Influence of irrigation water on black soils in Amravati district, Maharashtra

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In view of earlier reports on the occurrence of salt-affected shrink-swell soils in the Purna valley areas in Amravati district of Maharashtra, the present study was carried out to assess the current nature and extent of soil degradation due to use of irrigation water. Results indicate that the irrigation water used to raise agricultural crops in Amravati, Bhatkuli, Warud and Daryapur tehsils contains enough soluble Na-ions and residual sodium carbonate as the water belongs to C4S2 and C4S1 class of the United States Salinity Laboratory. The anthropogenic activities by introducing irrigation have caused severe drainage problem in the shrink-swell soils of the district, which are highly clayey and smectitic that have inherent low permeability. Only exception is the better drained soils of Warud tehsil, which are endowed with Ca-zeolite that help to ward off the ill effects of irrigation. The study thus suggests that continuing the present anthropogenic activities might render the soils unsuitable for agricultural production in the future. In contrast, the soils which are not irrigated do not suffer from any serious degradation in terms of high exchangeable Na (ESP) and low saturated hydraulic conductivity (sHC), suggesting that it would be prudent to encourage rainfed agriculture in the district under improved management practices.

Keywords: Anthropogenic activities, irrigation water quality, shrink-swell soils, soil degradation, soil quality.

Introduction

AN increased awareness of soil as a critical component of the earth's bio/geo-sphere has stimulated interest in the concept and assessment of soil quality[1]. The demand for information on soil and land resources for enhancing food security, improving water quality, disposing wastes and mitigating climate changes is recognized for increased food productivity vis-à-vis population growth. This increased demand has intensified anthropogenic activities and soil degradation. Although the threats of land degradation are widespread, it is more extensive and intensive in the poorer regions, where the land users entirely depend on the inherent capacity of the land for their basic needs. The ever-increasing population pressure exacerbates the situation. The world population is expected to increase to 9 billion by 2050, with 8 billion (86%) living in developing countries[2]. Therefore, soil quality management for enhanced productivity and sustained environmental services is important in the developing countries to meet the demands of the growing population. Soil quality can be enhanced or degraded in response to the prevailing management systems. The effects of soil management systems on sustainability can be monitored by evaluating soil quality[3]. The predominant reason of poor soil quality due to land degradation relates to the washing away of top soil and organic matter, intensive deep tillage which breaks stable soil aggregates and disturbing the habitat of soil microflora and fauna, excessive removal of plant available nutrients, near absence or low use of organic manures, nutrient losses due to leaching and volatilization, with gaseous emissions occurring due to faulty methods of fertilizer application, excessive use of agricultural inputs such as fertilizers, herbicides and waterlogging, salinity and alkalinity[4] due to continuous use of poor quality of irrigation water. Generally, soil quality changes in response to soil use and management[5].

Vertisols and associated soils are the most widely distributed soils in the world, and are found under varied climatic conditions. Such soils are spread over five continents from 45°S to 45°N, mainly in tropical and subtropical areas and their major areas of distribution are located in Asia and Africa[6]. These soils are widely distributed in the continents of Asia (mostly in India), America (mostly in USA, Venezuela and Argentina), Australia and Africa. In India, shrink-swell soils (Vertisols and associated soils also known as black soils) are found mostly in the peninsular region, extending from 8°45′N to 26°0′N lat., 68°0′E to 83°45′E long. These soils are developed in alluvium derived from weathering of the Deccan basalt[7]. The shrink-swell soils occupy about 26.62 m ha in India[8], of which 5.6 m ha are in Maharashtra. These soils contain a high proportion of swelling clays such as smectites. However, their unique physical properties are the greatest limitations to the dominantly low input agriculture. These soils require careful management to tap their potential by avoiding decline in soil

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quality. A thorough understanding of quality of these soils is crucial to develop and implement farming practices that will keep them productive for the current and future generations[9–12]. Black soils are mainly confined to the lower topographic positions such as valleys. One such valley in Amravati and Akola district of Maharashtra is the Purna valley. Considerable portions of this valley are saline and prone to be waterlogged[13–16]. The Soil Survey Department of Maharashtra also reported this problem on both sides of the Purna River. However, the presence of salinity is not always perceived because soil surface lacks salt efflorescence[16–19], but the soils remain waterlogged after rains and this disrupts the sowing of rainy season (*kharif*) crops. As a consequence, farmers are unable to maintain a sustainable production of agricultural crops. The Purna valley (20°07′–21°37′N and 75°58′–77°58′E) is an oval-shaped basin and covers an area of 583,200 ha, representing the districts of Amravati, Akola and Buldhana of Maharashtra. The area has a monsoonal climate, beginning from June or July through September; and this period receives 85–95% of the total annual rainfall of 700–975 mm. This is followed by a dry season from October to May or June. April and May are the hottest months with mean monthly temperature of 32.5°C and 35.2°C respectively. December and January are the coolest months with average monthly temperature of 22°C. The soils have a Typic Tropustic moisture regime[20]. The soil temperature regime is hyperthermic[21]. The water balance data for the Amravati district based on 30 years (1960–1990) of climatic data indicate that the humid period calculated according to FAO method[22] is 98 days and the growing period is 152 days. However, there is surplus water owing to P/PET ratios for the humid months, which ranges from 1.57 to 2.18.

