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Short Communication

Characterization of Some Salt Affected Soils and Poor Quality Waters of Kaithal District in Central Haryana for Reclamation and Management

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Salt affected soils and poor quality ground waters are primary constraints for sustainable agriculture in arid and semi-arid climatic zones of central Haryana (Yadav 2003). High evaporation during the dry season and lack of good quality water for irrigation caused salt accumulation in soil profiles. The use of poor quality ground water for irrigation has increased salt build-up in soil profiles and caused reduced productivity. Naturally, salts are drained from the Himalayas and Siwalik through rivers/streams and are accumulated at the alluvial plains (Sidhu *et al.* 1995). The lack of adequate internal drainage in lower topographic regions prompted soil salinization (Bhargava *et al.* 1980). Canal irrigation in undrained areas has caused waterlogging, formation of high water table and secondary salinization in soils. Due to dynamic nature, these soils showed variable extent during dry and wet seasons.

The reported extents of salt affected soils in Haryana varied from 4.54 to 2.32 lakh ha (Abrol and Bhumbla 1971; NRSA 2008) and needs verification using modern tools and field studies. The integrated approach combining interpretation of remote sensing imageries with ground truth and soil studies was successfully used for mapping waterlogging and soil salinity (Mandal and Sharma 2001). Due to complex nature, salt affected soils vary widely in salt composition, physical properties, internal drainage and pedogenic processes (Sharma *et al.* 2011). The irrigation with poor quality (sodic with RSC) ground water has favoured salt enrichment leading to poor soil health (Jain and Kumar 2007; Bhalla *et al.* 2011). Soil physicochemical characteristics and water quality appraisal for irrigation are valuable inputs for precise assessment of reclamation and management. In the present study, an attempt was made to analyze physicochemical characteristics of some salt affected soils profiles and appraise quality of ground water samples collected from benchmark locations in Kaithal district of central Haryana for reclamation and management.

The study area (2317 sq. km) lies between 29°31′27.43″ N and 76°09′2.99″ E to 30°13′7.45″ N 76°47′59.44″ E with an altitude of 180-300 m above mean sea level (msl), covering D3.3 agro-ecological zone (Yamuna alluvial plain, hot and semi-arid 90-120 days LGP). It consists of two administrative sub-divisions *viz.*, Kaithal and Guhla and six blocks namely, Kaithal, Pundri, Rajaund, Guhla, Kalayat and Siwan (Fig.1). The average annual rainfall is 550 mm, mean winter temperature is 14.2 °C and mean summer temperature is 31.8 °C. The area falls under the old and recent alluvium of the Indo-Gangetic Plain and is drained by the Yamuna, Ghaggar, Markanda and other seasonal streams originating from Siwalik range. The primary irrigation channels include Western Yamuna and Bhakra canals. Canal irrigation altered the moisture regime, soil pH and chemical composition of soil solution that resulted in soil salinity/ alkalinity, waterlogging, low permeability and hence low productivity (Singh 2009). The traditional agriculture such as maize, gram, moong bean and horticulture practices have been shifted to growing rice, wheat and cotton crops in the irrigated areas.

The Indian Remote Sensing data (IRS LISS III Resourcesat, path-row 95-50 and 95-51, ground resolution 23.5 m, spectral resolution: G, R, NIR and SWIR) for the pre-monsoon (February-March), summer (May-June), post-monsoon (October-November) period (2009-10) and the Survey of India topomaps on 1:50,000 scale (No. 53 C/1, 2, 5, 6, 9 and 10) were used for surveying salt affected soils. Field studies were conducted during March, June and October/ November to characterize salt affected soils and waterlogged areas. A total of 10 soil profiles (Pedon) supported by auger bores were studied for

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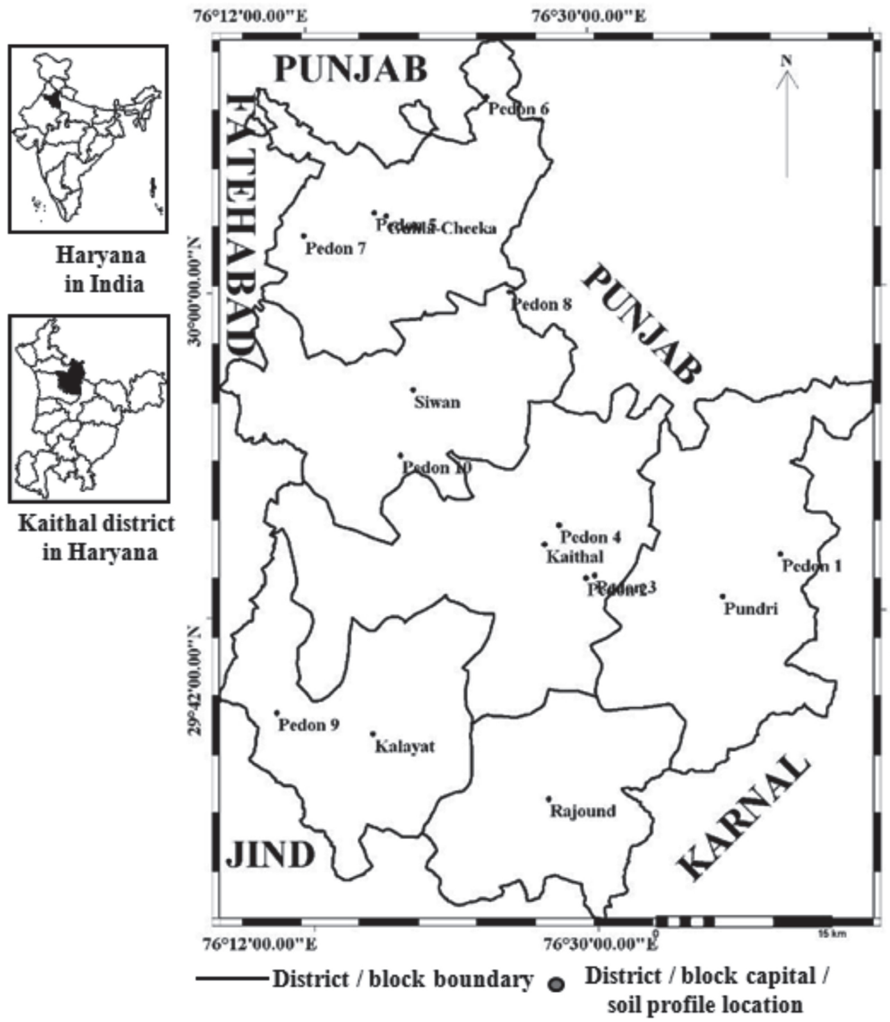

