss3	135-160	4.8	30.5	64.7	1.87	0.64	0.54	0.26	39.4	25.8	13.5
Pedon:4 *Very Fine, smectitic, hyperthermic (calc.), Sodic Haplusterts*											
Ap	0-18	7.1	32.3	60.6	1.56	3.23	0.89	0.21	35.1	23.0	12.1
Bw1	18-45	7.3	35.7	57.0	1.91	0.86	0.88	0.20	33.6	21.8	11.9
Bw2	45-90	5.6	32.9	61.5	1.91	0.51	0.70	0.22	34.5	24.3	10.3
Bss1	90-121	4.5	32.3	63.2	1.95	0.31	0.65	0.24	38.3	26.6	11.8
Bss2	121-140	4.5	32.5	63.1	2.07	0.48	0.68	0.25	41.3	27.0	14.4
Bss3	141-160	2.9	38.2	58.9	2.06	0.45	0.72	0.24	45.6	29.0	16.6

Pedon:5 *Very Fine, smectitic, hyperthermic (calc.), Typic Haplusterts*											
Ap	0-18	6.0	36.0	58.0	1.48	6.12	0.90	0.19	37.3	30.0	7.3
Bw1	18-39	5.4	34.1	60.6	1.60	3.52	0.91	0.21	38.5	25.6	12.9
Bw2	39-74	6.5	31.6	61.9	1.66	7.56	0.88	0.22	44.0	25.5	18.5
Bss1	74-100	5.4	33.2	61.4	1.75	0.99	0.76	0.21	39.2	29.6	9.6
Bss2	100-131	4.7	33.1	62.2	1.72	0.98	0.72	0.24	43.0	28.7	14.3
Bss3	131-162	5.7	34.7	59.5	1.76	0.79	0.72	0.25	43.8	25.5	18.3
Pedon:6 *Very Fine, smectitic, hyperthermic (calc.), Typic Haplusterts*											
Ap	0-16	6.4	31.7	62.0	1.47	3.57	0.91	0.22	40.9	35.8	5.0
Bw1	16-47	5.8	31.3	62.9	1.49	2.50	0.88	0.22	42.2	24.8	17.4
Bw2	47-80	6.3	30.0	63.7	1.75	1.41	0.83	0.24	41.8	25.8	16.0
Bss1	80-110	3.9	33.8	62.3	1.79	0.52	0.86	0.25	44.5	28.6	15.9
Bss2	110-135	5.2	32.4	63.4	1.87	0.53	0.78	0.24	46.7	28.7	18.0
Bss3	135-170	3.4	31.0	65.6	1.82	0.20	0.66	0.30	48.3	30.2	18.1
Pedon:7 *Very Fine, smectitic, hyperthermic (calc.), Typic Haplusterts*											
Ap	0-16	5.4	33.8	60.8	1.44	3.11	0.88	0.23	40.4	21.9	18.5
Bw1	16-43	6.5	29.6	63.9	1.48	1.21	0.90	0.23	38.2	23.5	14.7
Bw2	43-80	5.5	33.9	60.6	1.62	0.70	0.91	0.24	39.7	22.8	16.9
Bss1	80-103	6.0	31.4	62.6	1.65	0.54	0.83	0.25	42.8	22.5	20.3
Bss2	103-132	6.3	31.2	62.5	1.79	0.53	0.78	0.26	44.1	26.1	18.0
Bss3	132-157	3.5	32.9	63.6	1.85	0.40	0.64	0.26	47.2	28.6	18.5
Pedon:8 *Very Fine, smectitic, hyperthermic (calc.), Typic Haplusterts*											
Ap	0-18	2.9	35.4	61.7	1.65	5.76	0.53	0.19	43.5	23.3	20.2
Bw1	18-41	3.8	34.7	61.7	1.73	4.18	0.50	0.21	38.9	22.4	16.5
Bw2	41-57	3.2	33.4	63.4	1.72	6.85	0.56	0.22	40.1	23.0	17.1
Bss1	57-86	2.5	32.3	65.3	1.84	0.72	0.60	0.23	43.1	27.6	15.5
Bss2	86-117	3.0	34.7	62.3	1.79	0.50	0.86	0.24	44.1	25.3	18.8
Bss3	117-154	2.4	39.6	58.1	1.73	0.44	0.58	0.24	42.6	24.0	18.7