Chemical degradation of soils of the Purna valley in terms of increase in exchangeable sodium percentage (ESP) and exchangeable magnesium percentage (EMP) with depth has adversely affected the hydraulic and other properties important for crop growth[23]. The soils of the Purna valley have been extensively studied during 1990–1993 by several workers[17,24–26]. The salinity and/or sodicity problems are diagnosed in these soils, although most of the soils have good production potential. In view of the climate change during the Holocene period coupled with intensified agricultural practices, it becomes imperative to monitor the land degradation periodically to develop strategies for land development. In this context, it was proposed to conduct the present study by interpreting the soil datasets studied earlier.

The Department of Agriculture, Government of Maharashtra has delineated a strip of 15 to 20 km (*kharpatta*) wide and 90–100 km long, along the Purna River as salt-affected. It is obvious that a river or any natural drainage helps in reducing salts. However, the present observation is contrary to the general understanding. According to earlier reports[17,24,26], the soils of the Purna valley are neither saline, and sodic nor saline–sodic according to the criteria suggested by the US Salinity Laboratory Staff[27], still they have severe drainage problems following irrigation and/or rains, which affects the cultivation of crops in the rainy season. This condition becomes more severe if the soils are irrigated with the river or well water. Nimkar *et al.*[18] reported the development of sodicity in the surface and accumulation of salts in the surface soil when well water was used for irrigation. Precise pedogenic processes responsible for sodification are not known that lead to poor drainage, nor is there any comprehensive information about the extent of this problem and the suitability of water for irrigation. Many researchers who had worked in the Purna valley and similar soils concluded that considerable part of these soils has the problem of internal drainage along with accumulation of salts in the sub-surface horizons[13,15] and are prone to water-logging[17–19]. The salinity and/or sodicity of these soils pose major constraint in the attempt to conserve these soils. Poor drainage condition is the root cause of many problems. Due to poor drainage, salts have accumulated in the soils and further aggravated by the application of poor quality irrigation water. Indiscriminate use of irrigation water for getting higher yield has led to waterlogging, nutrient losses and increased salinization of lands that were once fertile; and this threatens the sustainability of crop yields.

Groundwater in the Purna valley occurs under the phreatic, semi-confined and confined conditions. The depth of the water table generally varies from 3 to 25 m below ground level. The average annual recharge to the groundwater is approximately 8% of the average annual rainfall[28]. Groundwater is highly brackish. Exceptionally high salinity was of marine origin as a result of incursion of a stretch of sea water into the Purna sub-basin[13]. However, this water does not have a source with very high salts because the ratios of major anions and cations in this saline water are not the same as those of sea water[29] and this water is digenetically altered meteoric water with a long residence time, as is evident from high Na/(Ca + Mg) ratio, negative indices of the base exchange and high SiO_2 content[29].

The majority of black soils in India occurs in the lower piedmont plains or valleys or in micro depressions. They are developed in the basaltic alluvium[30] and mostly formed in the Holocene period[31,32]. In Maharashtra, total irrigated area is 4.2 m ha which accounts to 19.6% of the gross cultivated land. Vidarbha covers 14.1% of its land under irrigation (0.7 m ha). Amravati district of Vidarbha is spread over 12,210 sq. km, with 6.9 lakh ha area under cultivation and 0.9 lakh ha irrigated area (14.1%). The dominant crops are orange (*Citrus reticulata*), cotton (*Gossypium* spp.), redgram (*Cajanuscajan*), soybean (*Glycine max*.), green gram (*Vigna radiata*) and chickpea (*Cicer arietinum*). Irrigation sources are river, canal and predominantly deep tube wells. Black soils are dominant in Amravati district. Farmers are not able to grow second crop (*rabi*) due to high intensity-short duration rainfall with intermittent long dry spells, leaving very less residual moisture in the soil. Thus irrigation becomes a necessity. However, poor quality of irrigation water, especially the groundwater, is a problem as it influences the soil health by affecting physical and chemical properties. Often farmers complain about the deterioration of soil quality due to application of irrigation water. Therefore, water is a limiting factor for the irrigation of many black soil areas. It has also been noticed that a part of the district experiences the problem of poor drainage resulting in water stagnation in *kharif* and moisture stress in post-rainy (*rabi*) season. Poor drainage is the major cause of many problems resulting in the accumulation of salts in these soils which is aggravated by the application of poor quality of irrigation water during the last 20 years. Therefore, evaluation of not only the water quality, but also the assessment of soil quality is a must to understand the status of soil health. The present study thus aimed to find out the causative factor of poor soil drainage in this part of Vidarbha, Maharashtra. An effort was also made for assessing the soil quality with the help of time-series data on irrigation water and soil parameters.

Materials and methods

Amravati district lies between 20°30′N and 21°46′N lat. and 76°37′E and 78°27′E long. with semi-arid (moist) climate with dry season from October to June and wet season from July to September, and during this period approximately 85–90% of the rainfall is received. April and May have very high temperature and December and January are the cooler months. The soils have ustic moisture regime and hyperthermic temperature regime[21]. The soils of Amravati district are formed in the alluvium of the weathering of the Deccan basalt showing variation in their depth. Rainfed agriculture is dominant in the study area with the exception of Warud tehsil where orange is grown under irrigation. Soil and water samples from eight pedons (one each under irrigated and unirrigated condition) were collected from each of the four tehsils (Amravati, Daryapur, Bhatkuli and Warud) from Amravati district, Vidarbha, Maharashtra (Figure 1). For spatial distribution of soils of selected site, the soils from minipits (0–10, 10–25 and 25–50 cm) and irrigation water samples from river and wells were also collected from each tehsil (Figure 2).

