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Characterization of Irrigated and Rainfed Saline Vertisols of Bara Tract (Bharuch) of Gujarat

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Abstract: Four representative pedons (2-irrigated and 2-rainfed areas) were studied, interpreted and horizon-wise sampled as per standard procedure (Soil Survey Staff, 1995) to characterize the salt affected soils of Bara tract of district Bharuch, Gujarat. Soil samples were collected at horizon-wise differentiation to a depth up to 150 cm. In general, soil color was dark brown (10YR 4/3) or very dark grayish brown (10YR 3/2) or very dark brown (10YR 2/2) with clayey texture having structure varying from medium moderate sub-angular to coarse strong angular blocky. Pedons were classified up to a family level where temperature regime is *Hyperthermic* and texture is fine with *Montmorillonite*. Classification up to sub group level were as follows: pedon 1- Entic *Chromusterts*, pedon 2-(calcareous) Entic *Chromusterts*, pedon 3 and 4 (calcareous), Udorthentic *Chromusterts*. Soil pH, ECe, SOC, $CaCO_3$, CEC and ESP of irrigated pedons varied respectively from 7.78 to 8.57, 0.75 to 12.50 dS m^{-1}, 2.2 to 7.2 g kg^{-1}, 2.6 to 196.4 g kg^{-1}, 39.0 to 52.3 cmol (p+) kg^{-1} and 3.3 to 27.1, while the corresponding values in rainfed pedons were 8.29 to 8.85, 0.75 to 8.90 dS m^{-1}, 2.6 to 5.7 g kg^{-1}, 2.6 to 272.1 g kg^{-1}, 36.9 to 50.7 cmol (p+) kg^{-1} and 2.8 to 18.1, respectively. Salinity/or Sodicity and calcareousness was occurred at sub-surface layers in irrigated saline Vertisols. Soil saturation extract revealed the dominance of Na^+ cation followed by Mg^{2+}, Ca^{2+} and K^+, while in anions the trend was $Cl^- > SO_4^{2-} \sim HCO_3^- + CO_3^{2-}$. SAR values were higher in irrigated conditions as compared to rainfed. The higher ESP was found due to regular irrigation of canal/ borewell/tubewell water etc. which ultimately induced the sodification process in the surface as well as sub-soils, while higher ESP was found in lower soil depths and tends to be sodic. The study thus advocates that continuing the present anthropogenic activities might render the soils unsuitable for agricultural production in the future. Further, looking at the sodicity/salinity build up, physical nature of Vertisols as well as groundwater quality constraints, suggests that it would be prudent to encourage irrigated/ or rainfed agriculture in the areas under improved management practices to sustainable crop production and improve the soil health.

Key words: Saline Vertisols, characterization, ESP, Bara tract - Gujarat.

Irrigation facilities can boost land productivity if all the conditions for irrigation suitability of a specific land are ideal, but if any other factors/ parameters are constraints, it may not be as sustainable. Salinity, one of the major hazards usually confined to arid and semi-arid regions of the world, constitutes a primary limit on crop productivity (Lin *et al.*, 1997). The problem of salinity and sodicity has affected about 6.74 M ha of land in India of which 2.22 M ha are present in Gujarat state (1.31 M ha coastal and 0.91 M ha inland salinity) (Mandal *et al.*, 2009). Because of their typical physicochemical characteristics, these soils have low productivity even at low salinity. Salinization and sodification are pedogenic processes unique to salt-affected soils. Bara tract area (Amod, Jambusar and Amod talukas of Bharuch district) have been classified in the *Vertisol* and associated soils and are also known as black cotton soils. Black cotton soil is having high water holding capacity due to high clay content but its permeability is very low and saturated hydraulic conductivity (Ks) is also very low or negligible (Nayak *et al.*, 2004; Chinchmalatpure *et al.*, 2011). The key

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part of Bara area comes under rainfed farming and some limited areas are under irrigated agriculture. Saline Vertisols of Bara tract area are being limited irrigated for the crops like cotton and wheat using Sardar Sarovar canal irrigation water besides saline water from tube wells in the region and the soils of this region has a significant concentration of soluble salts in the sub-soils, although the concentration is low in the surface layer (Chinchmalatpure *et al*., 2010; Rao *et al*., 2016). After the introduction of the canal, farmers have irrigated the field with canal water but now they are facing problems such as the hardness of surface soils and the formation of big clods in Cavery command areas of Karnataka (Jena and Natarajan, 2013). Kadu *et al*. (2009) found that SAR (2.2 to 12.0) and ESP (1.5 to 12.7%) showed elevated values in surface and sub-surface horizons due to the continuous use of canal irrigation in Vertisols of the command area of Maharashtra. However, these values were lower in the non-irrigated profile (ESP 1.0-1.3% and SAR 1.4-2.0). Further, the continuation of canal irrigation induced the sodification process in sub-soil and thereby reduced the hydraulic conductivity of these soils. Systematic studies on the characterization of salt affected soils are of prime importance in taking reclamation measures and evolving/ suggesting suitable agronomic practices. Looking at the magnitude of the problem of saline Vertisols of district Bharuch (Bara tract) was chosen for the proposed investigation to characterize the salt affected soils so that in the future it may serve as a tool for planning and suggesting management needs of the area.

