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Clay dispersion induced by changes in some soil properties in undulating salt-affected landscapes of southern Karnataka, India

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Effect of sodicity on clay dispersion in salt-affected black soils of the Kabini canal command area in Chamrajnagar district, southern Karnataka was studied. Forty-eight soil samples were collected from nine soil profiles and analysed for physical and chemical properties. The clay dispersion ranged from 0.57% to 62.1%. High positive and negative correlations with exchangeable sodium and exchangeable calcium respectively, with clay dispersion were recorded, which can be predicted better with exchangeable sodium and available soil water. Based on clay dispersion value, 2%, 27% and 71% soils are dispersive, intermediate dispersive and non-dispersive respectively. Based on exchangeable sodium percentage, 50, 21 and 29 soils are dispersive, intermediate dispersive and non-dispersive respectively. Application of gypsum and organics reduces the clay dispersion in surface soil. Sub-surface drainage will be more effective. Construction of soil and water conservation structures with pile foundation; providing cement lining for soil stabilization in normal construction; providing drainage lines for the structures; construction after refilling with non-dispersive soil will save the structures in salt-affected soils.

Keywords: Clay dispersion, sodicity, sub-surface effect, surface effect.

SOIL quality declines when the primary particles in soil aggregates start dispersing and soil becomes structurally weak and is prone to erosion. Clay particles are negatively charged; these negative charges are balanced by cations such as Ca^{2+}, Mg^{2+}, K^+ and Na^+. When sodium is dominant, the clay particles are weakly bound to each other so that the soil aggregates disperse easily in wet condition. In salt-affected soils, dispersive soils are developed much

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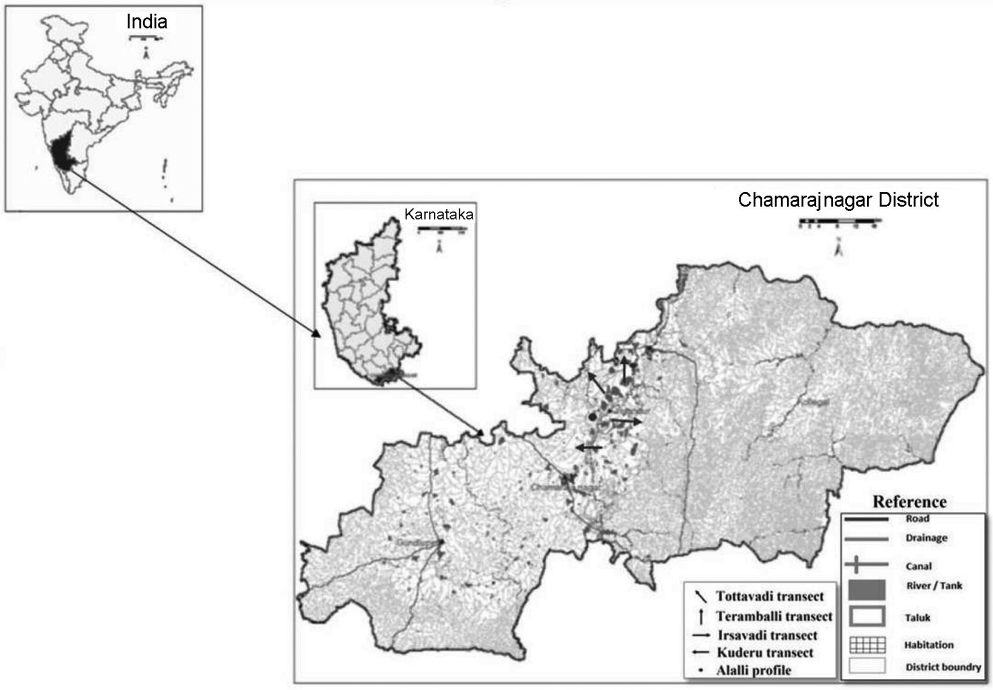
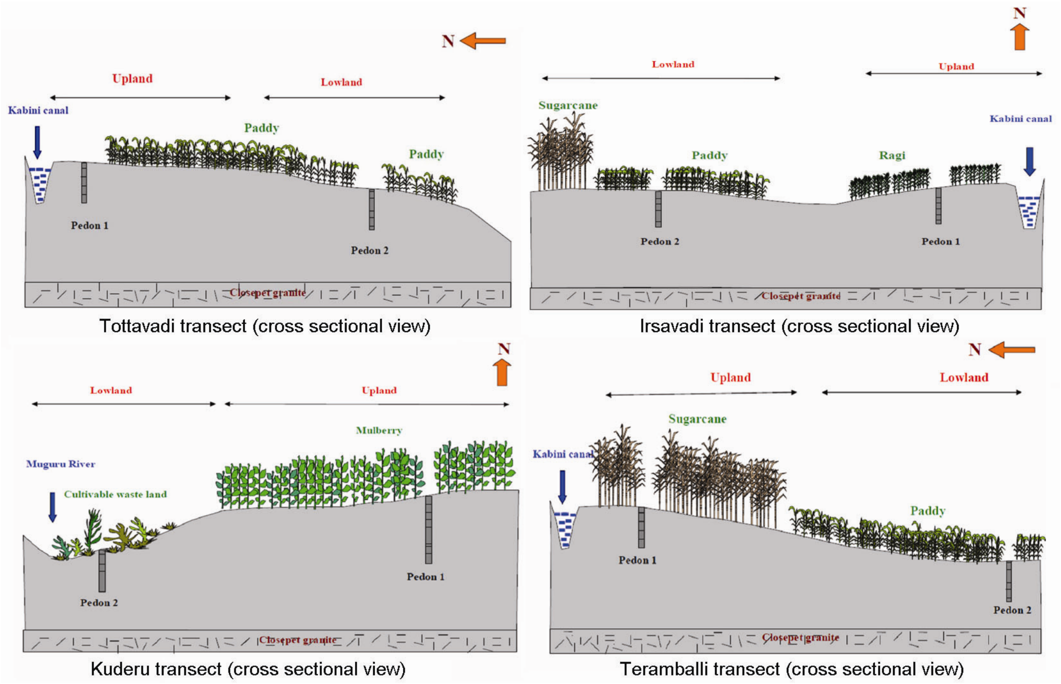