Chemical properties of soils

The soils are slight to moderately alkaline in reaction and pH varied from 8.4 to 9.4, and increased with depth (Table 3). The EC of all the pedons is well below 4 dSm^{-1} unit to be printed together The increase in EC with depth indicates that salinization process is also operative in these soils. All the soils are calcareous in nature and $CaCO_3$ varied from 5.9 to 9.9 per cent in different horizons with a tendency to increase with depth. This may be due to semi-arid climatic condition, where the leaching of bicarbonates during rainy season from upper layers and subsequent precipitation triggers development of sodicity in subsurface of black soils (Balpande *et al*. 1996; Kadam *et al*. 2013). These soils are impoverished of organic carbon and the SOC content ranged from 2.7 to 8.1 g kg^{-1} and it decreased with depth in all the pedons. The cation exchange capacity of the soils was high and it varied from 43.4 to 65.4 c mol (p^+) kg^{-1}. It was very high due to dominance of smectitic mineralogy of these soils. The clay CEC values estimated on the basis of soil CEC and clay percentage ranged from 74.7 to 98.1 c mol (p^+) kg^{-1}.

Table 3. Chemical Properties of Soils of village Ramagarh (Purna valley)

Horizon	Depth (cm)	pH (1:2 H_2O)	EC (1:2 H_2O)	OC ($g\ kg^{-1}$)	$CaCO_3$ (%)	Exchangeable bases					CEC	Clay CEC	BS	ESP	EMP	Ca^{2+}/Mg^{2+}
						Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	Total						
						………….. c mol (p+) kg^{-1}…………..								…%......		
Pedon:1 Fine, smectitic, hyperthermic (calc.), Typic Haplusterts																
Ap	0-16	8.6	0.23	6.7	6.5	37.2	17.6	2.3	1.1	58.3	54.5	95.6	106.9	4.3	32.3	2.1
Bw1	16-40	8.7	0.21	5.4	7.1	32.4	21.2	3.2	0.9	57.7	54.3	92.8	106.4	5.9	39.1	1.5
Bw2	40-64	9.0	0.23	4.8	7.6	28.0	22.4	4.4	0.8	55.6	52.5	89.7	105.8	8.3	42.6	1.2
Bss1	64-99	9.1	0.29	4.7	7.1	26.4	22.4	6.7	0.8	59.1	55.1	93.1	107.2	12.1	40.6	1.2
Bss2	99-130	9.2	0.29	4.9	7.1	27.2	22.4	7.2	0.8	58.8	53.7	90.2	109.5	13.4	41.7	1.2
Bss3	130-160	9.2	0.42	4.8	7.3	22.8	22.4	8.5	0.7	55.7	56.3	92.9	98.5	15.1	39.8	1.0
Pedon:2 *Very fine, smectitic, hyperthermic (calc.), Typic Haplusterts*																
Ap	0-18	8.6	0.17	5.4	7.9	40.8	19.2	2.7	0.9	63.6	61.7	95.5	103.2	4.4	31.1	2.1
Bw1	18-46	8.7	0.15	5.1	8.6	36.0	24.8	2.6	0.7	64.1	61.7	94.7	104.0	4.2	40.2	1.4
Bw2	46-70	8.7	0.19	5.1	8.4	34.0	26.4	3.7	0.7	64.8	60.5	95.9	107.0	6.0	43.6	1.3
Bss1	70-99	8.8	0.20	5.4	7.9	31.6	28.8	3.3	0.8	64.5	65.4	97.2	98.6	5.0	44.0	1.1
Bss2	99-128	8.8	0.21	5.2	6.9	13.6	25.2	3.6	0.8	43.1	62.8	97.0	68.7	5.7	40.1	0.5
Bss3	128-157	8.8	0.23	3.8	8.9	19.2	32.0	2.9	0.8	54.9	53.1	86.9	103.3	5.4	60.2	0.6
Pedon:3 *Very fine, smectitic, hyperthermic (calc.), Typic Haplusterts*																
Ap	0-19	8.8	0.21	5.8	8.2	37.6	16.8	2.1	1.2	57.7	56.5	95.2	102.0	3.7	29.7	2.2
Bw1	19-49	8.8	0.17	4.8	8.9	33.2	20.4	2.3	0.7	56.6	56.7	92.1	99.8	4.0	36.0	1.6
Bw2	49-82	8.9	0.19	4.8	8.4	32.0	26.0	2.5	0.7	61.2	59.5	98.1	102.9	4.2	43.7	1.2
Bss1	82-109	9.0	0.20	4.7	7.8	31.2	22.8	3.0	0.7	57.7	57.5	91.1	100.5	5.3	39.7	1.4
Bss2	109-135	9.1	0.29	4.7	8.5	26.8	28.4	4.8	0.7	60.7	59.6	92.2	101.9	8.0	47.7	0.9
Bss3	135-160	9.1	0.35	4.1	9.1	21.6	27.2	4.7	0.7	54.2	56.0	86.5	96.8	8.4	48.6	0.8
Pedon:4 *Very fine, smectitic, hyperthermic (calc.), Sodic Haplusterts*																
Ap	0-18	8.6	0.21	8.1	5.9	39.2	17.2	2.6	1.4	60.5	57.4	94.7	105.3	4.5	30.0	2.3
Bw1	18-45	9.0	0.27	5.3	6.8	37.6	13.6	4.4	0.8	56.5	54.2	95.0	104.2	8.2	25.1	2.8
Bw2	45-90	9.0	0.23	5.0	6.6	34.0	14.4	6.9	0.8	56.1	57.7	93.8	97.1	11.9	24.9	2.4
Bss1	90-121	9.3	0.32	4.8	6.4	30.8	17.6	11.6	0.7	60.7	59.7	94.5	101.6	19.4	29.5	1.8
Bss2	121-140	9.4	0.35	5.3	6.4	26.0	18.0	10.3	0.7	55.1	57.0	90.3	96.6	18.2	31.6	1.4
Bss3	140-160	9.3	0.47	4.9	7.3	23.6	21.6	9.6	0.7	55.6	55.6	94.3	100.0	17.4	38.9	1.1