Fig. 1. Location of study area and soil profile sites

field assessment of soil salinity/ alkalinity, identification of soil horizons and soil sampling for laboratory characterization. These soils were further classified as per Soil Taxonomy (Soil Survey Staff 1998; Soil Survey Division Staff 2004). Horizon-wise soil samples were analyzed for soluble ions (Na^+, K^+, Ca^{2+}, Mg^{2+}, CO_3^{2-}, HCO_3^-, Cl^- and SO_4^{2-}), pHs, electrical conductivity (ECe), $CaCO_3$, organic carbon (OC), cation exchange capacity (CEC), exchangeable sodium percentage (ESP), soil texture and available nitrogen (N), phosphorus (P) and potassium (K) using standard procedure (Richards 1954; Jackson 1986; Singh *et al.* 1999) Twelve ground water and a seepage water samples were collected from the tubewells and waterlogged areas, respectively. The water samples were analyzed for salt content, alkalinity level, salt composition, sodium adsorption ratio (SAR) and residual sodium carbonate (RSC) to assess suitability for agriculture (Table 2). The reclamation, management and use potentials of these pedons were also suggested

The physicochemical properties of soils are presented in table 1. Pedon 1 (Fine-Loamy Sodic Haplustepts) is located in the old Gangetic alluvial plain in central Haryana (Block Pundri) and is irrigated by the Western Yamuna canal (Narwana branch). The satellite imageries showed the presence of a paleo-channel of river Chautang close to the Pedon 1. The seasonal imageries showed higher moisture accumulation (temporary waterlogging) in the pre- and post-monsoon seasons. Soil profile studies showed salt accumulation, sodic condition (appearance of pink color by phenolphthalein indicator), moist soil strata, deep, finer soil texture, massive, fine to medium sub-angular blocky structure and the significant presence of iron and manganese mottles (1-2 mm, 10-20%) and calcium carbonate concretions (2-4 cm, 20-40%) at sub-surface (24-105