Materials and Methods

The study area, western region of Narmada river command area, an alluvial coastal plains adjoining the Gulf of Khambhat and lies between 21°40′ to 22°13′N latitude and 72°32′ to 72°55′E longitude is known as "Bara tract" which consists of Jambusar (AES-IV), Vagra (AES-V) and Amod (AES-V) talukas of Bharuch district of Gujarat. This area is bounded by the river Narmada in the south and the river Mahi in the north and forms a part of Mahi-Narmada Doab. The landscape is nearly flat with slope gradient of 1:2800-4500 or more. The climate of this region can be classified as semi-arid with average annual rainfall is 737 mm (during June to October). The maximum temperature rises up to 45°C in the month of May. The soil temperature regime is *hyperthermic* and soil moisture regime is *ustic*.

Four profiles were excavated in the representative sites of AES-V for studying the characterization of irrigated and rainfed saline Vertisols of Gujarat and profiles were studied horizon-wise during 2015-16 and sampled as per standard procedure (Soil Survey Staff, 1995). These sites were located in Kerwada, Amod (P1-irrigated and P2-rainfed), and Amod (P3-irrigated, P4-rainfed) tehsil of district Bharuch, Gujarat (Table 1). Soil profiles were excavated to study field morphology (Table 1) of these soils and soil samples from profiles were collected horizon wise for detailed study in laboratory. All the four pedons exposed in typical saline Vertisols were examined up to a depth of 150 cm. These samples were characterized using standard analytical techniques (Richards, 1954; Jackson, 1979). Soil samples were processed for analysing different properties like pH and ECe (Jackson, 1973), organic carbon (OC) by wet oxidation method (Walkley and Black, 1934). Cation exchange capacity (CEC) was determined by 0.1 N NaOAc-0.4 N NaCl method (Gupta *et*

Table 1. Topographical and location of soil pedons

Profile no.	Location	Village	Landform	Parent material	Drainage	Present land use
P1	21°54´50.62´´N, 072°51´09.76´´E	Kerwada, Amod, Bharuch	Very gently sloping (Plain)	Basalt	Moderately well to imperfect drained	Irrigated to single crop of Cotton/ Mung bean
P2	21°53´45.3´´N, 072°51´39.7´´E	Kerwada, Amod, Bharuch	Very gently sloping (Plain)	Basalt	Imperfect drained	Rainfed to single crop of Cotton
P3	21°59´26.4´´N, 072°51´16.0´´E	Amod, Bharuch	Very gently sloping (Plain)	Basalt	Moderately well to imperfect drained	Irrigated to single crop of Cotton
P4	21°59´29.9´´N 072°51´17.15´´E	Amod, Bharuch	Very gently sloping (Plain)	Basalt	Imperfect to moderately well drained	Rainfed to single crop of Cotton

al., 1985) with the help of a flame photometer and expressed the results in cmol (p+) kg^{-1} of soil. Exchangeable sodium percentage (ESP) by the method given by Tucker (1971), particle size analysis was carried out by International pipette method (Piper, 1966) and soil textural class was computed by USDA textural triangle, bulk density by the method given by Black *et al.* (1965).

Results and Discussion

Morphological characteristics of soils

Morphological characteristics of the soils (Table 2) indicate that the dry soils were very dark grayish brown (10 YR 3/2) to yellow brown (10 YR 5/4); dark brown (10 YR 4/3) to dark yellow brown (10 YR 4/4); dark brown (10 YR 3/3) to dark yellow brown (10 YR 4/4) in color; while the moist soils were very dark brown (10 YR 2/2) to dark yellow brown (10 YR 4/4); dark grayish brown (10 YR 4/2) to dark yellow brown (10 YR 4/4); very dark grayish brown (10 YR 3/2) to dark yellow brown (10 YR 4/4) in color. Soils were darker on the surface and lighter as one descended. Dark color is ascribed to admixture of organic matter/or chelates/or complexation of organic colloids and iron oxides on the surface of clay particles (Rao *et al.*, 2008; Dudal and Eswaran, 1988). The color variation in the soils of substratum in contrast to surface layer evidenced higher value and lower chroma which can be attributed to the presence of high amount of free $CaCO_3$ (Table 3) and to the saturation and reduction coupled with mixing of organic matter and soil