Pedon:5 *Very fine, smectitic, hyperthermic (calc.), Typic Haplusterts*																
Ap	0-18	8.5	0.26	6.5	6.8	39.2	13.6	0.8	1.4	54.9	55.9	96.6	98.3	1.4	24.3	2.9
Bw1	18-39	8.7	0.24	5.7	6.6	36.4	16.8	0.4	0.9	55.5	57.6	95.1	94.6	0.8	29.1	2.2
Bw2	39-74	8.9	0.29	5.4	6.8	31.2	18.4	1.6	0.9	52.1	53.1	85.8	98.0	2.9	34.6	1.7
Bss1	74-100	9.0	0.31	4.9	6.9	28.4	17.6	3.1	0.9	50.0	53.7	87.6	93.0	5.8	32.8	1.6
Bss2	100-131	9.2	0.35	4.5	7.8	23.6	21.6	4.0	0.8	50.0	50.3	80.8	99.5	8.0	43.0	1.1
Bss3	131-162	9.2	0.43	3.4	9.5	17.2	22.0	4.0	0.7	43.9	48.9	82.1	89.8	8.2	45.0	0.8
Pedon:6 *Very fine, smectitic, hyperthermic (calc.), Typic Haplusterts*																
Ap	0-16	8.4	0.16	6.2	6.8	31.6	22.0	1.1	1.0	55.8	55.2	89.1	101.0	2.0	39.8	1.4
Bw1	16-47	8.5	0.21	5.7	7.5	28.8	24.8	0.9	0.9	55.4	57.9	92.1	95.6	1.5	42.8	1.2
Bw2	47-80	8.7	0.31	5.5	7.0	23.6	25.6	2.3	0.8	52.3	55.5	87.1	94.2	4.1	46.1	0.9
Bss1	80-110	8.7	0.38	5.1	7.4	21.6	27.6	4.6	0.8	54.6	54.9	88.0	99.6	8.4	50.3	0.8
Bss2	110-135	8.8	0.43	5.4	8.1	17.6	29.2	4.4	0.8	52.0	50.3	79.3	103.4	8.8	58.1	0.6
Bss3	135-170	8.8	0.56	5.2	7.7	16.0	29.6	6.0	0.8	52.4	55.6	84.7	94.3	10.8	53.3	0.5
Pedon:7 *Very fine, smectitic, hyperthermic (calc.), Typic Haplusterts*																
Ap	0-16	8.7	0.19	7.1	7.3	36.0	16.8	1.8	1.3	55.9	55.6	91.4	100.6	3.3	30.2	2.1
Bw1	16-43	9.1	0.29	6.2	7.1	31.6	20.4	2.7	0.9	55.6	57.2	89.5	97.2	4.7	35.6	1.5
Bw2	43-80	9.3	0.30	6.0	7.1	30.4	20.8	3.0	0.9	55.1	53.7	88.7	102.5	5.5	38.7	1.5
Bss1	80-103	9.4	0.37	5.8	7.3	27.2	21.2	4.1	0.9	53.4	55.9	89.3	95.6	7.3	37.9	1.3
Bss2	103-132	9.4	0.45	5.5	7.7	24.8	21.6	4.8	0.8	52.0	57.0	91.1	91.2	8.4	37.9	1.1
Bss3	132-157	9.3	0.73	4.1	9.3	18.0	24.4	6.3	0.7	49.5	51.7	81.4	95.7	12.3	47.2	0.7
Pedon:8 *Very f ine, smectitic, hyperthermic (calc.), Typic Haplusterts*																
Ap	0-18	8.5	0.29	5.7	6.9	37.6	12.8	1.5	1.4	53.2	56.4	91.5	94.3	2.6	22.7	2.9
Bw1	18-41	8.7	0.23	5.4	7.6	35.2	15.6	1.5	1.1	53.3	53.8	87.3	99.1	2.7	29.0	2.3
Bw2	41-57	8.8	0.25	5.2	7.9	30.8	20.4	0.5	1.0	52.7	53.8	84.9	97.9	1.0	37.9	1.5
Bss1	57-86	9.0	0.28	5.1	7.5	29.2	23.2	1.2	1.0	54.6	57.7	88.5	94.5	2.1	40.2	1.3
Bss2	86-117	9.2	0.26	4.5	7.7	22.8	24.4	4.3	0.9	52.4	52.5	84.4	99.7	8.1	46.5	0.9
Bss3	117-154	9.2	0.43	2.7	9.9	12.8	24.0	3.8	0.8	41.4	43.4	74.7	95.5	8.8	53.3	0.5