Table 1. Physicochemical properties of soils from Kaithal district

Horizon	Depth (cm)	pHs	ECe (dS m^{-1})	Na^{+}	Ca^{2+}+ Mg^{2+}	CO_3^{2-}+ HCO_3^{-}	Cl^{-}	SO_4^{2-}	OC	ESP	$CaCO_3$	CEC [cmol (p^{+})kg^{-1}]	Texture	Clay	Silt	Sand	Av N	Av P	Av. K
				me L^{-1}					(%)					(%)			(kg ha^{-1})		
P1:29°47'38.9" N to 76°39'52.3" E Fine-Loamy Sodic Haplustepts, sodic soil in paleo-channel of the river Chautang, calcareous parent material																			
A1	0-24	10.3	1.6	15.6	4	15.6	8.0	2.8	0.2	76.6	1.9	24.6	sicl	36.6	38.9	24.4	31	17	208
Bw1	24-47	10.4	2.6	27.4	4	15.1	10.0	5.4	0.2	75.4	1.9	28.7	sicl	34.6	37.4	27.9	27	14	208
Bw2	47-72	10.3	2.3	22.9	4	14.5	10.0	4.2	0.2	83.2	1.2	25.4	sicl	28.0	32.1	39.8	23	10	188
B21k	72-105	10.4	3.4	28.7	4	16.7	14.0	5.7	0.2	74.8	2.3	21.1	l	18.3	24.1	57.5	23	10	151
B22k	105-135	10.4	4.0	44.9	4	16.9	13.0	7.0	0.1	80.1	11.4	14.6	l	12.3	17.6	70.0	19	10	88
BC k	135-187	10.4	3.6	39.4	4	15.2	14.0	6.4	0.1	82.4	10.2	13.6	l	12.2	16.8	71.0	19	10	93
P2: 29°46'38.9" N to 76°29'34.9" E Fine Typic Ustochrepts, waterlogged soil, rice basmati (CSR 30) irrigated by sodic water produce moderate yield																			
Ap	0-24	8.7	1.0	1.5	4	4.0	6.0	5.9	0.3	22.5	1.3	42.6	c	53.2	21.5	25.2	11	21	509
Bw1	24-61	8.0	6.5	49.5	20	4.5	9.0	41.8	0.3	27.2	0.7	44.1	c	55.6	23.2	21.1	78	16	488
Bw2	61-92	8.0	8.6	63.5	38	3.5	12.0	54.0	0.2	31.3	1.2	44.1	c	57.3	22.3	20.4	74	53	477
Bw3	92-121	7.9	8.0	44.2	24	4.5	19.0	44.2	0.2	21.8	1.3	42.6	c	57.6	23.6	18.8	70	39	466
P3: 29°46'46.4" N to 76°30'1.9" E Fine-Loamy Typic Ustochrepts, sodic soil and sodic GW, calcareous parent material, rice CSR 30 grown, low yield																			
Ap	0-21	8.6	2.5	22.3	6	4.5	10.0	13.6	0.3	44.6	3.2	13.2	sil	21.4	28.0	50.5	10	38	456
Bw1	21-62	9.2	1.2	12.4	6	4.0	8.0	5.9	0.1	52.3	3.8	19.7	sil	24.8	32.7	42.3	51	34	429
Bw2	62-94	9.2	1.7	19.4	4	4.5	8.0	8.8	0.1	45.8	1.5	22.6	sil	23.6	38.1	38.2	43	23	413
Ck	94-122	9.3	1.9	21.2	6	4.5	8.0	10.9	0.1	54.4	9.9	26.9	sil	19.6	29.3	51.0	31	13	360
P4: 29°49'6.7" N to 76°28'10.6" E, Fine Typic Ustochrepts, sodic soil and sodic GW in the old Ghaggar plain, severely waterlogged & partially barren																			
A1	0-18	8.3	2.3	18.8	8	1.5	10.0	13.7	0.4	32.3	2.3	21.5	c	40.0	24.1	35.8	10	33	392
Bw1	18-56	8.6	2.4	17.7	8	3.0	6.0	11.9	0.2	40.1	1.4	26.8	c	47.0	24.2	28.7	70	22	356
Bw2	56-89	8.4	2.5	19.9	8	4.0	8.0	16.5	0.2	37.3	1.7	31.8	c	49.8	25.4	24.7	70	12	339
Bw3	89-127	8.0	4.1	35.5	10	5.0	10.0	28.3	0.1	29.7	2.1	36.0	c	54.1	25.6	20.3	51	14	332
P5: 30°3'39" N to 76°18'33.9" E, Loamy Sodic Haplustepts, severely sodic soil and GW in the recent Ghaggar plain, barren with sparse vegetation																			
A1	0-22	9.9	6.1	64.5	1.5	6.5	23.0	33.9	0.2	56.0	2.1	16.4	l	14	17.8	68.6	88	28	377
B1	22-56	10.4	8.9	108	1.5	9.0	29.0	52.8	0.2	61.0	1.8	19.5	l	14	22.0	65.8	19	28	470
B2	56-84	10.6	5.8	56.7	1.5	8.5	16.0	38.4	0.1	60.0	3.0	20.0	l	18	22.1	59.3	15	19	203
Ck	84-121	10.7	5.0	42.3	2.0	17.5	14.0	16.5	0.1	64.0	2.9	19.5	l	21	19.6	59.1	15	25	203
P6: 30°8'56.3" N to 76°24'37.2" E, Fine-Loamy Typic Natrustalf, reclaimed sodic soil, calcareous, rice-wheat grown and produce moderate yield																			
A1	0-20	9.1	1.2	13.3	2	5.0	5.0	4.4	0.6	53.1	4.4	19.2	sil	25	28.1	47.1	86	14	321
Bt1	20-49	9.6	1.4	15.7	1	6.0	4.0	9.6	0.2	66.7	8.1	16.8	sicl	37	24.8	38.5	27	24	349
Bt2	49-88	9.7	1.6	18.5	1	7.0	4.5	9.2	0.1	69.0	5.2	20.0	sicl	29	33.3	38.0	14	27	488
Ck	88-125	9.6	1.7	19.5	3	6.0	3.0	8.4	0.2	58.5	9.5	21.2	sil	25	39.7	35.9	14	26	396
P7: 30°2'36.3" N to 76°14'49.5" E Loamy Typic Ustochrepts, sodic soil in recent alluvial plain, calcareous, rice-wheat crops showed moderate yield																			
Ap	0-22	8.9	4.4	39.2	4	5.3	12.5	22.4	0.4	40.0	2.3	24.5	l	23	21.6	55.0	82	10	243
Bw1	22-61	9.0	4.8	42.3	2	4.0	17.5	28.4	0.2	38.1	2.6	21.1	l	15	17.4	67.4	23	9	286
Bw2	61-93	9.1	3.6	34.1	4	4.8	15.0	17.9	0.2	46.6	2.3	16.3	l	15	18.1	66.6	20	14	340
Bw3	93-121	9.4	2.4	19.2	2	3.5	10.0	8.8	0.1	44.2	4.1	19.0	sil	19	31.6	49.9	16	18	303