Table 2. Morphological characteristics of soil

Horizon	Depth	Color		Texture	Structure	Consistency	Effervescence
		Dry	Moist				
P1 (Irrigated-Kerwada, Amod, Bharuch)							
Ap	0-26	10YR 3/2	10YR 2/2	c	m2sbk	h fi ssps	-
A12	26-55	10YR 3/2	10YR 2/2	c	c3sbk	h fi ssps	-
Bss1	55-80	10YR 3/2	10YR 2/2	c	c3abk	h fi sp	-
Bss2	80-107	10YR 3/2	10YR 2/2	c	c3abk	h fi sp	-
BC	107-135	10YR 5/4	10YR 4/4	gcl	m2sbk	h fr ssps	es
P2 (Rainfed-Kerwada, Amod, Bharuch)							
Ap	0-24	10YR4/3	10YR4/2	c	m2sbk	h fr ssps	e
A12	24-44	10YR4/3	10YR4/2	c	m2sbk	h fr ssps	e
A13	44-62	10YR3/2	10YR3/2	c	m2sbk	h fi sp	e
Bss1	62-74	10YR4/4	10YR4/3	c	m2sbk	- fi sp	es
BC	74-130	10YR4/4	10YR4/4	gcl	m2sbk	- fr sp	ev
P3 (Irrigated, Amod, Bharuch)							
Ap	0-24	10YR 3/3	10YR 3/2	c	m2sbk	h fr ssps	e
A12	24-49	10YR 3/2	10YR 3/2	c	m2sbk	h fr sp	e
A13	49-76	10YR 3/2	10YR 3/2	c	m2sbk	- fi sp	e
Bss1	76-102	10YR 3/2	10YR 3/2	c	c3abk	- fi sp	e
Bss2	102-136	10YR 3/2	10YR 3/2	c	c3abk	- fi sp	e
BC	136-150	10YR 4/4	10YR 4/4	c	m2sbk	- fr ssps	es
P4 (Rainfed, Amod, Bharuch)							
Ap	0-28	10 YR 4/3	10YR 4/2	c	m2sbk	h fr ssps	e
A12	28-62	-	10YR 3/2	c	m2sbk	h fi sp	e
A13	62-82	-	10YR 3/2	c	m2abk	h fi sp	e
Bss1	82-115	-	10YR 3/2	c	m2abk	- fi sp	e
Bss2	115-133	-	10YR 3/2	c	m2abk	- fi sp	e
BC	133-150	-	10YR 4/4	c	m2sbk	- fr ssps	e

Texture: c-clay; cl-clay loam, gcl-gravely clay loam; Structure: m-medium, 2-moderate, c-coarse; 3-strong; sbk: sub-angular blocky; abk-angular block; Consistence: fr-friable, fi-firm, s-sticky, p-plastic, ss-slightly sticky, ps-slightly plastic; Effervescence: e-slight effervescence, es-strong effervescence, ev-violent effervescence.

Table 3. Physico-chemical properties of soils

Depth (cm)	pH	ECe ($dS m^{-1}$)	OC ($g kg^{-1}$)	$CaCO_3$ ($g kg^{-1}$)	Sand (%)	Silt (%)	Clay (%)	BD ($Mg m^{-3}$)	PD ($Mg m^{-3}$)	Porosity (%)
P1 (Irrigated-Kerwada, Amod, Bharuch)										
0-26	8.09	0.75	7.20	2.6	28.7	20.5	50.8	1.41	2.55	44.7
26-55	8.41	1.33	6.38	7.2	24.5	21.6	53.9	1.51	2.51	39.8
55-80	8.49	2.60	6.00	9.8	23.7	20.3	56.0	1.53	2.50	38.8
80-107	8.25	4.60	6.15	10.5	20.3	24.3	55.4	1.49	2.43	38.7
107-135	8.57	9.40	3.78	28.5	28.8	31.6	39.6	1.48	2.41	38.7
P2 (Rainfed-Kerwada, Amod, Bharuch)										
0-24	8.45	1.07	4.95	34.2	29.6	24.4	46.0	1.44	2.59	44.5
24-44	8.74	0.98	2.68	34.5	27.6	23.9	48.5	1.51	2.50	39.5
44-62	8.72	0.87	3.68	36.4	26.5	18.8	54.7	1.56	2.43	35.9
62-74	8.85	1.55	4.75	125.8	31.6	26.8	41.6	1.55	2.54	39.1
74-130	8.71	4.00	3.23	201.9	34.3	28.1	37.6	1.54	2.53	39.0
P3 (Irrigated, Amod, Bharuch)										
0-24	7.78	6.70	6.30	10.4	30.1	22.1	47.8	1.43	2.44	41.5
24-49	8.25	2.60	5.62	15.0	29.3	14.2	56.5	1.52	2.47	38.5
49-76	8.31	2.30	4.23	16.9	26.6	16.1	57.3	1.55	2.47	37.2
76-102	8.32	2.75	3.65	18.1	28.6	17.4	54.0	1.57	2.33	32.7
102-136	8.11	7.30	3.78	23.3	30.1	22.6	47.3	1.51	2.44	38.1
136-150	8.15	12.50	2.24	196.4	32.5	30.2	37.3	1.47	2.57	42.7
P4 (Rainfed, Amod, Bharuch)										
0-28	8.29	0.75	5.70	19.6	31.3	20.0	48.7	1.46	2.41	39.3
28-62	8.59	0.81	3.68	23.2	29.7	20.3	50.0	1.53	2.49	38.6
62-82	8.60	1.20	3.65	24.7	29.1	14.7	56.2	1.58	2.49	36.5
82-115	8.57	2.40	3.45	26.1	24.9	17.6	57.5	1.61	2.47	34.9
115-133	8.52	3.80	3.22	98.6	27.4	26.3	46.2	1.51	2.40	37.0
133-150	8.45	8.90	2.25	272.1	29.1	32.3	38.6	1.47	2.59	43.3