Among the exchangeable cations, calcium is the dominant cation followed by magnesium, sodium or potassium in surface layers of the soils. On the other hand magnesium is the dominant cation followed by calcium, sodium or potassium in sub-surface layers of the soils. The exchangeable Ca^{2+} and K^{+} content decreased with the depth in all the soils however, exchangeable Mg^{2+} and Na^{+} showed trend. The exchangeable Ca^{2+} content ranged from 12.8 to 40.8 c mol (p^{+}) kg^{-1}. On the contrary exchangeable Mg^{2+} varied from 12.8 to 32.0 c mol (p^{+}) kg^{-1}. The exchangeable sodium percentage (ESP) ranged from 0.8 to 19.4 in different pedons and in general it increased with depth. This can be attributed to lower topographical situation of these soils formed in this valley, which favours accumulation of soils and subsequent sodification under the semi –arid climatic condition coupled with slow permeability of these soils. An increase in ESP with depth is general observation for black soils in the semi- arid region of the peninsular India (Nimkar *et al*., 1992 and Kadu *et al*., 1993). The exchangeable K^{+} content ranged from 0.7 to 1.1 c mol (p^{+}) kg^{-1}. The exchangeable magnesium percentage (EMP) ranged from 22.7 to 60.2 and it increased with depth in all the soils. Similar trend of EMP with depth were also reported by Magar (1990) and Kadu (1991) for soils of the central and southwest part of the valley. This increase in EMP with depth causes structural deterioration under the specific conditions and results into reduction in SHC and increase in COLE values (Table 2). The Ca^{2+}/Mg^{2+} ratio varied from 0.5 to 2.9 and it decreased with depth in all the soils. The opposite depth function of exchangeable magnesium resulted in the reduction in Ca^{2+}/Mg^{2+} ratio in the sub-soils and leads to impairment of SHC.