Figure 1. Location map of study area and transects in Chamrajnagar district, Karnataka.

in saline-sodic and sodic soils due to high amount of exchangeable sodium over other cations. Continuous accumulation of sodium due to indiscriminate use of irrigation water causes high exchangeable sodium percentage (ESP), which increases the soil dispersion index[1]. It creates an imbalance in electrochemical forces and makes the clay particles repel each other. Apart from sodium, montmorillonite (smectite) clay, ESP and electrical conductivity (EC) also significantly contribute to clay dispersion[2]. Dispersion of soils results in impeded infiltration of water, prolonged water logging, poor water use efficiency, more flexible in wet and crusting when dry, increased mechanical impedance to plant roots and reduced movement of air and water to the root zone. Structurally weak and dispersive soils are prone to erosion by water which is very severe if the land is sloping. Soil erosion induced by sodicity along with intensive rainfall and slope condition lead to land degradation. Soil and water conservation structures such as bunds and masonry structures are severely affected when sub-surface soils are dispersive in nature. Saline-sodic and sodic soils become more flexible and they lose their bearing capacity which makes the soil and water conservation structures weak. Therefore, identification of dispersive soil is essential for improving soil quality, increasing crop productivity and planning of soil and water conservation measures in large areas under salt-affected soils. Salt-affected soils occupy 6.75 M ha in India (2% of total geographical area) and 0.15 M ha in Karnataka (0.78% of total geographical area). Saline-sodic, sodic and saline soils occupy 89%, 9.5% and 1.5% area of salt affected soils in Karnataka. The study area as per agroclimatic zones of Karnataka lies in southern dry zone with total area of 18,038 ha in which salt affected soils occupy 2165 ha (ref. 3). Therefore, the effect of changes in some soil properties on clay dispersion was investigated and dispersive soil was classified in the salt affected black soils of southern Karnataka.

Publications of the Government of India[4], National Bureau of Soil Survey and Land Use Planning, Nagpur[5] and Karnataka State Remote Sensing Application Centre, Bengaluru[6] reported that large tracts of salt-affected lands exist in the southern parts of Karnataka and the soils of Chamrajnagar district are severely affected by salinity and sodicity (Figure 1). PAN-merged LISS III satellite imageries for the entire district of Chamrajnagar on 1 : 50,000 scale were interpreted for identification of salinity and sodicity-affected area based on visual interpretation keys. Lowlands and uplands were demarcated on the basis of the tonal variations and pattern for selecting transect. Four transects were selected and named after nearby villages, viz., Tottavadi transect, Teramballi transect, Kuderu transect and Irsavadi transect and one profile was opened outside canal irrigated area near Allali village (Figure 2). The tonal variation ranged from white to very dark grey. Lowlands were white to light grey in tone due to severe salinity and sodicity. Out of five imageries for the district, 57D/16 and 57H/04 were selected for the study. Two profiles were opened in each transect. Geographical coordinates of profile sites were marked with global positioning system (GPS). Black (vertisols) and alluvial (entisols) soils are dominant soils of the study area with smectite group clay, dominated by



Tottavadi transect (cross sectional view)

Irsavadi transect (cross sectional view)

Kuderu transect (cross sectional view)

Teramballi transect (cross sectional view)

Figure 2. View of four transects and profiles in Chamrajnagar district, Karnataka.

2 : 1 expanding type montmorillonite. Location and site characteristics are given in Table 1.