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P8: 29°59'54.3" N to 76°25'41.3" E Fine-Loamy Typic Natrustalf, strongly sodic soil in old alluvial plain, natural vegetation and forestry plantations																			
A1	0-22	10.6	7.4	98.7	4	15.0	31.0	10.9	0.1	99.5	2.4	14.3	l	15.2	14.7	69.9	79	56	543
Bt1	22-56	11.0	5.5	80.0	4	15.0	18.0	12.8	0.1	91.8	2.4	20.6	cl	24.9	19.4	55.5	73	43	490
Bt2	56-91	11.1	4.6	70.4	3	20.0	15.0	9.1	0.1	96.9	0.9	25.7	cl	25.8	18.8	55.2	67	24	463
BC	91-118	11.2	5.3	83.9	3	27.0	12.0	6.2	0.1	94.1	1.4	24.6	cl	23.3	18.5	58.1	56	15	390
P9: 29°40'35.9" N to 76°13'8.5" E Coarse-Loamy Typic Ustochrepts (Saline phase), waterlogged (WT <0.5 m) soil under canal irrigation, cotton crop																			
A1	0-18	7.9	21.7	168	78	3.0	112	131	0.3	51.5	0.6	14.6	sl	14.7	16.5	68.6	121	25.	437
Bw1	18-53	7.8	19.3	144	74	3.5	104	111	0.2	32.6	0.2	13.6	sl	15.8	15.6	68.5	109	15	389
Bw2	53-94	7.9	16.7	123	60	3.0	90	90	0.1	43.8	0.5	17.1	sl	19.1	18.7	62.0	90	13	320
B k	94-128	7.9	12.5	88	48	2.5	80	53	0.1	37.3	10.0	14.1	sl	11.8	23.3	64.8	82	10	277
P10: 29°52'25.3" N to 76°19'49.9" E Loamy Sodic Haplustepts, reclaimed sodic soil in the old alluvial plain, medicinal & aromatic plants growing																			
A1	0-26	9.6	9.2	117	4.0	20.0	33.0	0.6	0.1	75.9	0.1	13.6	l	13.8	21.8	64.7	115	10	425
B1k	26-58	10.4	13.7	193	4.0	44.5	32.0	4.6	0.1	91.2	0.6	14.3	l	14.1	24.7	61.1	105	6	358
B2k	58-94	10.8	13.4	193	3.0	33.0	35.0	8.1	0.1	92.3	0.7	16.6	sil	12.2	26.5	61.2	25	7	268
B3k	94-129	10.8	11.5	151	3.0	30.0	31.0	7.1	0.1	96.7	0.8	15.0	sil	11.7	25.1	63.1	20	15	186

P= Pedon, The mixed parent materials and hyperthermic temperature regimes are common in all pedons, GW = Ground water

Table 2. Quality of ground water samples from Kaithal district

Sl. No.	Location, source and depth of ground water and classification	pH_{iw}	EC_{iw} (dS m^{-1})	Na^+	K^+	$Ca^{2+}+Mg^{2+}$	$CO_3^{2-}+HCO_3^-$ (me L^{-1})	Cl^-	SO_4^{2-}	RSC	SAR
Water samples from Kaithal sub-division											
1	Vill.Mundri Block Kaithal (75 m), C3-S1	8.3	1.1	10.3	0.06	10.0	9.0	10.0	tr	tr	4.8
2	Vill. Mundri Block Kaithal (80 m), C3-S1	8.3	1.1	10.3	0.05	10.0	9.5	15.0	tr	tr	4.7
3	Vill.Sampli Kheri Block Kaithal (75 m) C3-S1	7.6	1.1	9.9	0.08	8.0	10.5	12.0	tr	tr	4.9
4	Devigarh farm (HAU) Kaith al Seepage water C4-S1	7.2	2.3	17.7	0.01	10.0	8.5	16.0	7.1	tr	7.9
5	Vill. Kolekha Block Kalayat (18-21 m), C4-S4	7.6	12.7	164.8	0.05	48.0	5.0	80.0	54.8	tr	33.6
6.	Vill. Bhaini Majra Block Kaithal (80 m), C3-S1	9.3	1.2	9.9	0.07	2.0	8.5	3.0	tr	6.5	9.9
Water samples from Guhla and Siwan blocks											
7	Vill. Sehun Majra, Block Guhla (75 m), C3-S1	8.6	1.3	10.6	0.1	3.0	2.5	10.0	8.8	tr	8.6
8	Vill. Kheri Daban, Block Guhla (75 m), C3-S2	9.1	1.3	12.6	0.1	1.5	2.5	10.0	6.4	1.0	14.5
9	Vill. Hansu Majra, Block Guhla (75 m), C3-S3	9.3	1.4	14.1	0.1	1.0	3.0	6.0	4.7	2.0	19.9
10	Vill. Majri, Block Guhla (90 m), C3-S2	9.1	1.2	12.1	0.1	2.0	4.0	20.0	2.9	2.0	12.1
11	Vill. Tatiana, Block Guhla (90 m), C3-S3	9.1	1.6	16.6	0.1	1.0	3.0	5.0	7.7	2.0	23.4
12	Vill. Kamheri Block Guhla (90 m), C3-S1	8.8	0.8	6.8	0.1	3.0	2.5	3.0	0.4	tr	5.5
13	Vill. Bichian, Block Siwan (80 m), C3-S2	8.8	1.1	13.9	0.1	2.9	15.7	1.7	tr	12.7	11.5

and 70-135 cm) depths, respectively. Based on the pH values (10.3 to 10.4, ECe 1.6 to 4.0 dS m^{-1}) and ESP (75.4 to 83.2) values, P1 is characterized as strongly sodic (Richards 1954). The saturation extract analysis showed higher contents of CO_3^{2-} + HCO_3^- (14.5 to 16.9 me L^{-1}) and Na^+ (15.6 to 44.9 me L^{-1}) followed by Cl^- (8.0 to 14.0 me L^{-1}) and SO_4^{2-} (2.8 to 7.0 me L^{-1}) ions. The CEC varies from 28.7 to 13.6 cmol(p^+)kg^{-1} at surface and sub-surface depths, respectively. The silty clay loam to loam texture is attributed due to higher clay content (36.6%). The calcretes ($CaCO_3$) are present significantly (10.2 to 11.4%) at a depth (1 m) below the surface. The OC, available N and P contents are low throughout. These soils can be suitably used for rice-wheat cropping following reclamation with gypsum (4-6 t ha^{-1}) and be applied based on gypsum requirement (GR).