Water samples were analysed for different chemical constituents[27]. Soil samples were air-dried and analysed following the standard methods[27,33–35]. Mechanical analysis of soils was done by the international pipette method. Sand, silt and clay fractions were separated following the segregation procedure of Jackson[36]. Intensive crop production in arid and semi-arid region depends heavily on irrigation during second crop (*rabi*) or for the *kharif* crop when the monsoon is late or there is a long dry spell after the onset of monsoon. Climate and soil conditions of this region require irrigation water of good quality. Quality of irrigation water depends on total concentration of soluble salts, with special reference to the relative proportion of sodium to other cations. In order to avoid deleterious effect of poor quality irrigation water on soil properties and plant growth, it is desirable to have quality evaluation prior to its use for irrigation. A scheme proposed by the United States Salinity Laboratory (USSL)[27] has generally been accepted to evaluate irrigation water. Electrical conductivity has been proposed to measure total soluble salts in irrigation water. Four salinity classes, viz. C1, C2, C3

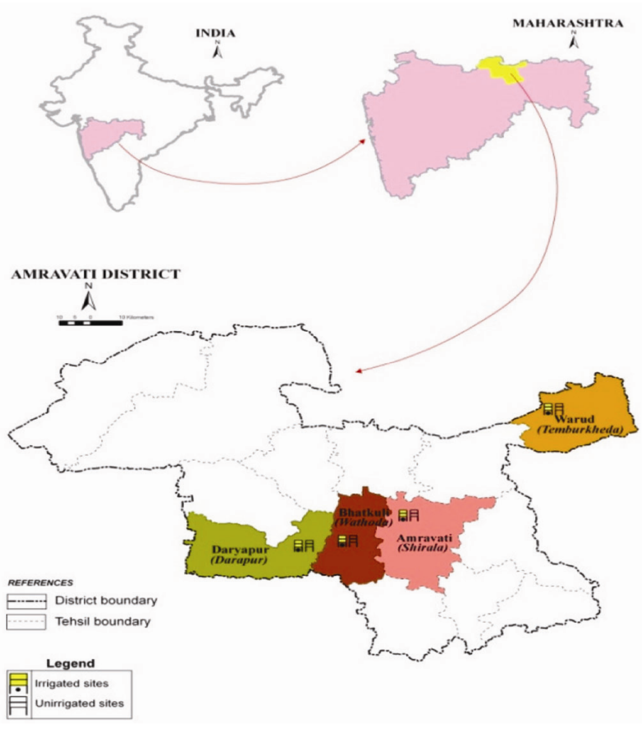

Figure 1. Location map of study area showing sites of soil sampling (pedons).

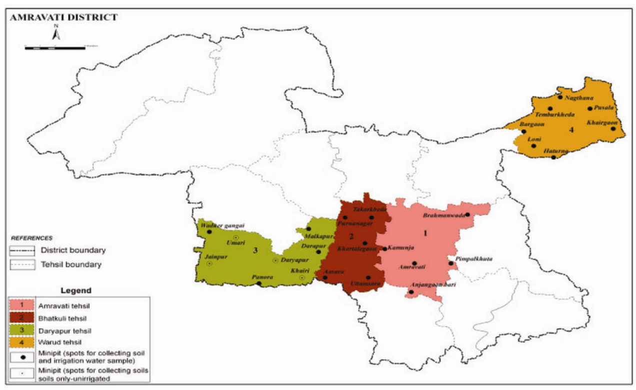

Figure 2. Location map of study area showing sites of collecting soil samples from the minipits.

Table 1. Various parameters for rating quality of irrigation water

Classes	EC (dS m^{-1})	Remarks
Salinity classes		
C1	<0.25	Safe, no likelihood of any salinity problem (no salinity)
C2	0.25–0.75	Needs moderate leaching (medium salinity)
C3	0.75–2.25	High salinity
C4	>2.25	Very high salinity
C5	5–20	For Indian soils[2]
Classes	SAR	Remarks
Sodicity classes		
S1	0–10	Low sodicity
S2	10–18	Medium sodicity
S3	18–26	High sodicity
S4	>26	Very high sodicity
Classes	RSC (meq l^{-1})	Remarks
Carbonates		
R1	<1.25	Safe for irrigation
R2	1.25 – 2.5	Marginal
R3	>2.5	Unsuitable for irrigation
FAO guidelines		
EC	<2.5	Suitable
SAR	<10	
RSC (meq l^{-1})	<1.25	
pH	6.5–8.4	
EC	0.25–0.75	Moderately suitable
SAR	10–18	
RSC (meq l^{-1})	1.25–2.5	
pH	8.5–9.5	
EC	>0.75	Not suitable
SAR	>18	
RSC (meq l^{-1})	>2.5	
pH	>9.5	

Refs 27, 39, 43.