Forty-eight soil samples were collected horizon-wise from nine profiles. The collected soil samples were processed and analysed for soil texture (by international pipette method[7]), soil reaction (potentiometeric method using glass electrode[7]), electrical conductivity (using conductivity meter[8]), available nitrogen (by alkali-permanganate method[9]), available phosphorus (Olsen’s method[10]), available potassium (neutral normal ammonium acetate extract method[8]) and exchangeable calcium, sodium, potassium and magnesium (neutral normal ammonium acetate extract method[8]). ESP percentage was calculated with exchangeable sodium and cation exchange capacity. Clay dispersion was estimated as described by Rengasamy *et al.*[11].

According to Knodel[12], soils of the study area were identified and categorized for different degrees of dispersion based on clay dispersion percentage and ESP. As per the clay dispersion percentage values, the categories are: <30 is non-dispersive, 30–50 is intermediate and >50 is dispersive. As per the ESP, the categories are: <7 is non-dispersive, 7–10 is intermediate and >10 is dispersive.

Simple correlation was carried out to determine the strength of association between soil parameters and clay dispersion. Step-wise regression was performed to select the best model to predict clay dispersion using physical and chemical properties of soil.

The soil of the study area has become saline-sodic due to excessive irrigation; sodicity is severe. Soil properties such as soil reaction (pH), EC, exchangeable cations and available major nutrients are varied widely along diverse transects of the study area. Soil texture of the study area is clayey in nature; but in some profiles, the texture changes up to sandy clay loam (Table 2). It might be due to dispersion of clay where the sodicity is severe as observed in Irsavadi and Teramballi upland soils. Clay content of the upland soils (weighted average of 44.8%) was lower than lowland soils (weighted average of 54%). Available soil water in the profiles ranges from 13.8 to 33.1 cm. Higher quantity of available soil water is recorded in non-saline-sodic soils, whereas it is less than 18.0 cm in severe sodic soil as observed in upland of Tottavadi, as well as along the upland and lowland transects of Irsavadi. Soil reaction in the study area is alkaline and it ranges from moderately alkaline to strongly alkaline due to high sodium content in the soil[13]. The soil reaction value ranges from 8.12 to 9.87. Soil reaction of upland and lowland soils of Teramballi and Irsavadi and lowland of Kuderu, is more than 9.0 (mean of profile), which indirectly contributes to clay dispersion. Electrical conductivity of the soil in the study area varies from 0.89 dS m^{-1} in non-salt affected soils, to 30.20 dS m^{-1} in salt affected soils. Due to sodicity, high amount of sodium contributes to high EC which also increases the clay dispersion. Soil fertility status in the saline-sodic soils varies differently in all the profiles. Available nitrogen, phosphorus and potassium ranges from 41 to 223, 10 to 122 and 104 to 350 kg ha^{-1} respectively, in surface soils. The available nitrogen has been recorded as low as 40.8 kg ha^{-1} in the severely dispersed soil in lowland Kurderu transect where the soil was abandoned for cultivation. Available

Table 1. Details of site characteristics and profile locations in the saline–sodic soil areas of Chamrajnagar district, Karnataka

			Location of profiles				
Taluk	Transect location	Land form/physiography	Latitude and longitude	Elevation (MSL)	Distance between the profiles (metres)	Soil taxonomy classification	Land use
Kollegal	Tottavadi village	Nearly level upland with <1% slope	Latitude: 12°11′03.96″N Longitude: 76°57′09.98″E	655	1200	Fine, montmorillonitic, isohyperthermic Typic Haplusterts (Smectite clay >50%)	Paddy and ragi cultivation
		Gently sloping lowland with 1–2% slope	Latitude: 12°10′35.78″N Longitude: 76°57′13.66″E	642		Typic Haplusterts (Smectite clay >50%)	Paddy and ragi cultivation
	Teramballi village	Gently sloping upland with 1–2% slope	Latitude: 12°07′49.40″N Longitude: 77°03′16.66″E	654	2200	Fine, mixed, isohyperthermic Aquic Haplustepts (Smectite clay <50%)	Sugarcane cultivation
		Nearly leveled low land with <1% slope	Latitude: 12°07′13.99″N Longitude: 77°03′14.75″E	641		Fine, montmorillonitic, isohyperthermic Sodic Haplusterts (Smectite clay >50%)	Paddy cultivation
Chamrajnagar	Kuderu village	Nearly leveled upland with <1% slope	Latitude: 12° 01′27.53″N; Longitude: 77°02′20.44″E	694	1300	Fine, montmorillonitic, isohyperthermic Typic Haplusterts (Smectite clay >50%)	Mulberry cultivation
		Gently sloping lowland with 2–3% slope	Latitude: 12°03′12.10″N Longitude: 76°55′45.45″E	676		Fine, mixed, isohyperthermic Aquic Haplustepts (Smectite clay <50%)	Abandoned scrub land
Yelandur	Irsavadi village	Gently sloping upland with 2–3% slope	Latitude: 12° 01′25.18″N Longitude: 77° 02′26.89″E	671	700	Fine, mixed, isohyperthermic Aquic Haplustepts (Smectite clay < 50%)	Ragi, paddy and sugarcane cultivation
		Nearly leveled lowland with <1% slope	Latitude: 12°01′27.53″N Longitude: 77°02′20.44″E	667		Fine, montmorillonitic, isohyperthermic Typic Haplusterts (Smectite clay >50%)	Paddy cultivation
	Alalli village	Nearly leveled upland with <1% slope	Latitude: 12° 05′51.89″N Longitude: 76°59′24.07″E	664	–	Typic Haplusterts (Smectite clay >50%)	Mulberry cultivation