Soil classification and mapping

Based on morphometric, physical and chemical characteristics, the pedons were grouped into different taxa. The pedons were very deep (>150cm) with cracks, clay content more than 30 per cent and slickensides (>25 cm thick) and hence meet the requirement for the subgroup *Typic Haplusterts* with very fine or fine textural family. However, the ESP of P4 soils within the 100 cm depth from the surface is more than 15%. Hence, these soils have been grouped into order *Sodic Haplusterts*. In view of ustic soil moisture regime for the region, all the soils qualify for Ustert suborder. In the entire horizons of all soils the clay CEC was found to be more than 74.7 c mol (p^{+}) kg^{-1}. Soil Taxonomy (Smith, 1986) advocates clay CEC limit of 16-24 c mol (p^{+}) kg^{-1} or less for a kaolinitic mineralogy class, and 24-45 c mol (p^{+}) kg^{-1} for soils of mixed mineralogy class and > 45 c mol (p^{+}) kg^{-1} for soils of montmorillonitic mineralogy class at family level of soil classification. Thus the mineralogy class of all these soils is montmorillonitic as has beenreported earlier for the black soils (Pal and Deshpande, 1987) through x-ray diffraction technique.

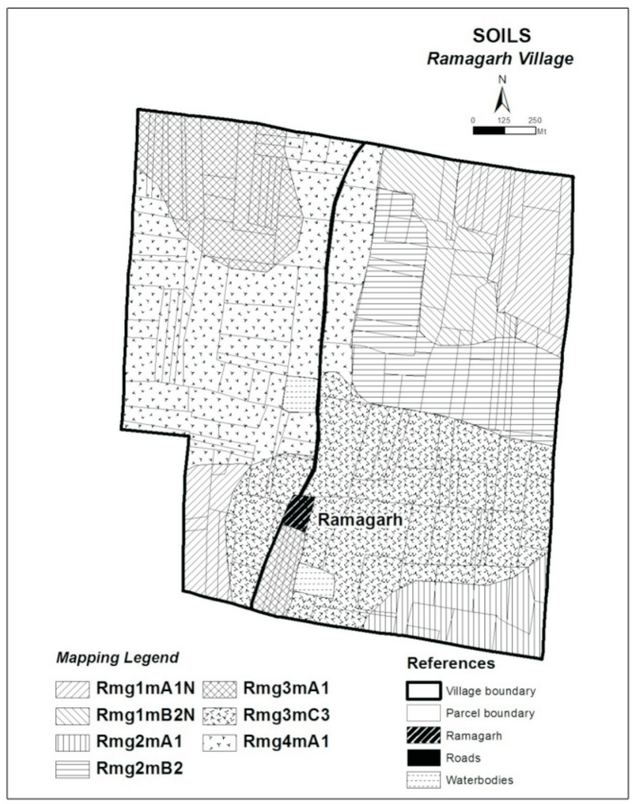

Fig 2. Soil map of the Ramagarh village

Soil mapping is basically an inference process based on Jenny's model (Jenny, 1941). According to this model, if the environmental conditions at a given location and its soil-environmental relationship are known, then it is possible to infer the condition of soil at any other location with similar environment conditions. This has great significance in mapping the soils in different physiographic units. After systematic study of soils in different landform units, the landform-soil relationship was established. 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. Based on soil correlation, tentatively four soil series namely Ramagarh-1 (Rmg-1), Ramagarh-2 (Rmg-2), Ramagarh-3 (Rmg-3) and Ramagarh-4 (Rmg-4) were identified in the area. On the basis of surface texture, slope, erosion and kind of degradation in four soil series were further sub-divided into soil phases and mapped into seven soil mapping units at. The soil map (1:8000 Scale) of the study area is presented in figure 2. Vertisols of arid and semi-arid climates contain more pedogenic carbonates (PC) in their soil control sections (SCSs) than those of sub humid climates lowlands (Vaidya and Pal, 2002). Based on information of related studies made earlier in the region it was observed that formation of PC is the prime chemical reaction responsible for the increase in pH, the decrease in the Ca^{2+}/Mg^{2+} ratio of exchange site with depth and in the development of subsoil sodicity and higher ESP values in the uplands than the lowlands in their soil control sections. The study indicates that the soils of the area had chemical degradation especially sub-soil sodicity and occupy 18.2% area of the TGA of the village. The higher ESP was related to corresponding decrease in exchangeable calcium and increase in exchangeable magnesium in the subsoil.