Pedon 2 (Fine Typic Ustochrept) is located at the old alluvial plain of Ghaggar covering Kaithal block (Sachdev *et al.* 1995) and is irrigated by salty ground water. The March and November satellite data showed water stagnation at soil surface which is interspersed with patchy crop stand. It is characterized by deep, massive to medium sub angular blocky structure, clayey texture and pale yellow to dark yellowish brown color. Waterlogging and soil sodicity appeared due to inadequate drainage, permeability and infiltration. The moist to wet sub-surface layers and the presence of iron and manganese nodules showed anaerobic condition in soil profile. The physicochemical analysis data showed slight soil sodicity (pH 8.7), moderate soil salinity (ECe 6.5 to 8.6 dS m^{-1}) at sub-surface depths indicating influence of salty ground water. The salt composition indicated the presence of Na^+ (1.5 to 63.5 me L^{-1}), Ca^{2+}+Mg^{2+} (4 to 38 me L^{-1}), Cl^- (128 to 725 me L^{-1}) and SO_4^{2-} (5.9 to 54.0 me L^{-1}) ions. The clay content, ranging from 53 to 57%, caused poor internal drainage (Mandal and Sharma 1997; Mandal 2014). The CEC values were high (42.6 to 44.1 cmol(p^+) kg^{-1}) due to higher clay content. The soil is low in OC (0.2 to 0.3%), available N (11 to 78 kg ha^{-1}) and medium to high P (16 to 53 kg ha^{-1}) contents and showed high available K (466 to 509 kg ha^{-1}). The soil may be treated with FYM or compost to improve physical properties and drainage. The poor quality ground waters may be treated suitably with amendments such as gypsum (for alkali water) or may be applied in mixing or cyclic mode (for saline water) prior to irrigation. The soil may be used for arable cropping (rice and wheat), with proper soil and water management practices to control waterlogging and supply adequate nutrients.

Pedon 3 (Fine-Loamy Typic Ustochrept) is located at the old alluvial plain (Block Kaithal) and is characterized by sub-angular blocky structure, silty loam texture and pale yellow to yellowish red color. The water table depth lies at 75-90 m and water quality is sodic in nature (Jain and Kumar 2007). The satellite imageries showed scattered crop and dark grey tone for higher water absorption (waterlogging) at the surface. The ranges of pHs (8.6 to 9.3), ECe (1.2 to 2.5 dS m^{-1}) and ESP (44.6 to 54.4) values indicated slight to moderate sodicity and strongly alkaline pHs value (8.6) at surface indicated soil reclamation at 0-30 cm depth for rice-wheat cropping. The fine texture (silt loam) strata favoured waterlogging and the use of poor quality ground water for irrigation caused poor physical properties (low permeability and infiltration) of soil. The dominance of alkaline salts such as Na^+ (12.4 to 22.3 me L^{-1}), CO_3^{2-} and HCO_3^- (4.0 to 4.5 me L^{-1}) ions prompted sodicity development while the Cl^- (8.0 to10.0 me L^{-1}) and SO_4^{2-} (5.9 to 13.6 me L^{-1}) contents showed the presence of mixed parent materials (Sachdev *et al.* 1995). The contents of $CaCO_3$ (1.5 to 9.9%) showed the presence of calcareous nature. The higher contents of $CaCO_3$ at sub-surface depth may be ascribed to the use of sodic ground water with sufficient carbonate content. The CEC values ranging from 13.2 to 26.9 cmol(p^+) kg^{-1} showed inverse relation with the clay content (ranging from 19.6 to 24.8%) apparently due to mixed mineralogy. The OC (0.1 to 0.3%), available N (10 to 51 kg ha^{-1}) contents were low. The treatment of soil and water with gypsum and FYM is required to neutralize carbonates/ bicarbonates, improve soil physical properties and reduce waterlogging, prior to use for agriculture.