Table 2. Soil physical and chemical properties of different profiles in Chamrajnagar district

				Soil properties													
Location of transect and profile		Depth of horizon (cm)	Horizon designation*	Sand (%)	Silt (%)	Clay (%)	Textural classes**	Available soil water (cm)	Soil reaction or pH	Electrical conductivity (dSm^{-1})^1	Available nitrogen (kg ha^{-1})^2	Available phosphorus (kg ha^{-1})	Available potassium (kg ha^{-1})	Exchangeable cations (cmol (p+) kg^{-1})^3			
														Ca^{2+}	Mg^{2+}	K^+	Na^+
Tottavadi transect	Upland	0–20	Ap	30.59	18.90	50.52	c	1.01	8.31	3.33	116.0	60.7	174	34.53	5.42	0.07	1.39
		20–49	Bw	17.12	19.07	63.81	c	2.48	8.51	6.68	109.8	5.1	150	32.79	5.14	0.07	2.93
		49–83	Bss1	9.49	27.62	62.89	c	3.42	8.51	11.91	69.0	2.5	113	32.08	4.83	0.05	3.78
		83–115	Bss2	20.16	14.44	65.40	c	3.34	8.37	19.34	50.3	2.5	126	19.54	4.45	0.05	5.11
		115–150	Bss3	20.00	13.46	66.54	c	3.64	8.21	30.20	54.2	5.1	149	24.89	4.86	0.06	5.38
		Mean		19.47	18.70	61.83		2.78	8.38	14.29	79.86	15.18	142.40	28.77	4.94	0.06	3.72
		Standard error		3.39	2.50	2.90		0.48	0.06	4.81	13.88	11.39	10.57	2.83	0.16	0.00	0.73
	Lowland	0–17	Ap	17.08	36.71	46.21	c	1.53	7.47	1.83	125.4	35.4	105	27.13	4.95	0.06	3.85
		17–50	Bw	15.81	16.50	67.68	c	4.07	8.76	2.22	69.0	5.1	89	26.71	5.20	0.05	3.15
		50–83	Bss1	17.83	9.97	72.20	c	5.21	8.80	4.08	69.0	10.1	100	26.47	5.47	0.05	2.32
		83–113	Bss2	16.48	13.43	70.09	c	5.17	8.86	5.64	53.3	3.8	99	26.54	6.86	0.05	2.89
		113–156	Bss3	17.55	10.17	72.28	c	4.31	8.92	7.26	56.4	5.1	130	26.77	7.71	0.05	3.85
		Mean		16.95	17.36	65.69		4.06	8.56	4.21	74.62	11.90	104.60	26.72	6.04	0.05	3.21
		Standard error		0.37	4.98	4.94		0.67	0.27	1.02	13.09	5.97	6.86	0.12	0.53	0.01	0.29
Teramballi transect	Upland	0–18	Ap	60.47	13.95	25.58	scl	3.81	8.96	3.56	106.6	39.2	147	26.25	1.40	0.08	1.20
		18–38	Bw1	52.10	16.85	31.05	scl	4.79	9.36	2.85	65.9	7.6	63	23.73	1.98	0.07	2.60
		38–76	Bw2	50.95	18.15	30.90	scl	9.33	9.57	4.09	50.2	5.1	57	20.50	4.03	0.04	2.64
		76–126	Bw3	52.25	15.94	31.81	scl	15.18	9.70	5.60	50.2	5.1	64	19.88	4.39	0.05	3.90
		126–151	Bw4	44.60	16.42	38.98	scl	10.00	9.57	7.03	47.0	2.5	75	19.36	3.84	0.06	5.59
		Mean		52.07	16.26	31.66		8.62	9.43	4.63	63.98	11.90	81.20	21.94	3.13	0.06	3.19
		Standard error		2.53	0.68	2.14		2.04	0.13	0.75	11.15	6.87	16.70	1.32	0.60	0.01	0.74
	Lowland	0–17	Ap	28.96	38.46	32.58	c	4.47	8.73	4.18	125.4	121.5	350	17.32	3.04	0.22	2.19
		11–40	Bw1	23.24	28.17	48.59	c	6.41	9.31	6.07	87.7	2.5	252	15.49	4.76	0.17	4.89
		40–82	Bw2	15.94	34.18	49.88	c	14.45	9.05	8.96	59.6	2.5	205	12.97	5.46	0.15	11.57
		82–130	Bss1	11.44	35.95	52.61	c	16.47	8.88	10.30	53.3	2.5	214	13.79	5.97	0.16	12.58
		130–150	Bss2	10.14	33.38	56.48	c	7.77	8.80	12.73	34.5	2.5	226	13.37	6.31	0.16	8.57
		Mean		17.94	34.03	48.03		9.91	8.95	8.45	72.10	26.30	249.40	14.59	5.11	0.17	7.96
		Standard error		3.58	1.70	4.09		2.35	0.10	1.51	15.82	23.80	26.36	0.81	0.58	0.01	1.97
Kuderu transect	Upland	0–20	A	40.89	20.93	38.17	scl	2.83	8.70	0.80	90.9	32.9	226	24.19	1.39	0.13	0.13
		20–51	Bw1	25.08	11.71	63.21	c	5.89	8.62	1.04	75.3	2.5	139	29.31	2.61	0.10	0.34
		51–77	Bw2	24.06	24.29	51.66	c	4.99	8.66	1.17	65.9	2.5	137	31.86	3.02	0.09	0.36
		77–116	Bw3	18.11	24.28	57.61	c	8.35	8.71	1.27	65.9	12.7	142	37.57	3.54	0.10	0.49
		116–140	Bw4	15.57	33.26	51.17	c	5.18	8.70	1.36	59.6	13.9	154	43.08	3.80	0.10	0.57
		Mean		24.74	22.89	52.36		5.45	8.68	1.13	71.52	12.90	159.60	33.20	2.87	0.10	0.38
		Standard error		4.41	3.47	4.17		0.89	0.02	0.10	5.45	5.56	16.86	3.28	0.42	0.01	0.08