matrix with carbonate (Schaetzl *et al*., 1996). In general, soil color was dark brown or very dark grayish brown or very dark brown (10YR 2/2) with clayey texture. Soils were deep to very deep with color variation due to the nature and type of parent materials. In all pedons, surface and subsurface soils were clayey in texture, which however changed to clay loam texture in lower-most horizons of pedon -1 and -2. Further, the variation in texture of the soils is also mainly due to the differences in the composition of parent materials (Nayak *et al*., 2000). Morphological structure varies from medium moderate sub-angular/or angular to coarse strong angular blocky. In sub-horizons generally, slickensides (Bss1 and Bss2 horizons) and/or pressures faces were found within 75 cm deep with wide cracks. However, horizons associated with slickenside showed a strong coarse angular blocky structure. Generally, the consistency of the soils occurring on plains varied from hard (dry), friable to firm (moist) and slightly sticky to sticky and slightly plastic to plastic (wet). These wide variations in consistence were due to variation in clay content of pedons situated on different topographic positions. The boundary of the pedons varied from clear smooth boundary to clear/angular/ gradual wavy boundary in distinctness. Cracks (3 to 4 cm wide) were found up to 136 cm and a layer of $CaCO_3$ nodules was observed in the C horizon. The variation in soil structure is a reflection of the physiographic position of the pedons (Singh and Agrawal, 2003). Root size and quantity differed with depth among pedons. The surface horizon gave slight effervescences with dilute HCl except for pedon-1, while sub-surface horizons the same were slight to violent as one proceeds down the depth of pedon indicating an increase in the content of $CaCO_3$ as is also evidenced by the content of $CaCO_3$ observed. Similar results were corroborated by (Chinchmalatpure *et al*., 2008).

Physico-chemical characteristics

The physico-chemical characteristics of the soils of different pedons (Table 3) indicated that the soil particle density varied from 2.33 to 2.59 Mg m^{-3} and, it did not exhibit greater variation within or among the pedons. Likewise, bulk density (BD) values (1.41 to 1.61 Mg m^{-3}), which showed a negative correlation with organic carbon (r= -0.39), tended to increase with depth of the pedon. Among the irrigated pedons, surface horizon of pedon had the lowest mean BD (1.42 Mg m^{-3}) as compared to rainfed pedon (1.45 Mg m^{-3}) which might be due to higher content of organic matter / clay and lower quantum of coarse fragments in the surface horizon as reported by Maji *et al*. (2005). In general, BD increasing trend with depth which might be due to increasing clay content in profile. This could be attributed to clogging of pores by dispersed clays in subsoil layers (Mathan and Mahendran, 1994) and reduction of organic carbon with depth. The results of increasing BD in soil-horizons with depth with its lowest values at surface layer were supported by Walke *et al*. (2012). Irrigated pedon soils had lower mean BD (1.50 Mg m^{-3}) as compared to that of rainfed soils (1.52 Mg m^{-3}). Similar results were also reported by Negash and Mohammed (2014) whereby, they found that the highest bulk density (1.38 Mg m^{-3}) under rainfed agriculture, while the lowest (1.16 Mg m^{-3}) was registered in irrigated floodplain. In general, in pedons of the both situations, the variation in BD of horizon soils of all pedons might be attributed to the variation in clay along with coarse fractions/gravels, partially decomposed rocks and intensity of plant roots/ organic matter in different horizons. The results were in good agreement to the findings of Leelavathi *et al.* (2009). Among all the pedons, irrigated soils had slightly higher mean total porosity (39.3%) as compared to rainfed soils (38.9%), which possibility due to the relatively lower BD and higher OM that made the soil more loose and porous leading to improvement in aggregation under irrigated soils as compared to soils under the rain-fed agriculture. Similar results on irrigated soils as compared to rainfed soils was observed by Negash and Mohammed (2014), whereby they cited improved aggregation, clay content and lower BD as the main factors for higher porosity under irrigated system.

The sand, silt and clay content of all soil-horizons determined from <2 mm soil are presented in Table 3, result revealed that clay content of irrigated and rainfed pedons of different horizons ranged from 37.3 to 57.3% and 37.6 to 57.5%, respectively with mean values 50.6 and 47.6%, respectively. The content of clay gradually increased with depth nearly up to 90 cm and slightly decreased again to a small extent at lower depth in all the pedons. In most pedons, surface and subsurface soils were clayey in texture, which however changed to clay loam texture in lower most horizons while lower most horizons of pedon-1 and -2 had gravely clay loam texture. In general, clay fraction is more concentrated in the subsurface layers of the various pedons leading to its accumulation in subsurface layers which can be attributed to mass movement of fine clay (Pal *et al*., 1999). Usually, surface-and sub- horizon of irrigated pedons of any place had higher clay content as compared to rainfed pedon, similar results as reported by Padekar *et al*. (2016). The overall increase in clay content from surface to down below in both irrigated and rainfed pedons was observed with the concomitant decrease in sand content mainly, while silt content in all the pedons showed somewhat irregular trend. Chinchmalatpure *et al.* (2001) and Arunkumar and Sriramachandrasekharan (2013) obtained similar type of results from black cotton soil belt. The total porosity of all pedon-soils was rated high to very high as per FAO (2006). Among all the pedons, irrigated soils had slightly higher mean total porosity (39.3%) as compared to rainfed soils (38.9%), which possibility due to the relatively lower BD and higher OM that made the soil more loose and porous leading to improvement in aggregation under irrigated soils as compared to soils under the rain-fed agriculture.