Table 2. Chemical composition of irrigation water

Soil site	Mg^{2+} ($mmol_c l^{-1}$)	Na^{+} ($mmol_c l^{-1}$)	pH	EC* (dS m^{-1})	SAR	RSC	Water class
Amravati	2.5	14.0	8.4	1.8	11.8	10.1	C3S2
Daryapur	2.4	11.5	8.5	1.6	9.0	7.3	C3S1
Bhatkuli	11.2	19.0	8.3	3.0	7.8	–0.2	C4S1
Warud	3.5	3.5	7.9	0.9	2.2	1.4	C3S1

*EC, Electrical conductivity; SAR, Sodium adsorption ratio; RSC, Residual sodium carbonate.

and C4 were proposed (Table 1). C5 class of water was included with EC from 5 to 20 dS m^{-1}, particularly for Indian soils[37]. In addition to the degree of salinization, the type of salinization, the sodium hazard and concentration of residual sodium carbonate have to be taken into account. Richards[27] suggested sodium adsorption ratio (SAR) according to which water can be classified as low sodium water (S1-SAR 0-10), medium sodium water (S2-SAR 10-18), high sodium water (S3-SAR 18–26) and very high sodium water (S4–SAR > 26). Water containing CO_3^- and HCO_3^- ions in excess of $Ca^{2+} + Mg^{2+}$ often leads to higher alkalization than SAR[38]. This happens due to precipitation of calcium and magnesium ions, resulting in an increase in SAR. To quantify precipitation of Ca^{2+} and Mg^{2+} ions (by carbonate), the concept of residual sodium carbonate (RSC) for evaluating high carbonate water was postulated[39]. Various parameters for rating the quality of irrigation water are given in Table 1.

Results and discussion

Assessing quality of irrigation water

The electrical conductivity (EC) of irrigation water (river and well) collected from the irrigated profile sites in Amravati district ranges from 0.9 to 3.0 dS m^{-1} (Table 2) which falls under C3 and C4 classes, indicating their unsuitability for irrigation and also falls under medium category of sodicity (S2) for Amravati and low (S1) for Daryapur, Bhatkuli, and Warud.

Table 3. Comparison of particle size separates in irrigated and unirrigated soils*

		Amravati		Daryapur		Bhatkuli		Warud	
Particulars	Soil layer (cm)	Irrigated	Unirrigated	Irrigated	Unirrigated	Irrigated	Unirrigated	Irrigated	Unirrigated
Clay %	0–30	65.6	65.5	66.8	69.8	73.0	67.4	45.2	51.4
	30–50	65.4	67.4	67.6	72.5	77.3	68.6	51.5	56.3
	50–100	69.3	71.2	60.7	63.5	69.8	64.0	51.1	44.3
Silt %	0–30	29.9	29.1	29.8	28.0	23.8	29.6	53.3	43.9
	30–50	30.3	29.4	29.9	25.2	19.8	28.5	44.6	41.1
	50–100	26.4	25.3	34.9	32.3	27.1	26.6	46.0	52.5
Sand %	0–30	4.5	5.3	3.4	2.2	3.2	3.1	4.1	4.7
	30–50	4.3	3.2	2.6	2.4	2.8	2.8	3.9	2.7
	50–100	4.3	3.6	4.4	4.2	3.1	9.4	2.9	3.2

*Values indicate weighted mean averages.

Table 4. Comparison of soil quality parameters in irrigated and unirrigated soils*

			Extractable bases (c mol(p^+) kg^{-1})					
Soil layer (cm)	pH	EC (dS m^{-1})	Ca^{2+}	Mg^{2+}	Na^+	K^+	ESP*	Saturated hydraulic conductivity (cm h^{-1})
Pedon 1. Shirala soil – Amravati tehsil (irrigated)								
0–30	8.4	0.28	53.5	10.1	5.5	1.4	9	0.08
30–50	8.2	0.24	66.7	9.1	2.0	1.4	3	0.22
50–100	8.1	0.21	53.8	11.1	1.3	1.5	2	0.26
Pedon 2. Shirala soil – Amravati tehsil (unirrigated)								
0–30	8.2	0.15	45.9	8.3	0.4	1.4	1	0.71
30–50	8.3	0.17	45.3	13.2	0.5	1.2	1	0.48
50–100	8.3	0.16	42.1	5.8	0.5	1.2	1	0.41
Pedon 3. Darapur soil – Daryapur tehsil (irrigated)								
0–30	8.7	0.27	45.5	1.0	4.9	2.2	9	0.14
30–50	8.6	0.26	49.9	1.5	4.1	1.0	7	0.16
50–100	8.4	0.36	44.9	1.1	5.0	0.9	9	0.19
Pedon 4. Darapur soil – Daryapur tehsil (unirrigated)								
0–30	8.0	0.21	58.1	0.7	0.6	1.5	1	0.40
30–50	8.1	0.13	42.7	0.6	0.5	1.3	1	0.42
50–100	8.2	0.13	45.5	0.8	0.5	1.1	1	0.46
Pedon 5. Wathoda soil – Bhatkuli tehsil (irrigated)								
0–30	7.9	0.66	48.0	1.2	4.2	1.3	6	0.17
30–50	7.9	0.44	48.7	1.1	2.5	1.0	4	0.22
50–100	7.9	0.53	47.6	1.3	1.0	1.0	2	0.26
Pedon 6. Wathoda soil – Bhatkuli tehsil (unirrigated)								
0–30	7.9	0.16	52.2	1.2	0.8	1.5	1	0.65
30–50	8.1	0.16	56.4	0.8	0.7	1.2	1	0.67
50–100	8.2	0.17	48.6	0.9	0.6	0.9	1	0.93
Pedon 7. Temburkheda soil – Warud tehsil (Irrigated)								
0–30	8.3	0.19	35.2	12.0	1.3	1.4	3	0.98
30–50	8.3	0.18	36.1	12.2	1.3	1.0	3	0.71
50–100	8.5	0.19	35.2	13.6	1.7	1.0	4	0.47
Pedon 8. Temburkheda soil – Warud tehsil (Unirrigated)								
0–30	8.3	0.17	34.5	11.3	0.6	2.5	1	1.63
30–50	8.3	0.18	33.0	13.6	0.5	1.4	1	0.72
50–100	8.4	0.18	33.2	13.7	1.2	1.1	4	0.78

*Values indicate weighted mean averages.