(*Contd*)

Table 2. (*Contd*)

Location of transect and profile		Depth of horizon (cm)	Horizon desig-nation*	Soil properties										Exchangeable cations (cmol (p+) kg^{-1})^3			
				Sand (%)	Silt (%)	Clay (%)	Textural classes**	Available soil water (cm)	Soil reaction or pH	Electrical conductivity (dSm^{-1})^1	Available nitrogen (kg ha^{-1})^2	Available phosphorus (kg ha^{-1})	Available potassium (kg ha^{-1})	Ca^{2+}	Mg^{2+}	K$^+$	Na$^+$
	Lowland	0–13	Ap	16.75	40.57	42.68	c	3.89	9.38	15.46	40.8	10.1	290	9.45	1.90	0.17	8.09
		13–48	Bw	25.93	42.46	31.61	cl	4.74	9.40	11.28	44.3	5.1	250	13.69	2.07	0.13	6.75
		48–77	Bss1	36.85	14.66	48.49	c	5.35	9.31	8.72	43.9	29.1	193	15.94	2.98	0.12	6.38
		77–116	Bss2	60.92	20.80	18.28	sl	3.38	9.51	5.79	34.2	3.8	135	13.87	1.92	0.06	4.14
		116–152	Bss3	80.23	3.61	16.16	sl	1.42	9.74	2.85	22.4	8.9	69	10.32	1.03	0.04	1.01
		152–162	Bss4	90.36	1.80	7.84	s	0.34	9.74	1.77	12.5	2.5	45	5.83	0.68	0.04	0.54
		Mean		51.84	20.65	27.51		3.19	9.51	7.65	33.02	9.92	163.67	11.52	1.76	0.09	4.49
		Standard error		12.25	7.20	6.55		0.79	0.08	2.13	5.30	4.02	40.06	1.50	0.33	0.02	1.28
Irsavadi transect	Upland	0–19	Ap	47.36	25.15	27.49	scl	2.01	9.31	3.49	222.7	43.0	188	15.23	3.12	0.06	1.13
		19–56	Bw1	38.98	21.97	39.05	scl	3.99	9.87	8.65	125.4	20.2	380	12.28	3.35	0.08	3.84
		56–101	Bw2	37.85	22.07	40.08	sicl	5.04	9.74	9.00	84.7	10.1	310	10.76	3.37	0.09	5.96
		101–122	Bw3	31.78	24.51	43.72	c	1.92	9.63	9.76	50.2	5.1	246	7.52	3.56	0.10	6.20
		122–150	Bw4	36.45	18.94	44.61	cl	2.47	9.57	7.91	69.0	2.5	191	5.91	3.60	0.10	5.49
		Mean		38.48	22.53	38.99		3.09	9.62	7.76	110.40	16.18	263.00	10.34	3.40	0.09	4.52
		Standard error		2.53	1.10	3.06		0.61	0.09	1.11	30.69	7.36	36.74	1.66	0.09	0.01	0.94
	Lowland	0–20	Ap	40.83	14.85	44.32	c	1.53	9.24	2.73	106.6	21.5	315	20.38	2.65	0.18	1.45
		20–57	Bw	31.83	23.65	44.52	c	3.48	9.52	5.61	96.3	2.5	273	18.95	2.91	0.16	1.59
		57–93	Bss1	33.12	26.60	40.29	c	3.65	9.55	6.63	50.2	2.5	202	18.19	3.17	0.17	1.41
		93–130	Bss2	27.63	25.60	46.77	c	4.49	9.47	7.91	52.1	7.6	194	16.83	4.92	0.15	5.62
		130–145	Bss3	24.81	25.98	49.21	c	4.81	9.44	8.93	47.0	5.1	204	16.57	5.53	0.12	7.89
		Mean		31.64	23.34	45.02		3.59	9.44	6.36	70.44	7.84	237.60	18.18	3.84	0.16	3.59
		Standard error		2.73	2.18	1.48		0.57	0.05	1.07	12.79	3.54	24.02	0.70	0.58	0.01	1.34
Alalli profile		0–22	Ap	37.49	26.67	35.84	cl	2.67	8.52	0.86	97.2	13.9	104	22.86	1.59	0.07	0.15
		22–47	Bw	29.03	30.66	40.31	c	4.13	8.69	1.10	72.1	10.1	63	24.90	3.97	0.06	0.39
		47–92	Bss1	22.96	30.64	46.40	c	8.40	8.74	1.23	65.9	7.6	86	29.30	4.71	0.05	0.47
		92–126	Bss2	21.73	27.32	50.95	c	6.39	8.88	1.44	62.7	7.6	76	38.61	4.47	0.05	0.58
		126–152	Bss3	20.61	40.90	38.49	cl	8.12	8.97	1.76	53.3	5.1	85	44.36	4.51	0.06	0.88
	Mean			26.36	31.24	42.40		5.94	8.76	1.28	70.24	8.86	82.80	32.01	3.85	0.06	0.49
	Standard error			3.14	2.55	2.75		1.12	0.08	0.15	7.39	1.49	6.72	4.11	0.58	0.00	0.12