Pedon 4 (Fine Typic Ustochrept, Block Kaithal) is characterized by the strong medium sub-angular blocky structure, clay texture and pale yellow to yellowish red color. Due to clay texture and poor internal drainage, waterlogging has appeared and the irrigation with salty ground water caused the development of soil salinity. The soil pHs (8.0 to 8.6), ECe (2.3 to 4.1 dS m^{-1}) and ESP values (29.7 to 40.1) showed the initiation of sodicity development. The $CaCO_3$ (<2 mm) is evenly distributed (1.4 to 2.3 %) in the soil profile, higher values at surface may be attributed due to the application of carbonate containing water for irrigation. The ECe values increased from surface (2.3 dS m^{-1}) to sub-surface (4.1 dS m^{-1}) depths, indicating the influence of salty ground water. Soil saturated extract showed the presence of Na^+ (17.7 to 35.5 me L^{-1}), Ca^{2+} + Mg^{2+} (8.0 to 1.0 me L^{-1}), CO_3^{2-} + HCO_3^- (1.5 to 5.0 me L^{-1}), Cl^- (6.0 to 10.0 me L^{-1}) and SO_4^{2-} (11.9 to 28.3 me L^{-1}) ions. The clay content ranges from 40.0 to 54.1% and is related to the CEC values [21.5 to 36.0 cmol(p^+) kg^{-1}]. The ESP values (29.7 to 40.1) indicated the initiation of soil alkalization due to the use of sodic ground water. It is suggested to use sprinkler and drip irrigation for application of salty ground water (in absence of canal water supply). The use of amendment such as gypsum is suggested prior to the use of alkali/sodic ground water to neutralize carbonate and bicarbonate ions. The soil is suitable for growing low water requiring crops, fruits (*jamun, ber*) and forestry plantations (*Eucalyptus* spp.) which can tolerate waterlogging and soil/water salinity.

Pedon 5 (Loamy Sodic Haplustepts) is a barren sodic soil with sparse vegetation and located in the Ghaggar plain (Block Guhla). It showed loam texture, moderate medium sub-angular blocky structure, sticky consistence and yellowish brown (moist) color. It is strongly sodic at surface and sub-surface depths (pHs ranges from 9.9 to 10.6). The ECe values ranges from 5.0 to 8.9 dS m^{-1} and higher values at surface layers may be ascribed due to the salt accumulation through runoff (Qureshi *et al.* 1996) and irrigation by salty ground water. The dominance of Na^+ (42.3 to 108.0 me L^{-1}) and CO_3^{2-} + HCO_3^- (6.5 to 17.5 me L^{-1}) caused increase of soil pH. The Ca^{2+}+Mg^{2+} (1.5 to 2.0 me L^{-1}), Cl^- (14.0 to 29.0 me L^{-1}) and SO_4^{2-} (16.5 to 52.8 me L^{-1}) ions were also present. The CEC values are low and related to the clay content. The soil showed higher ESP (56.0 to 64.0) due to the saturation with Na^+ ions that hydrolyzed to produce alkali and caused the increase of pH. The $CaCO_3$ (<2 mm) contents (1.8 to 3.0%) showed even distribution with depth. The soil showed low OC (0.1 to 0.2%), available N (15 to 88 kg ha^{-1}) and P (19 to 28 kg ha^{-1}) contents. The soil should be reclaimed using gypsum @ 8-10 t ha^{-1} and be applied based on the GR. Following reclamation, it would be suitable for arable crops such as rice and wheat. The sodic ground water may be treated with gypsum prior to the application of irrigation in agriculture.

Pedon 6 (Fine-Loamy Typic Natrustalfs) is a reclaimed sodic soil located under the recent Ghaggar plain (Block Guhla) and currently used for rice-wheat crops showing moderate yield. It showed silt loam to silty clay loam texture, moderate medium to massive sub-angular blocky structure, fine consistency and yellowish brown color. Poor to imperfect drainage and the presence of lime, iron, manganese nodules and concretions of $CaCO_3$ (calcareous layer) were also found at a depth below the surface. The presence of fine texture (silty clay loam) sub-surface layer showing higher clay content (29 to 37%) and higher ESP (66.7 to 69.0%) indicated natric horizon formation below the surface. Soil pHs and ECe values ranges between 9.1 to 9.7 and 1.2 to 1.7 dS m^{-1} and indicated strong sodicity except reclaimed at surface. Higher contents of Na^+ (13.3 to 19.5 me L^{-1}), CO_3^{2-} + HCO_3^- (5.0 to 7.0 me L^{-1}) as compared to Ca^{2+} + Mg^{2+} (1.0 to 3.0 me L^{-1}), Cl^- (3.0 to 5.0 me L^{-1}) and SO_4^{2-} (4.4 to 9.6 me L^{-1}) ions indicated the presence of strongly alkaline ions in sodicity development. The $CaCO_3$ (<2 mm) contents (4.4 to 9.5%) indicated the presence of calcareous parent materials, precipitated due to the increasing pH and ESP. The Pedon can be used for arable crops following reclamation with gypsum (@ 6-8 t ha^{-1}), based on the GR of the surface soil. Due to the presence of natric horizon and poor quality ground water, it is more suitable for forestry plantation, medicinal and aromatic plants and similar low water requiring food crops.

Pedon 7 (Loamy Typic Ustochrept) is located in the alluvial plain of Ghaggar (Block Guhla) showing loam to silty loam texture, weak to moderate medium sub-angular to angular blocky structure, moderate to fine consistence and the presence of significant amount of $CaCO_3$ concretion at a depth below the surface. The ranges of pH and ESP values (8.9 to 9.4 and 38.1 to 44.2) indicated moderately sodic soil, the ECe values (2.4 to 4.8 dS m^{-1}), indicated higher salt concentration, apparently due to the use of salty ground water. The dominance of Na^+ (19.2 to 42.3 me L^{-1}) and CO_3^{2-}+HCO_3^- (3.5 to 5.3 me L^{-1}) increased soil sodicity, the neutral salts of Cl^- (10.0 to 17.5 me L^{-1}) and SO_4^{2-} (8.8 to 28.4 me L^{-1}) increased soil salinity. The CEC values [16.3 to 24.5 cmol(p^+) kg^{-1}] are related to the clay content (15 to 23%). The $CaCO_3$ contents (2.3 to 4.1%) indicated calcareous parent materials that caused restricted drainage. The available nitrogen (16 to 83 kg ha^{-1}) and phosphorus (9 to 18 kg ha^{-1}) contents are low. The use of salt resistant varieties of rice and wheat is suggested to improve productivity.