Table 5. Changes in selected soil properties over time and due to irrigation in soils of Amravati tehsil in Amravati district, Maharashtra

	Soil depth (cm)	Unirrigated		Irrigated
Particulars	Location	Pusad* 1990	Shirala** 2010	Shirala** 2010
Physical properties of soils				
BD (Mg m^{-3})	0–30	–	1.5	1.7
	30–50	–	1.7	1.8
sHC (cm h^{-1})	0–30	1.76	0.71	0.08
	30–50	1.59	0.48	0.22
AWC (%)	0–30	17.1	23.8	24.7
	30–50	14.6	13.3	23.5
Chemical properties of soils				
pH	0–30	8.0	8.2	8.4
	30–50	8.2	8.3	8.2
EC (dS m^{-1})	0–30	0.13	0.15	0.28
	30–50	0.14	0.17	0.24
% OC	0–30	0.6	0.8	0.8
	30–50	0.5	0.6	0.7
% $CaCO_3$	0–30	7.9	7.2	7.1
	30–50	9.0	8.1	6.4
CEC (cmol (p^+) kg^{-1}	0–30	67.8	55.7	60.4
	30–50	66.8	54.7	61.6
ESP	0–30	0.5	0.7	9.1
	30–50	0.6	1.0	3.3
pHs	0–30	7.8	8.1	8.3
	30–50	7.8	8.1	8.3
ECe (dS m^{-1})	0–30	0.4	0.4	1.6
	30–50	0.4	0.3	0.8
SAR	0–30	1.1	0.4	6.1
	30–50	1.2	0.4	2.0
SSP	0–30	37.3	11.0	65.1
	30–50	39.9	17.1	34.4
Irrigation water: pH				8.4
EC (dS m^{-1})				1.8
SAR				11.8
Irrigation water class***				C3S2

*This spot is ~2 km within Shirala irrigated and unirrigated pedons. All the pedons have similar soils (Typic Haplusterts)[44]; **Present Work; *** (ref. 27).

According to the criteria mentioned above, the irrigation water from Amravati and Daryapur tehsils is unsuitable for irrigation with RSC of 10.1 and 7.3 meq l^{-1} respectively. Warud irrigation water is marginally suitable (RSC, 1.4 meq l^{-1}). In Bhatkuli tehsil the irrigation water has low RSC due to the dominance of Mg^{2+} ion concentration (Tables 1 and 2). When all the parameters are considered, the water being used for irrigation is unsuitable for irrigation in Amravati district. The quality of water used for irrigation is C3S1 for Warud, C3S1 for Daryapur, C3S2 for Amravati and C4S1 for Bhatkuli.

Effect of irrigation water on soil properties

More amount of pedogenic $CaCO_3$ and a higher ESP were observed in irrigated soils. Perceptible changes in morphological properties (colour, texture and structures) were not noticed in the irrigated soils except the consistence of soils which indicated increased firmness in the peds of irrigated soils compared to the unirrigated ones. The colour of Shirala irrigated soil is very dark brown to very dark grey to yellowish brown at the lower layer. Unirrigated site of Shirala has very dark greyish brown colour at surface and dark greyish brown at lower depth. Darapur irrigated profile is greyish brown to dark greyish brown to yellowish brown throughout the soil depth whereas unirrigated soils have dark greyish brown which is very dark at the slickensided zone and yellowish brown at lower layer of profile. Surface layer of Wathoda irrigated soil shows very dark greyish brown colour with dark brown colour throughout the profile; at the lower horizons the colour is dark yellowish brown to yellowish brown. Unirrigated profile is dark greyish brown in upper layer, dark brown to very dark greyish brown in the slickensided zone and dark yellowish brown at the lower part of profile. Irrigated soil of Temburkheda in Warud tehsil reflects dark greyish brown to dark brown

Table 6. Changes in selected soil properties over time and due to irrigation in soils of Daryapur tehsil in Amravati district, Maharashtra