[1]dSm^{-1}, Deci Siemens per metre; [2]kg ha^{-1}, Kilogram per hectare; [3]cmol (p+)kg^{-1}, Centi mole per kilogram of soil; *Horizon designation: A, Surface (compact currently not ploughed) layer; Ap, Surface plough layer; Bw, Subsurface cambic horizon; Bw1, Subsurface cambic horizon below A/Ap horizon with altered colour; Bw2, Subsurface cambic horizon below Bw1 with altered colour; Bw3, Subsurface cambic horizon below Bw2 with altered colour; Bw4, Subsurface cambic horizon below Bw3 with altered colour; Bss1, Subsurface altered B horizon with intersecting slickensides due to high percentage of swell-shrink clay; Bss2, Similar to Bss1 with altered colour; Bss3, Similar to Bss2 with altered colour; Bss4, Similar to Bss3 with altered colour. **Textural classes based on United States Department of Agriculture classification; c, clay; cl, clay loam; scl, sandy clay loam; silc, silty clay loam; sl, sandy loam; s, sandy.

phosphorus ranged from 13.9 to 121.3 kg ha^{-1} in the area. Higher level of available phosphorus in upland soil of Tottavadi and lowland soil of Teramballi transects might be due to formation of sodium phosphate with high exchangeable sodium. Available potassium status is low to medium. Exchangeable calcium has been observed to increase with increasing depth in non-saline-sodic soils, whereas it shows a decreasing trend in saline-sodic soil. Exchangeable sodium[16] and magnesium content increases with depth.

Correlation analysis between soil properties and clay dispersion shows both positive and negative relationships (Table 3). All the positive associations (*r* value) were significant with clay dispersion and ranged from 0.26 to 0.88. The highest association has been observed with exchangeable sodium, which causes severe dispersion when its concentration is very high. Soil particles remain in dispersed state even when the ESP ranges from 3.7% to 5.2% (ref. 17). Electrical conductivity, available soil water, exchangeable potassium[18] and magnesium[19] are positively and significantly associated with clay dispersion. Decreasing Ca^{2+} and Ca^{2+}/Mg^{2+} ratios also enhance the clay dispersion in sodic soils[20–22]. Soil properties (exchangeable Ca, available N and sand) showed a negative correlation with clay dispersion with *r* values ranging from –0.29 to –0.49. Exchangeable calcium and available N show highly significant and negative association with clay dispersion. Calcium is a flocculating agent when its concentration increases, the clay dispersion decreases. Similarly, sand also showed a significant negative association with clay dispersion.

Prediction of clay dispersion with single soil parameter through simple linear regression shows that the exchangeable sodium recorded the highest R^2 value (0.77) followed by SAR and ESP ($R^2 = 0.72$**). EC has R^2 value of 0.44** followed by exchangeable Ca^{2+} with R^2 of 0.24^{**} (Table 4). The soil parameters, viz. Mg^{2+}, silt and sand are significant for clay dispersion. In case of predicting clay dispersion with more soil properties through step-wise forward regression, exchangeable sodium emerged with lowest *P* value in first step. Available soil water (ASW) with exchangeable sodium showed the lowest *P* value in the second step and the remaining soil parameters have been found to be non-significant. Hence, exchangeable sodium with ASW will give the best prediction for clay dispersion which shows lowest AIC (Akaike Information Criterion) value of 204.5 in saline-sodic soils (Table 4).