Soil pH of all the horizons of different pedons respective to the irrigated and rainfed situations was found to vary widely from slightly to strongly alkaline in nature (pH: 7.78 to 8.85). No definite trend of pH was observed with the increase in soil depth in all the pedons. The reason for irregular trends in both irrigated and rainfed pedons with depth might be the presence of the varying amounts of free calcium carbonate, exchangeable Ca and

Mg, organic carbon and clay content. Kadu *et al*. (2009) and Kadam *et al*. (2012) also reported the similar reasons in irrigated and rainfed pedons, whereby calcareous nature of most of the soils, presence of free calcium carbonate, moderately to strongly alkaline in reaction and high soil pH were projected as the main reason for having irregular trend in irrigated and rainfed pedons. For any particular area surface soil of irrigated pedon (8.26) registered low pH value as compared to that of rainfed pedon (8.60). This was might be due to higher organic matter in irrigated soils as compared to rainfed soils.

The ECe of the soils under study ranged between 0.75 to 12.5 dS m^{-1} (Table 3). Surface horizon of the pedon had a slightly higher ECe value for pedon-2 and -3 and slightly lower for pedon-1 and -4 and then after, it gradually increased with depth showing the highest EC value in the bottom horizon. In rainfed pedons, because of their locations nearby to sea coast sub-surface soil salinity was more. The present results are strongly supported by the findings of Chinchmalatpure *et al*. (2008) for cotton growing area of Bharuch, wherein they reported that salinity increased with soil depth (ECe: 1.2 to 11.2 dS m^{-1}). In irrigated pedons (4.71 dS m^{-1}) had higher mean ECe as compared to respective rainfed pedons (2.34 dS m^{-1}), which might be due to accumulation of salts from irrigation water of varying quality and quantum, similar types of finding were reported by Padekar *et al*. (2014) and Kadu *et al* (2009).

The results revealed that organic carbon content (Table 3) of different horizons in irrigated and rainfed pedons varied from very low to medium. The organic carbon content ranged between 2.2 to 7.2 g kg^{-1}, which decreased with the depth (Somasundaram *et al*., 2018) and somewhat irregular trend with depth due to might be the churning process in these black soils with deep and wide cracks up to 1 meter. Results clearly indicated that surface horizon registered higher SOC in all pedons as compared to lower depth horizons. All the irrigated pedons recorded higher mean SOC as compared to rainfed pedons. Further, when all the irrigated pedons were compared with rainfed pedons, the magnitude of mean SOC (5.1 g kg^{-1}) was found higher under irrigated condition than rainfed (3.8 g kg^{-1}). The reason might be due to application of higher quantum of organic manures, apart from higher litter fall and higher quantum of roots and their subsequent deposition under irrigated condition as a result of luxurious growth of plants. Results of SOC in the present study were in good agreement with work done elsewhere by Kadu *et al*. (2009) on irrigated and non-irrigated soil profiles. The present results were strongly supported by the findings of Kadam *et al*. (2012) and Sunitha *et al*. (2010) in respect of SOC content with increasing soil depth.

The $CaCO_3$ content of all the horizons of different pedons respective of irrigated and rainfed situation was found to vary widely from 2.6 to 196.4 g kg^{-1} and 19.6 to 272.1 g kg^{-1}, respectively. Rainfed pedons recorded higher mean $CaCO_3$ content as compared to irrigated pedons. This might be due to the effect of dissolution process of $CaCO_3$ under irrigated condition and at the same time rainfed (low rainfall and its erratic distribution) and semi-arid to arid climatic situation favored the formation of more $CaCO_3$ in the pedon under the same parent materials. The content of $CaCO_3$ increased with depth, indicating the precipitation of calcium due to poor drainage condition. The formation of $CaCO_3$ in pedons of present study were in good agreement with the work done in black cotton soils by Nayak *et al*. (2000) and Chinchmalatpure *et al*. (2005), whereby they mentioned that increased $CaCO_3$ with depth in pedons due to leaching of bicarbonates from upper layer during the rainy season and their subsequent precipitation as carbonate in the lower layer due to poor drainage condition. Arunkumar and Sriramachandrasekharan (2013) also found accumulation of free carbonates in pedon which they opined as a result of moderate to slow permeability. Pal *et al*. (2006) observed precipitation of $CaCO_3$ in profile soil under semi-arid climatic conditions due to dispersion and subsequent movement of clays under alkaline chemical environment (Vaidya and Pal, 2002; Kadu *et al*., 2003).