	Soil depth (cm)	Unirrigated		Irrigated
Particulars	Location	Chendikapur* 1990	Darapur** 2010	Darapur** 2010
Physical properties of soils				
BD (Mg m^{-3})	0–30	1.7	1.7	1.7
	30–50	1.7	1.8	1.8
	50–100	1.8	1.8	1.8
sHC (cm h^{-1})	0–30	0.30	0.40	0.14
	30–50	0.26	0.42	0.16
	50–100	0.21	0.46	0.19
AWC (%)	0–30	16.5	25.0	21.4
	30–50	14.4	20.5	19.0
	50–100	16.9	18.8	19.6
Chemical properties of soils				
pH	0–30	8.3	8.0	8.7
	30–50	8.4	8.1	8.6
	50–100	8.6	8.2	8.4
EC (dS m^{-1})	0–30	0.61	0.21	0.27
	30–50	0.50	0.13	0.26
	50–100	0.64	0.13	0.36
% OC	0–30	0.6	0.6	0.7
	30–50	0.6	0.5	0.7
	50–100	0.5	0.5	0.6
% $CaCO_3$	0–30	6.5	5.5	6.9
	30–50	7.3	8.0	8.6
	50–100	11.1	10.7	11.9
CEC (cmol(p^+) kg^{-1}	0–30	50.8	59.8	55.7
	30–50	49.7	60.5	60.6
	50–100	50.7	59.4	57.7
ESP	0–30	3.7	1.1	8.8
	30–50	3.5	0.9	6.8
	50–100	3.8	0.9	8.7
pH	0–30	7.8	8.1	8.6
	30–50	7.8	8.2	8.4
	50–100	7.9	8.2	8.2
ECe (dS m^{-1})	0–30	1.95	0.26	0.73
	30–50	1.61	0.30	0.61
	50–100	2.19	0.35	0.94
SAR	0–30	3.2	0.3	9.0
	30–50	3.0	0.3	5.9
	50–100	3.3	0.5	6.7
SSP	0–30	40.8	8.5	79.8
	30–50	41.2	11.5	76.6
	50–100	40.2	17.4	76.0
Irrigation water: pH				8.5
EC (dS m^{-1})				1.6
SAR				9.0
Irrigation water class***				C3S1

*This spot is 1.5 km within Darapur irrigated and unirrigated pedons. Chendikapur and Darapur has similar soils (Typic Haplusterts)[26]. **Present Work; ***ref. 27.

colour which is dark yellowish brown near the parent material down the lower depth of soil whereas the unirrigated profile shows dark greyish brown colour throughout the layers ending with yellowish brown. All the soils are very deep with very high clay content (45–77%) (Table 3). The soils have subangular blocky structures at the surface and angular blocky at the subsurface showing sticky and plastic consistence. The soils of the irrigated and unirrigated sites of Amravati district have similar texture and have similar substrate suggesting their comparable texture (Table 3).

The pH of the soils did not reflect any specific comparable trend, but pH was higher in irrigated than unirrigated soils of Daryapur tehsil, particularly in the upper layer of the soil profile. EC of the irrigated and unirrigated soils ranged from 0.18 to 0.66 dS m^{-1} and 0.13 to

Table 7. Changes in selected soil properties over time and due to irrigation in soils of Bhatkuli tehsil in Amravati district, Maharashtra

	Soil depth (cm)	Unirrigated		Irrigated
Particulars	Location	Wathoda* 1990	Wathoda** 2010	Wathoda** 2010
Physical properties of soils				
BD (Mg m^{-3})	0–30	–	1.5	1.7
	30–50	–	1.7	1.8
sHC (cm h^{-1})	0–30	0.12	0.65	0.17
	30–50	0.11	0.67	0.22
AWC (%)	0–30	–	22.3	19.5
	30–50	–	16.3	16.7
Chemical properties of soils				
pH	0–30	7.8	7.9	7.9
	30–50	8.0	8.1	7.9
EC (ds m^{-1})	0–30	0.5	0.2	0.7
	30–50	0.3	0.2	0.4
% OC	0–30	–	0.6	0.8
	30–50	–	0.6	0.6
% $CaCO_3$	0–30	3.0	5.5	5.2
	30–50	6.0	5.3	5.9
CEC (cmol(p^+) kg^{-1}	0–30	82.0	68.7	68.4
	30–50	80.4	66.8	65.4
ESP	0–30	1.7	1.1	6.1
	30–50	2.0	1.0	3.8
pHs	0–30	7.4	8.0	8.1
	30–50	7.5	8.1	8.0
ECe (dS m^{-1})	0–30	0.6	0.3	2.5
	30–50	0.5	0.3	1.2
SAR	0–30	0.8	0.5	6.6
	30–50	1.0	0.5	3.0
SSP	0–30	18.0	13.4	59.3
	30–50	25.0	18.1	42.9
Irrigation water				
pH				8.3
EC (dS m^{-1})				3.0
SAR				7.8
Irrigation water class***				C4S1

*This spot is ~1 km within Wathoda irrigated and unirrigated pedons. All the pedons have similar soils[17]; **Present work; ***ref. 27.

0.21 dS m^{-1} respectively. The EC was higher in all the irrigated soils than the unirrigated ones. Effect of poor quality irrigation water in terms of increased EC was most conspicuous in the soils of Bhatkuli tehsil.

In general, calcium was the dominant exchangeable cation at all the sites. In Shirala irrigated soil, the extent of calcium was high and this was followed by magnesium, sodium and potassium. But in unirrigated soil profile Na^+ ion concentration was less than K^+. This clearly indicates preponderance of Na^+ ion in irrigated soils due to the use of irrigation water with higher Na^+ concentration (C3S2). A similar trend was noticed in other irrigated soils except in Warud soils which may be due to presence of Ca-rich zeolites[30,32,40–41]. Release of Ca ions from zeolites improved the soil water composition as reflected in lower value of soluble Na ions. ESP of the irrigated soils in Amravati (1.9–9.1), Daryapur (6.8–8.8) and Bhatkuli (1.7–6.1) was higher when compared to that of the unirrigated soils (Table 4).

Effect of irrigation water on soils over time

In order to assess the changes in soil properties in Amravati, Daryapur and Bhatkuli tehsils, an effort was made to compare the values of selected soil parameters obtained in the present study with those obtained in 2010 and also interpreting the data from the studies conducted during 1990s.