It has been observed that clay dispersion in non-saline-sodic soils (Kuderu upland and Alalli) ranges from 0.55% to 2.88%, where the Ca^{2+}/Na^{+} ratio is high. Clay dispersion in saline-sodic soils is observed up to 62.1%, because high sodium causes ‘auto-disintegration’ of soil aggregates[23]. Teramballi-lowland profile recorded the highest clay dispersion (37.1% as weighted average), which is due to severe saline-sodic condition as compared to Allali profile (0.92% weighted average), which is characterized by non-saline-sodic condition. Soil starts dispersing at field capacity moisture content (between 28% and 32%) due to high exchangeable sodium content. When sodicity is severe, soil disperses even below field capacity moisture content. Uplands of Tottavadi and Irsavadi show clay dispersion of 26.0% and 21.4% respectively; while soils of lowlands of Irsavadi and Kuderu show 27.6% and 24.3% (weighted average) respectively. In the later group of soils, the Ca^{2+}/Na^{+} ratio is very low. Within profiles, subsurface horizons record higher clay dispersion than surface horizons as exemplified by the upland profile at Tottavadi transect in which Bss3 horizon recorded 37.95% clay dispersion compared to surface horizon (18.98%). This is because of presence of sodic groundwater with high residual sodium carbonate ranging from 9.27 to 34.94 meq l^{-1} (refs 24, 25). In Irsavadi transect, both upland and lowland profiles recorded severe clay dispersion with highest dispersion of 39.1% in upland profile (Table 5). Along Kuderu transect-lowland, severe saline-sodic[26] condition and clay dispersion have led to severe soil erosion (Figure 3 *a*) and the micro-aggregate (53–250 μ size) ranges from 0.1% to

Table 3. Degree of association of soil parameters with clay dispersion

Soil properties	Correlation coefficients
Positive associations	
Exchangeable sodium	0.88**
Exchangeable sodium percentage	0.85**
Electrical conductivity	0.66**
Available K	0.40**
Exchangeable Mg	0.32**
Available soil water	0.26*
Negative associations	
Exchangeable calcium	–0.49**
Available N	–0.32**
Sand	–0.29*

*Significant; **Highly significant.

Table 4. Effect of soil properties on predictability of clay dispersion

Regression equations	R^2
Simple linear regression models	
$Y = 0.1069 + 5.064$ Na	0.77**
$Y = -1.452 + 1.575$ ESP	0.72**
$Y = 4.971 + 2.099$ EC	0.44**
$Y = 37.738 - 0.899$ Ca	0.24**
$Y = 4.273 + 3.531$ Mg	0.10*
$Y = 5.903 + 0.5184$ silt	0.08*
$Y = 26.901 - 0.286$ sand	0.08*
Multiple linear regression model	
$Y = 2.963 + 5.513$ Na – 0.873 ASW	0.79** (AIC[#] is 205 out of 275 for full model)

*Significant; **Highly significant; [#]AIC – Akaike information criterion.

Table 5. Dispersive soils based on clay dispersion and exchangeable sodium percentage

Location of transect and profile		Horizon depth (cm^1)	Horizon designation	Classification I		Classification II	
				Clay dispersion (%)	Degree of dispersion	Exchangeable sodium percentage	Degree of dispersion
Tottavadi	Upland	0–20	Ap	18.98	NDS	4.49	NDS
		20–49	Bw	20.98	NDS	8.11	IDS
		49–83	Bss1	23.13	NDS	10.29	DS
		83–115	Bss2	28.97	NDS	14.25	DS
		115–150	Bss3	37.95	IDS	15.24	DS
	Lowland	0–17	Ap	5.61	NDS	6.11	NDS
		17–50	Bw	7.48	NDS	7.52	IDS
		50–83	Bss1	7.48	NDS	8.49	IDS
		83–113	Bss2	14.95	NDS	9.96	IDS
		113–156	Bss3	22.43	NDS	10.77	DS
Teramballi	Upland	0–18	Ap	0.58	NDS	7.13	IDS
		18–38	Bw1	2.30	NDS	15.17	DS
		38–76	Bw2	3.45	NDS	13.60	DS
		76–126	Bw3	10.35	NDS	18.05	DS
		126–151	Bw4	39.67	IDS	24.95	DS
		151–160	Bw5	41.98	IDS	25.38	DS
	Lowland	0–17	Ap	0.57	NDS	8.85	IDS
		17–40	Bw1	24.73	NDS	15.01	DS
		40–82	Bw2	49.45	IDS	32.13	DS
		82–130	Bss1	48.88	IDS	38.27	DS
		130–150	Bss2	62.10	DS	25.29	DS
Kuderu	Upland	0–20	Ap	0.55	NDS	0.60	NDS
		20–51	Bw	0.58	NDS	1.18	NDS
		51–77	Bss1	1.15	NDS	1.11	NDS
		77–116	Bss2	2.30	NDS	1.50	NDS
		116–140	Bss3	2.30	NDS	1.68	NDS
		140–155	Bss4	2.88	NDS	1.74	NDS
	Lowland	0–13	A	40.83	IDS	24.51	DS
		13–48	Bw1	42.55	IDS	20.39	DS
		48–77	Bw2	39.10	IDS	24.22	DS
		77–116	Bw3	18.40	NDS	19.32	DS
		116–152	Bw4	4.02	NDS	8.48	IDS
		152–162	Bw5	0.57	NDS	6.37	NDS
Irsavadi	Upland	0–19	Ap	1.73	NDS	7.26	IDS
		19–56	Bw1	23.58	NDS	7.58	DS
		56–101	Bw2	35.08	NDS	7.10	DS
		101–122	Bw3	38.52	IDS	21.34	DS
		122–150	Bw4	39.10	IDS	26.20	DS
	Lowland	0–20	Ap	0.57	NDS	9.23	IDS
		20–57	Bw	18.40	NDS	13.03	IDS
		57–93	Bss1	23.58	IDS	17.57	IDS
		93–130	Bss2	31.05	IDS	19.84	DS
		130–145	Bss3	33.35	IDS	22.77	DS
Alalli		0–22	Ap	0.58	NDS	0.59	NDS
		22–47	Bw	0.58	NDS	1.45	NDS
		47–92	Bss1	0.58	NDS	1.54	NDS
		92–126	Bss2	1.15	NDS	2.00	NDS
		126–152	Bss3	1.73	NDS	3.08	NDS