Pedon 8 (Fine-Loamy Typic Natrustalf) is a strongly saline-sodic soil located in the old alluvial plain of Ghaggar (Block Siwan) and is currently used for forestry plantations. The Pedon showed finer soil texture (loam to clay loam), massive to moderate medium sub-angular to angular blocky structure, yellowish brown to pale yellow color and poor to imperfect drainage. The ranges of pHs values (10.6 to

11.2) showed strongly sodic soil and the ECe values ranges from 4.6 to 7.4 dS m^{-1}. The high ESP values showed complete saturation of exchange sites with sodium favoring hydrolysis and alkalinity. The dominating ions include Na^+ (70.4 to 98.7 me L^{-1}) and CO_3^{2-} +HCO_3^- (15.0 to 27.0 me L^{-1}) that favored sodic soil formation (Sharma *et al.* 2011). The CEC values [14.3 to 25.7 cmol(p^+) kg^{-1}] showed dominance of mixed micaceous clay minerals. The OC contents are low, $CaCO_3$ are distributed evenly in the soil profile. The increasing clay content (24.9 to 25.8%) and higher ESP (91.8 to 96.9) favored development of natric horizon. To neutralize high contents of CO_3^{2-} +HCO_3^-, Na^+ and ESP, gypsum application @ 8 to 10 t ha^{-1} is required for reclamation. Following reclamation, the soil can be used for arable (rice-wheat) cropping.

Pedon 9 (Coarse-Loamy Typic Ustochrept, Saline phase) is a saline soil located in the arid sandy alluvial plain of Ghaggar (Block Kalayat) and is under the canal irrigation (Narwana branch of Western Yamuna canal). Prolonged irrigation for rice-wheat has resulted waterlogging (water table depth 0.5 m) in the irrigated areas, causing poor productivity. The soil showed sandy loam texture, weak to moderate medium sub-angular blocky structure and yellowish brown color. A thick layer of $CaCO_3$ concretions (2-5 mm, 50 to 60%) is found at a depth (120 cm) below the surface. The soil pH ranges from 7.8 to 7.9 and ECe values (12.5 to 21.7 dS m^{-1}) indicated high soil salinity throughout the soil profile. The saturation extract analysis showed higher contents of Na^+ (88 to 168.0 me L^{-1}), Ca^{2+}+Mg^{2+} (48 to 78 me L^{-1}), Cl^- (80 to 112 me L^{-1}) and SO_4^{2-} (53 to 131 me L^{-1}). The $CaCO_3$ (<2 mm) content increased from 0.6 at surface to 10.0% below. The organic carbon contents are low in general. The CEC values are low [13.6 to 17.1 cmol(p^+) kg^{-1}] due to coarse soil texture (sand content ranges from 62.0 to 68.8%). The soil needs installation of sub-surface drainage to lower the water table depth below the root zone and reduce soil salinity. The low dosage of gypsum @ 2 to 4 t ha^{-1} application may be required for soil reclamation.

Pedon 10 (Loamy Sodic Haplustepts) is a strongly saline sodic soil located at the old alluvial plain of Ghaggar in central Haryana (Block Siwan) and is currently used for forestry, medicinal and aromatic plantations. The soil texture varies from loam to silty loam, while strong to medium soil structure, pale yellow to dark yellowish brown color at surface and sub-surface depths resulted due to soil sodicity and impaired drainage. The pH and ESP values ranged from 9.6 to 10.8 and 75.9 to 96.7 at surface and sub-surface depths, respectively. Strong sodicity has developed due to the presence of high Na^+ (117.0 to 193.0 me L^{-1}) and CO_3^{2-}+HCO_3^- (20.0 to 44.5 me L^{-1}). The higher soil salinity (ECe 9.2 to 13.7 dS m^{-1}) resulted due to runoff and accumulation of salts and the presence of salty (high RSC) ground water. The CEC values are low due to loamy soil texture (sand content ranges from 61.1 to 64.7%). The soil needs suitable dosage (@ 10 to 12 t ha^{-1}) of gypsum application to neutralize CO_3^{2-}+HCO_3^- and reduce ESP. The arable cropping (rice-wheat) is suggested after reclamation

The ground water samples were collected from the tube wells under the Kaithal and Guhla subdivisions and were characterized for classification and quality appraisal (Table 2). The water samples (PW 1 to 4) showed sodic nature due to CO_3^{2-}+HCO_3^- (8.5 to 10.5 me L^{-1}) ions (C3-S1, C4-S1, C4-S4). The PW5 is saline (EC 12.7 dS m^{-1}) and showed higher SAR (33.6) (C4-S4). The dominating ions include Na^+ (164.8 me L^{-1}), Ca^{2+}+ Mg^{2+} (48.0 me L^{-1}), Cl^- (80.0 me L^{-1}) and SO_4^{2-} (54.8 me L^{-1}). PW 6 showed sodic nature (pH 9.3) and high RSC (6.5) due to the presence of CO_3^{2-} +HCO_3^- (8.5 me L^{-1}) and Na^+ (9.9 me L^{-1}) ions (C3-S1). The water samples in Guhla and Siwan blocks (PW 7-13) showed sodic nature (pH 8.6 to 9.3), high SAR (5.5 to 23.4) and at places high RSC (1.0 to 12.7 me L^{-1}) dominated by the presence of Na^+ (6.8 to 14.1 me L^{-1}) and CO_3^{2-}+HCO_3^- (2.5 to 15.7 me L^{-1}), Cl^- (1.7 to 20.0 me L^{-1}) and SO_4^{2-} (0.4 to 8.8 me L^{-1}) (C3-S1, C3-S2, and C3-S3) These should be treated with gypsum to neutralize residual $NaHCO_3$. PW 5 can be used by mixing with good quality water. The PW 1-4 may be used for salt resistant varieties.