Amravati tehsil

The selected soils in this tehsil showed a decrease in saturated hydraulic conductivity (sHC) over the last 20 years

Table 8. Composition of saturation extract of irrigated and unirrigated soils*

Soil depth (cm)	ECe (dS m^{-1})	Soluble anions ($mmol_c l^{-1}$) HCO_3^-	Cl^-	SO_4^{2-}	Ca^{2+}	Soluble cations ($mmol_c l^{-1}$) Mg^{2+}	Na^+	K^+	SAR**	Soluble sodium %
Pedon 1. Shirala soil – Amravati tehsil (irrigated)										
0–30	1.59	5.7	7.2	2.1	3.6	1.5	9.9	0.17	6.1	65
30–50	0.83	3.8	3.3	1.1	3.4	1.3	3.4	0.10	2.0	34
50–100	0.59	2.2	2.0	1.3	3.1	0.9	1.3	0.10	0.9	23
Pedon 2. Shirala soil – Amravati tehsil (unirrigated)										
0–30	0.36	2.6	0.5	0.4	2.2	0.7	0.3	0.08	0.4	11
30–50	0.27	2.3	0.5	0.4	1.4	0.6	0.4	0.04	0.4	17
50–100	0.33	1.9	0.8	0.6	0.6	0.7	0.7	0.03	0.7	24
Pedon 3. Darapur soil – Daryapur tehsil (irrigated)										
0–30	0.73	3.9	1.7	1.8	0.9	0.5	5.8	0.15	9.0	80
30–50	0.61	3.0	1.2	1.8	0.8	0.4	4.5	0.21	5.9	77
50–100	0.94	3.3	2.5	3.3	1.4	0.6	6.9	0.05	6.7	76
Pedon 4. Darapur soil – Daryapur tehsil (unirrigated)										
0–30	0.26	1.8	0.5	0.4	1.7	0.5	0.3	0.10	0.3	9
30–50	0.30	2.3	0.6	0.3	2.1	0.6	0.4	0.05	0.3	12
50–100	0.35	2.4	0.7	0.3	1.9	0.7	0.6	0.06	0.5	17
Pedon 5. Wathoda soil – Bhatkuli tehsil (irrigated)										
0–30	2.47	1.9	12.9	7.1	7.0	3.1	14.9	0.12	6.6	59
30–50	1.23	1.7	2.7	7.3	4.9	1.7	5.7	0.07	3.0	43
50–100	1.50	1.0	1.8	11.8	9.2	3.2	2.0	0.09	0.9	14
Pedon 6. Wathoda soil – Bhatkuli tehsil (unirrigated)										
0–30	0.34	1.5	1.2	0.4	2.0	0.6	0.4	0.09	0.5	14
30–50	0.31	1.6	0.8	0.5	1.6	0.6	0.5	0.07	0.5	18
50–100	0.34	2.2	0.4	0.8	1.7	0.7	0.6	0.05	0.6	20
Pedon 7. Temburkheda soil – Warud tehsil (irrigated)										
0–30	0.52	3.0	1.4	0.8	2.2	1.0	1.7	0.11	1.4	36
30–50	0.48	2.3	1.7	0.8	2.1	1.0	1.6	0.05	1.3	34
50–100	0.45	1.8	2.0	0.5	1.2	0.6	2.3	0.05	2.6	58
Pedon 8. Temburkheda soil – Warud tehsil (unirrigated)										
0–30	0.44	2.8	0.5	1.2	2.4	0.9	0.5	0.13	0.6	14
30–50	0.37	2.9	0.3	0.6	1.9	0.7	0.8	0.05	0.7	34
50–100	0.41	3.0	0.4	0.6	1.4	0.6	1.7	0.08	1.8	45

*Values are weighted mean average; **SAR, Sodium adsorption ratio.

from 1.76–0.71 cm h^{-1} in the surface (0–30 cm) and from 1.59–0.48 cm h^{-1} in the subsurface (30–50 cm), resulting in impairment of soil drainage[16,19,32]. However, pH, EC, organic carbon (OC), CEC, $CaCO_3$ and ESP showed slight to no significant change (Table 5). Reduction in the drainage was recorded over passage of time due to poor quality irrigation water as evidenced by decrease in the values of sHC from 0.71 (unirrigated, 2010) to 0.08 cm h^{-1} (irrigated, 2010) to 0.22 cm h^{-1} in both the layers (0–30 and 30–50 cm) (Figure 3). The effect of poor quality irrigation water (C3S2) was indicated by increase in EC, ESP, soluble sodium percentage (SSP) (Figure 4) and the SAR values of the irrigated soils compared to the present and previously studied unirrigated soils (Table 5). Similarly, there was a significant increase in the values of bulk density from 1.5 Mg m^{-3} (unirrigated soils) to 1.7 Mg m^{-3} (irrigated soils) in the surface layer (0–30 cm) (Figure 3). The bulk density of subsurface layer (30–50 cm) increased marginally from 1.7 to 1.8 Mg m^{-3}.