Centimetre^1; NDS, Non-dispersive soil; IDS, Intermediate dispersive soil; DS, Dispersive soil.

0.6% with poor soil structure (Figure 3 *b*). By contrast, in non-saline-sodic condition in the upland of the same transect, erosion has been found to be slight (Figure 4 *a*) and here the micro-aggregate ranged from 9.3% to 11.3% with well-formed angular blocky structure (Figure 4 *b*).

Identification of dispersive soil leads to the inference that more than 30% clay dispersion with more than three horizons is found in Irsavadi-upland, Kuderu-lowland and Teramballi-lowland (Table 5). Out of 48 soil horizons in the study area, 2% are dispersive soils, 27% are

Figure 3. Severe saline-sodic land with severe erosion (***a***) and structure less soil in the profile (***b***) at lowland of Kuderu transect.

Figure 4. Non-saline-sodic land with slight erosion (***a***) and well-developed angular blocky structure of soil in the profile (***b***) at upland in Kuderu transect.

intermediate dispersive and the remaining are non-dispersive soils. Non-saline-sodic soils have showed ESP from 0.59 to 3.08 whereas in the soils of saline-sodic region, ESP ranged from 4.49 to 38.27 (ref. 27). Highest ESP (weighted average) of the profile has been recorded in Teramballi-lowland (27.9) followed by Kuderu-lowland (18.1), Teramballi-upland (16.9), Irsavadi-upland (16.7), Irsavadi-lowland (13.0), Tottavadi-upland (11.3) and Tottavadi-lowland (8.8). Levy and Torrento[28] have studied that when ESP increased, the clay dispersion also increased. Fifty per cent of soil horizons observed to be dispersive, followed by 21% under intermediate dispersive and the remaining in non-dispersive category. Clay dispersion needs to be reduced to improve the quality and productivity of soil. Gypsum application is a common practice to reduce exchangeable sodium and clay dispersion followed by application of organic manure. Gypsum requirement varies depending upon cation exchange capacity (CEC) and exchangeable sodium of soil. Gypsum requirement of the study area varies from 2.0 to 12.0 tonnes per ha. Calculated quantity of gypsum based on CEC and exchangeable sodium needs to be broadcasted on soil and the soil has to be ploughed. Water has to be impounded and drained to leach out the exchangeable sodium and other soluble salts. Sub-surface drainage will be more effective. Construction of structures with pile foundation, providing cement lining for soil stabilization, filling non-dispersive soils and erecting structure on it and providing drainage lines from the structures will save and conserve structures in sub-soil.

In saline-sodic soils of the study area, the highest clay dispersion recorded is 62.1%, whereas in non-saline-sodic soils it is only 2.88%. In the study area, 27% of soils are intermediate dispersive, 2% dispersive and remaining 71% non-dispersive, based on clay dispersion characteristic. Based on ESP, 50% of soils are dispersive, 21% are intermediate dispersive and the remaining 29% non-dispersive. Therefore, application of gypsum and organic manure will reduce the sodicity and clay dispersion, which will help to reduce soil erosion. Providing sub-surface drainage will remove the exchangeable sodium and other salts. Construction of structures with pile foundation, filling non-dispersive soils and erecting structure on it and providing drainage lines from the structures will save and conserve structures in the sub-soil.

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