To conclude the present study, the physicochemical characteristics of salt affected soils in Kaithal district of central Haryana showed complex saline and sodic nature. Coarse texture soils under canal irrigation showed the development of waterlogging and soil salinity. The presence of concretionary $CaCO_3$ at sub-surface depths caused poor internal drainage and favored waterlogging. Suitable management options and alternate land uses are suggested for growing salt resistant crops, horticulture and forestry plantations with proper water management practices. The quality of water samples was also poor.

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References

Abrol, I.P. and Bhumbla, D.R. (1971) Saline and Alkali Soils in India - Their occurrence and management. *World Soil Resources Report No. 41:* Food and Agricultural Organization of United Nations, pp. 42-51.

Bhalla, A., Singh, G., Kumar, S., Shahi, J.S. and Mehta, D. (2011) Elemental analysis of ground water from different regions of Punjab State (India) using EDXRF technique and the sources of water contamination. In *Proceedings of the International Conference of Environmental and Computer Science*, IPCBEE, IACSIT Press, Singapore, pp. 156-164.

Bhargava, G.P., Sharma, R.C., Pal, D.K. and Abrol, I.P. (1980) A case study of distribution and formation of salt affected soils in Haryana state. In *Proceedings International Symposium on Salt Affected Soils*, Karnal, pp. 83-90.

Jackson, M.L. (1986) *Advanced Soil Chemical Analysis*. Prentice Hall of India (Pvt.) Ltd., New Delhi.

Jain, A.K. and Raj Kumar (2007) *Water Management Issues*. In *Proceedings of the Indo-US Workshop on Innovative E-technologies for Distance Education and Extension Outreach for Efficient Water Management*, March 5-9, 2007, ICRISAT, Patancheru, Hyderabad, India.

Mandal, A.K. (2014) Characterization of some salt affected soils of Punjab for reclamation and management. *Journal of the Indian Society of Soil Science* **62**, 161-167.

Mandal, A.K. and Sharma, R.C (2001) Mapping of waterlogged areas and salt affected soils in the IGNP command area. *Journal of the Indian Society of Remote Sensing* **29**, 229-235.

Mandal, A.K. and Sharma, R.C. (1997) Characterization of some salt affected soils of Indira Gandhi Nahar Pariyojona command area, Rajasthan. *Agropedology* **7**, 84-89.

National Remote Sensing Agency (2008) *Mapping Salt Affected Soils of India*. National Remote Sensing Agency, Department of Space, Government of India, Hyderabad, 60 p.

Qureshi, F.M., Singh, S.K., Chaudhari, S.K. and Das, K. (1996) Genesis and Taxonomy of some saline and sodic soils of Bharatpur (Rajasthan). *Journal of the Indian Society of Soil Science* **44**, 130-135.

Richards, L.A. (Ed.) (1954) *Diagnosis and Improvement of Saline and Alkali Soils*. Agriculture Handbook No. 60 United States Department of Agriculture, Washington D.C.

Sachdev, C.B., Lal, T., Rana, K.P.C. and Sehgal, J. (1995) *Soil of Haryana: their kinds, distribution and interpretation for Optimizing Land Use.* NBSS Publ. 44 (Soils of India Series 4), National Bureau of Soil Survey and Land Use Planning, Nagpur, 59 p.

Sharma, R.C., Mandal, A.K., Singh Ranbir, Singh, Y.P. (2011) Characteristics and use potential of sodic and associated soils in CSSRI experimental farm, Lucknow, Uttar Pradesh. *Journal of the Indian Society of Soil Science* **59**, 381-387.

Sidhu, G.S., Walia, C.S., Lal, Tarsem, Rana, K.P.C. and Sehgal, J. (1995) *Soil of Punjab for Optimizing Land Use.* NBSS Publ. 45 (Soils of India Series 4), National Bureau of Soil Survey and Land Use Planning, Nagpur, 75 p.

Singh, D., Chhonkar, P.K. and Pandey, R.N. (1999) *Soil Plant Water Analysis - A Methods Manual*. Indian Agricultural Research Institute, New Delhi, 146 p.

Singh, G.B. (2009) Salinity Related Desertification and Management Strategies: Indian Experience. *Land Degradation and Development* **20**, 367-385.

Soil Survey Division Staff (2004) *Soil Survey Manual*. United States Department of Agriculture Handbook No.18. Scientific Publishers (India) Jodhpur.

Soil Survey Staff (1998) *Keys to Soil Taxonomy*. Eighth Edition, U.S. Soil Conservation Service, Washington, D.C.

Yadav, J.S.P. (2003) Managing soil health for sustained high productivity. *Journal of the Indian Society of Soil Science* **51**, 448-465.

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