Conclusions

It can be concluded that these soils are formed in the basin or lower topographical position in the valley under semi-arid climate with high amount of smectitic clay. The soils are slight to moderately alkaline in reaction and pH increased with depth. All the soils are calcareous and the $CaCO_3$ increased with depth. Exchangeable Ca^{2+} ions decreased with depth on one side and on the other hand exchangeable Mg^{2+} and Na^{+} increased with depth in all the soils. ESP in the sub-soil deteriorate the soil structure and impaired the hydraulic conductivity of these soils. The reduction in mean weight diameter and SHC observed in the sub soil with concomitant increase in ESP is the cause of degradation of these soils and it also further becomes apparent that these adverse degradative processes occurs in these soils at much lower ESP values than 15. The study further indicates that the soils of the study area had chemical degradation in terms of sodicity even at ESP 45 especially in subsoil.

References

Adyalkar, P. G. (1963). Paleogeography, nature and pattern of sedimentation and groundwater potentiality of the Purna Basin of Maharashtra. Proc. Int. Sci. India, 29, 25-45.

Ahuja, L.R., Naney, J., Williams, W.R.D. and Ross, J.R. (1998). Vertical variability of soil properties in a small watershed. *J. Hydrology*, 99: 307-318.

Balpande, S.S. (1993). Characteristics, genesis and degradation of Vertisols of the Purna valley, Maharashtra. Ph.D. Thesis, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola, Maharashtra.

Balpande, S. S., Deshpande, S. B. and Pal, D. K. (1996). Factors and processes of soil degradation in Vertisols of the Purna valley, Maharashtra. *Land Degradation and Development*, 7, 313-324.

Bharambe, P.R., Awasarmal, B. C. and Ghonsikar, C. P. (1986). Physical properties of soils in Jayakwadi and Purna commands. Agricultural development of Jayakwadi and Purna command areas. Publ. Marathwada Agril. Univ., Parbhani, Maharashtra. Pp. 137-144.

Bhattacharyya, T., Sarkar, D. and Sehgal, J. (2009). Soil taxonomic database of India and the states (1: 250,000 scale), NBSS & LUP Publication. 142: 266.

Black, G.R. and Hartge, K.H. (1986). Bulk density, In: Method of Soil Analysis Part I. In Physical and Mineralogical Methods; A. Klute Ed. *Agronomy Monograph*, 9,1 2nd Ed. pp.363- 375.

Jackson, M.L. (1973). Soil Chemical Analysis. Prentice Hall of India Pvt. Ltd., New Delhi.

Jenny, H. (1941). Factors of soil formations. McGraw-Hill Book Co., New York.

Kadam, Y. B. (2011). Decadal change in land degradation in Purna valley of Maharashtra. M.Sc, (Agri.) Thesis, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola, Maharashtra.

Kadam, Y.B., Kharche, V.K., Naitam, R.K., Katkar, R.N. and Konde. N.M. (2013). Characterization and classification of salt-affected soils of Purna valley in Vidarbha region of Maharashtra. *Journal of Soil Salinity and Water Quality*:5 (2), 125-135.

Kadu, P.R. (1991). Physical and chemical properties affecting hydraulic conductivity of black soils of the Purna valley. M.Sc, (Agri.) Thesis, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola, Maharashtra.

Kadu, P. R., Pal, D. K. and Deshpande, S. B. (1993). Effect of low exchangeable sodium on hydraulic conductivity and drainage in shrink-swell soils of the Purna Valley, Maharashtra. *Clay Research,* 12, 65-70.

Klute, A. and Dirksen, C. (1986). Hydraulic conductivity and diffusivity laboratory methods in methods of soil analysis Part-I. In Klute, A. Ed. *Agron Monograph* 9, Madison, Wisconsin. pp. 716-719.