The analysis of saturation extract showed the dominance of Na^+ cation followed by Mg^{2+}, Ca^{2+} and K^+, while in anions the trend was $Cl^- > SO_4^{2-} \sim HCO_3^- + CO_3^{2-}$. The SAR of irrigated and rainfed pedons varied from 7.6 to 51.7 and 3.7 to 39.0, respectively with increase in

Table 4. Water-soluble ions (me l^{-1}) and exchangeable phenomenon [cmol (p^+) kg^{-1}] of soil

Depth (cm)	Water-soluble cations				Water soluble anions			SAR	Exchangeable bases				CEC	ESP
	Ca^{2+}	Mg^{2+}	Na^+	K^+	CO_3^{2-}+ HCO_3^-	Cl^-	SO_4^{2-}		Ca^{2+}	Mg^{2+}	Na^+	K^+		
P1 (Irrigated-Kerwada, Amod, Bharuch)														
0-26	1.6	1.5	9.5	0.08	4.5	6.8	1.5	7.6	26.1	14.5	1.44	0.98	43.5	3.3
26-55	1.0	1.5	10.7	0.07	4.3	6.1	2.9	9.6	30.7	11.8	3.84	0.84	47.8	8.0
55-80	1.6	1.7	22.6	0.08	4.3	18.3	3.4	17.6	31.0	15.0	4.58	0.64	52.3	8.8
80-107	1.3	2.5	42.0	0.08	3.5	35.1	7.0	30.5	28.3	13.8	4.98	0.56	48.6	10.2
107-135	2.3	3.5	88.1	0.05	4.3	84.5	5.0	51.7	22.0	11.8	7.18	0.42	42.4	16.9
P2 (Rainfed-Kerwada, Amod, Bharuch)														
0-24	1.6	1.2	7.9	0.03	3.8	4.7	2.2	6.7	29.3	10.0	1.20	0.52	42.3	2.8
24-44	1.5	1.5	6.8	0.04	3.0	4.2	2.6	5.6	31.0	10.3	3.00	0.43	46.6	6.4
44-62	1.0	1.0	6.6	0.06	2.5	3.8	2.4	6.6	32.3	12.8	4.13	0.47	50.7	8.1
62-74	1.5	1.5	10.2	0.03	4.3	4.8	2.3	8.3	29.5	12.0	3.02	0.38	46.0	6.6
74-130	1.8	3.0	34.6	0.04	3.5	30.8	5.5	22.3	28.3	7.5	2.29	0.34	39.5	5.8
P3 (Irrigated, Amod, Bharuch)														
0-24	3.5	9.0	54.1	0.26	2.5	60.4	3.8	21.6	20.5	15.8	4.17	1.02	42.8	9.7
24-49	2.0	3.1	20.8	0.06	2.5	19.3	4.2	13.0	19.5	16.5	5.40	0.75	43.7	12.4
49-76	1.0	2.0	20.0	0.04	3.8	16.1	3.1	16.3	27.3	11.7	5.60	0.65	45.8	12.2
76-102	1.0	1.5	25.0	0.04	3.0	20.8	3.6	22.4	25.3	12.3	8.50	0.65	47.5	17.9
102-136	4.5	6.5	61.7	0.08	2.5	68.7	1.7	26.3	21.0	10.5	12.70	0.75	46.9	27.1
136-150	12.0	14.5	98.4	0.14	2.0	120.4	1.6	27.0	13.3	15.3	9.40	0.50	39.0	24.1
P4 (Rainfed, Amod, Bharuch)														
0-28	1.0	2.0	4.5	0.05	2.3	4.5	0.7	3.7	22.3	11.3	1.41	0.76	36.9	3.8
28-62	1.5	1.5	5.1	0.02	2.1	4.8	1.0	4.2	20.3	16.8	4.21	0.67	43.9	9.6
62-82	1.0	2.5	8.4	0.07	4.3	4.5	3.1	6.3	23.8	13.5	5.21	0.57	45.4	11.5
82-115	0.5	2.5	20.9	0.04	3.8	14.1	5.7	17.1	24.5	11.6	8.28	0.53	47.5	17.4
115-133	1.8	3.0	33.1	0.04	3.0	27.2	7.4	21.4	23.8	12.3	8.54	0.55	47.3	18.1
133-150	3.0	5.5	80.3	0.08	2.3	75.2	10.6	39.0	21.8	13.3	5.90	0.40	42.6	13.8

SAR = Sodium adsorption ratio; CEC = Cation exchange capacity cmol (p+) kg^{-1}; ESP = Exchangeable sodium percentage

depth. Irrigated pedons showed the highest mean SAR over rainfed. The reason might be due to the predominance of higher quantum of salts accumulation in deeper layer for their locations nearby to sea coast, which caused high SAR and high ECe and perhaps soil dispersion, deteriorating ultimately soil structure. Kadu *et al*. (2009) found higher SAR value in irrigated (2.2 to 12.0) soils than rainfed (SAR 1.4-2.0) in soils of Wardha command area of Maharashtra. The results were also strongly supported by the findings of Nayak *et al*. (2000) and Chinchmalatpure *et al*. (2008) relating to predominance of anions order and increase in SAR and ECe with depth and also on dispersion and structural stability in salt affected soils.