Klute, A. (1986). Methods of Soil Analysis, Part 1. In Physical and Mineralogical Methods; A. Klute Ed. *Agronomy Monograph*, 9,1. 2nd Ed.

Magar, A.S. (1990). An appraisal of the nature of salinity and sodicity in black soils of the Purna Valley, M.Sc. Thesis (unpub.) Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola, Maharashtra.

Murthy, R.S., L.R. Hirekerur, S.B. Deshpande and B.V. Venkat Rao, (1982). Benchmark Soils of India. National Bureau of Soil Survey and Land Use Planning (ICAR), Nagpur, India, 308p.

Naitam, R.K., Singh, R.S., Mohrana, P.C. and Singh, S.K. (2016). Characterization and evaluation of soils occurring on toposequence in Eastern Plains, Bhilwara district, Rajasthan for land use planning. *Agropedology*, 26 (01):94-104.

Nayak, A.K., Chinchmalatpure, A.R., Rao, G.G. and Verma, A.K. (2006). Swell shrink potential of Vertisols in relation to clay content and exchangeable sodium under different ionic Environment. *Journal of Indian Society Soil Science*, 54: 1-5.

Nimkar, A.M. (1990). Evaluation of physical and chemical characteristics of soils of the Purna valley of Maharashtra. M.Sc. (Agri.) Thesis. Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola, Maharashtra.

Nimkar, A. M., Deshpande, S. B. and Babrekar, P. G. (1992). Evaluation of a salinity problem in swell-shrink soils of a part of the Purna valley, Maharashtra. *Agropedology*, 2, 59-65.

Padekar, D. G. (2014). Soil quality as influenced by land use management with special reference to irrigation in selected tehsils of Amravati district, Maharashtra. Ph. D. (Agri.) Thesis. Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola, Maharashtra.

Pal, D. K. and Deshpande, S. B. (1987). Characteristics and genesis of minerals in some benchmark Vertisols of India. *Pedologie* (Ghent), 37, 259-275.

Pal, D.K., Deshpande, S.B., Valayutham, M., Srivastava, P. and Durge, S.L. (2000). Climate change and polygenesis in Vertisols of the Purna valley (Maharashtra) and their management. NBSS Res. Bult. 83. NBSS & LUP, Nagpur, p-35.

Piper, C. S. (1966). Soil and Plant Analysis. Hans Publishers, Bombay.

Richards, L. A. (1954). Diagnosis and Improvement of Saline and Alkali Soils. USDA Handbook No. 60, Oxford and IBH Publ. Co. Calcutta 160.

Schafer, W. M. and Singer, M. J. (1976). A new method of measuring shrink swell potential using pastes. *Soil Science Society America Journal,* 40: 805-806.

Sharma, R.C., A.K. Mandal, R.K.Saxena and K.S. Verma, (1999). Characterization, formation and reclamability of sodic soils under different geomorphic plains of Ganga basin. Extended Summary, International Conference on Sustainable Management of Sodic Lands, Feb 9-4, 2004, Lukhnow, India Vol.I, pp 168-170.

Sehgal, J.L. (1996). Pedology: Concepts and Applications, Kalyani Publishers, New Delhi.

Smith, G.D. (1986). *The Guy Smith interview*: Rationale for concepts in Soil Taxonomy. SMSS. *Technical Monograph* No. 11, SMSS, SCS, USDA.

Soil Survey Staff (1998). Keys to Soil Taxonomy (8 edn). Soil Conservation Service, US Department of Agriculture, Washington, D.C. 1998.

Vaidya, P. H. and Pal, D. K. (2002). Microtopography as a factor in the degradation of Vertisols in central India. *Land Degradation and Development*, 13, 429-445.

Van Wambeke, A. (1985). Calculated Soil Moisture and Temperature Regimes Of Asia. *SMSS Technical Monograph* No. 9. Cornell University, Ithaca, NY.

Walkley, A. and Black, C.A. (1934). An examination of degtijareff method for determining soil organic matter and a proposed modification of chromic acid titration method. *Soil Science*. 37: 29-38.

Zonn, S.V. (1986). Tropical and Subtropical Soil Science (Translated from the Russian), Mir. Publishers, Moscow, p-260.