In irrigated and rainfed pedons, CEC varied from 39.0 to 52.3 and 36.9 to 50.7 cmol (p+) kg^{-1} (Table 4), respectively indicating the presence of 2:1 type expanding clay minerals as dominant clay in soil. However, the magnitude of CEC increased with depth irregularly which might be due to presence of varying proportions of clay/silt + clay and exchangeable Na^{2+}, Ca^{2+} and Mg^{2+} ions. The CEC observed in these soils is essentially contributed by their clay content ($r = 0.62^{**}$). It was also observed that as the finer fraction (Table 3) increased, there was a corresponding increase in exchangeable bases which can be attributed to an increase in clay content provided more exchange sites to get the cations adsorbed on it (Datta *et al*., 1990; Yeresheemi *et al*., 1997). Irrigated pedon was found to show higher mean CEC as compared to that of rainfed pedon. In both irrigated and rainfed soils, exchangeable cations followed the trend as Ca^{2+}> Mg^{2+}> Na^{+}> K^{+}. However, the magnitudes of these cations were slightly higher in irrigated soils as compared to rainfed soils due to addition of salts from irrigation water. Similar results were corroborated by Padekar *et al.* (2014). The CEC results in the study were strongly supported by the findings of Gabhane *et al*. (2006), Chinchmalatpure *et al*. (2008), Arunkumar and Sriramachandrasekharan (2013), Walke *et al*. (2012) and Paramasivan and Jawahar (2014), whereby, they noticed higher CEC with high base saturation and considerably high exchangeable cations in soils and the exchangeable cations maintained the trend Ca^{2+}> Mg^{2+}> Na^{+}> K^{+}.

The ESP of soils under irrigated and rainfed pedons found a wide variation ranging 3.3 to 27.1% and 2.8 to 18.1% which increase with soil depth (Table 4). The ESP of soils from all irrigated and rainfed pedons were within the permissible limit of 15 instead of lower depths. However for heavy swelling-shrinkage black soils critical level of ESP might lie between 6 and 10 (Balpande *et al.*, 1996; Sharma *et al.*, 1998) and accordingly irrigated area encompassing all the pedons depicted mean ESP higher than critical level and as a result might cause yield reduction in cotton crop to certain extent depending upon the soil-clay content (Minhas, 2010). The higher ESP was possibly due to regular irrigation of canal/borewell/tubewell water etc. which ultimately induced the sodification process in surface as well as sub-soils, while higher ESP was found in lower soil depths and tends to be sodic in near future (sub-surface sodicity exists) (Chinchmalatpure *et al.*, 2018). The tendency of ESP to increase with the depth of pedons indicates the beginning of the sodification process in subsoil layers (Balpande *et al.*, 1996; Panwar *et al.*, 2015). Mean ESPs of irrigated soils (13.34%) were generally higher than that of rainfed soils (9.15%). Padekar *et al*. (2014) at Amravati district observed increased ESP by 7-9 times in all the layers of irrigated profiles compared to the un-irrigated. So, appropriate precautionary measures such as, application of judicious amount of gypsum with good drainage provision in both irrigated as well as rainfed area as above should be adopted to enhance the yield of cotton crop.

Based on soil-site and morphological characteristics (Table 2) and analytical data (Table 3), the soils of the study area have been classified taxonomically down to family category, taking further in to consideration, the moisture regimes, soil temperature classes, particle size classes and pedons properties (Soil Survey Staff, 2014). The soils of the study area as per the criteria predominantly come under orders namely, Vertisols as per 7th approximation, USDA and developed mainly under *ustic* moisture regime and under one temperature class of *hyperthermic* regime. The taxonomic classification up to family level for investigated soils is as follows:

- P1, P2 - Fine, Montmorillonitic (calcareous), Hyperthermic *Entic Chromusterts*
- P3, P4 - Fine, Montmorillonitic (calcareous), Hyperthermic *Udorthentic Chromusterts*

Ground water quality

Bara tract area under study is endowed with Narmada Canal irrigation facility, yet some farmers are compelled to use ground water owing to crisis of water in sufficient quantity during post monsoon period. Some farmers are also using ground water for irrigation in the event of prolonged dry spell, particularly at critical growth stages of crop during monsoon season. Similarly, the very few farmers also practice combined use of canal and ground water during rabi season and during summer seasons in very specific cases. In view of this, it is worth to assess the quality of ground water from irrigation point of view. So, total 50 nos. of water samples (40-ground/tubewell water and 10- canal water) were collected from different sources from irrigated and rainfed area of Bharuch district. The result revealed that the pH of ground water (Table 5) samples varied from 7.3 to 8.7 (neutral to strongly alkaline) with a mean value of 7.9 which indicated that in study area water resources were moderately alkaline in reaction. From salinity point of view, EC ranged from 1.0 to 12.0 dS m^{-1} (medium to very high salinity) with a mean value 4.9 dS m^{-1} (high salinity), which falls under salinity class C_4 i.e. very high salinity indicating unsuitability for irrigation. However, out of 40 samples, 7 samples came under C_3 class i.e. high salinity class (0.75 to 2.25 dS m^{-1}) which might create salinity problems in soils, 14 samples came under C_4 salinity class i.e. very high salinity

Table 5. Water quality of ground and canal water in the study area

Scenario	pH_w	EC_w (dS m^{-1})	Water-soluble cations (me L^{-1})				Water soluble anions (me L^{-1})				RSC	SAR	Salinity class
			Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	CO_3^{2-}	HCO_3^{-}	Cl^{-}	SO_4^{2-}			
Ground water (N=40)													
Min	7.3	1.0	1.0	1.3	3.1	0.0	0.0	1.3	2.6	0.1	-35.0	1.9	
Max	8.7	12.0	12.0	26.0	74.3	0.6	5.0	7.0	93.8	6.1	8.3	18.2	C_4S_1
Mean	7.9	4.9	4.6	11.2	27.6	0.1	2.1	3.0	32.7	2.0	-10.7	9.5	
SD	0.3	2.8	2.8	6.1	19.2	0.1	0.9	1.3	24.4	1.5	9.6	4.9	
Canal water (N=10)													
Min	7.1	0.1	0.7	0.0	0.2	0.0	0.6	0.0	0.2	0.0	-0.9	0.4	
Max	7.5	0.4	3.0	0.0	1.0	0.2	2.5	0.0	1.0	0.1	0.2	0.9	C_2S_1
Mean	7.2	0.3	1.7	0.0	0.6	0.1	1.5	0.0	0.6	0.0	-0.1	0.7	
SD	0.13	0.11	0.76	0.00	0.22	0.06	0.60	0.00	0.24	0.02	0.30	0.14	

class (>2.25 dS m^{-1}) which also might create salinity problems in soil and 19 samples belonged to C_5 class i.e. very very high salinity class (5-20 dS m^{-1}) and hence is not advisable to irrigation purposes due to possibility of high salinity development in soil. SAR valued ranged from 1.9 to 18.2 i.e. from sodicity class S_1 to marginally S_3 class which indicated that some water samples were of medium sodicity class. However, mean value of SAR was 9.5 which fell into sodicity class (S_1). Combining salinity class with sodicity class, quality of water samples varied from C_3S_1 to C_5S_3. Out of 40 samples, 7 samples came under C_3S_1 (high salinity with low sodicity class), 11 samples came under C_4S_1 (very high salinity with low sodicity class), 3 samples came under C_4S_2 (very high salinity with medium sodicity class), 6 samples came under C_5S_1 (very very high salinity with low sodicity class), 11 samples came under C_5S_2 (very very high salinity with medium sodicity class) and 2 samples came under C_5S_3 (very very high salinity with high sodicity class). In major cases water samples were unsafe for irrigation due to high salinity problems, though sodicity problem along with salinity may also arise to certain extent. The mostly of ground water samples had low RSC due to the dominance of Mg^{2+} ion concentration. When all the parameters were considered, the ground water sources which are being used for irrigation, was found unsuitable for irrigation purposes in present study area. However, mean of all the water samples came under combined category of C_4S_1. Similar results for irrigation water quality parameters were supported by Adamu (2013). Results of irrigation water on black soils of Amravati district of Maharashtra as reported by Padekar *et al*. (2016) was corroborated with the present study, where they found that irrigation water fell under C_3 and C_4 classes, indicating their unsuitability for irrigation and also fells under medium category of sodicity (S2) and low (S_1), high RSC (>2.5 me L^{-1}). In case of canal water, result revealed that the pH of water samples varied from 7.1 to 7.5 (neutral) with a mean value of 7.2 (Table 5). From salinity point of view, EC ranged from 0.10 to 0.40 (very low to low) with a mean value 0.30 dS m^{-1} (low). SAR of all the samples <1.0 i.e. no sodicity problem and all the samples came under S_1 sodicity class. Combined class of salinity and sodicity class was C_2S_1 for all samples i.e. all the samples were suitable for irrigation with moderate leaching due to low salinity and sodicity problems. The data of RSC revealed that all the water samples came under the category of safe group.

Soils exhibited high (severe to extreme limitation) BD and were of either imperfectly or imperfect to moderately well drained. The addition of organic matter like, decomposable farm wastes/compost/FYM/Biocompost/ Vermi-compost etc. as well as deep tillage once in every three years would be most advantageous to overcome limitations and possible improvement in cotton yield. In cases, installation of low-cost surface and sub-surface drainage would be more useful. Swelling-shrinkage clayey nature of the soils, tillage operation must be done at conducive/ optimum moisture level at proper time. High soil pH and ESP in the soils beyond threshold limit and also medium to high salinity level of these black soils necessitate adoption of sodicity and/or salinity tolerant crop varieties (as in question), besides addition of gypsum in requisite quantity in soil with appropriate low-cost drainage facility in sodic soils would be beneficial for sustain soil health as well as crop yield. Particularly in saline soils, leaching of salts beyond root zone through making of field bunding and ponding rain water for required leaching would be most useful, whereas raising green manuring crop like, Dhaincha/Sunhemp etc. would be added advantageous for sodic/calcareous soils for sustain soil health and crop yield. Owing to low rainfall and its aberrant distribution in this semiarid study area, rainwater harvesting and recycling, making of field bunds for maximum moisture storage in profiles would be highly advantageous particularly under rainfed situation for getting higher crop yield. As the ground water is saline and unsafe for irrigation in the entire tract, under both irrigated and rainfed situation during scarcity of good quality water, ground water can be used only by mixing with good quality water/rain water/ canal water or alternately with good quality water as supplementary/life-saving irrigation to sustain crop yield and soil health.

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