Daryapur tehsil

The properties of soils such as BD, OC and $CaCO_3$ remained unaffected during a span of 20 years under unirrigated conditions. An increase in sHC was recorded (0.30, 0.26 and 0.21 cm h^{-1} to 0.40, 0.42 and 0.46 cm h^{-1}) at the surface (0–30 cm) and subsurface (30–50 and 50–100 cm) layers. Similarly, available water content (AWC) also increased during the two decades (Figure 5). Soil pH decreased (8.3–8.6 to 8.0–8.2). A significant decrease in EC values was recorded (0.61, 0.50 and 0.64 to 0.21, 0.13

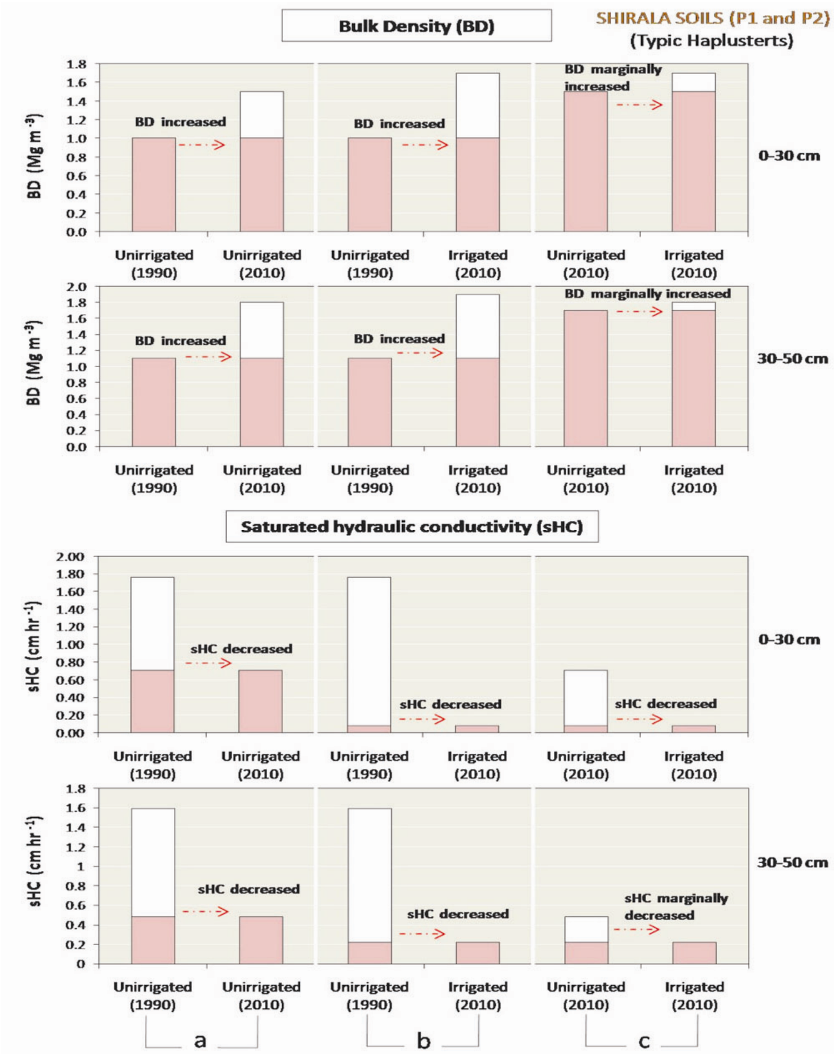

Figure 3. Changes in the physical properties of soils in Amravati tehsil over the last 20 years (a) comparison in unirrigated soils, (b) comparison in unirrigated (1990) and irrigated soils (2010) and (c) comparison in unirrigated and irrigated soils (2010) (During 1990 we did not find any reference of irrigation in this area and therefore irrigated black soils during 1990 and those during 2010 could not be compared.)

and 0.13 dS m^{-1}) along with ESP (3.7, 3.5 and 3.8 to 1.1, 0.9 and 0.9) and SSP (40.8, 41.2 and 40.2 to 8.5, 11.5 and 17.4) in the unirrigated soils. Due to application of irrigation water, the soils showed a significant decrease in (sHC) (from 0.40 to 0.14 cm h^{-1}) and from 0.46 to 0.16 cm h^{-1} in both surface (0–30 cm), subsurface (30–50 cm and 50–100 cm) layers. The soils previously studied also showed impaired drainage condition after irrigation supported by the increased ESP of irrigated soils (Figure 6). No significant effect of irrigation water was seen in OC and $CaCO_3$ content in soils over years and those under unirrigated conditions at present. Considerable increase in ESP, SAR and SSP was noticed in irrigated soils due to irrigation water (Table 5). We may, therefore, infer that the soils which are rainfed agricultural practices show improved soil conditions compared to the soils irrigated (Table 6).

Bhatkuli tehsil

The present study was carried out in nearby (~1 km) areas of Wathoda soils reported earlier[17] with and without irrigation (Table 7). The sHC is much better after two decades as shown in Figure 7. The other soil parameters such as pH, EC, $CaCO_3$ were slightly changed. In the rainfed (unirrigated) agriculture of the area, soil parameters of 1990 and 2010 indicate a general trend of slight decrease in ESP, ECe, and SAR and SSP values (Table 7). Earlier during 1990 till 2000, the entire area of Bhatkuli tehsil was under cotton and pigeon pea. Later, the cropping system changed to soybean and sunflower along with pigeon pea and gram. Although the farmers apply inorganic fertilizers such as urea, diammonium phosphate and single super phosphate, there is a tendency to apply farmyard manure and or cowdung at least 1 tonne/ha/year.

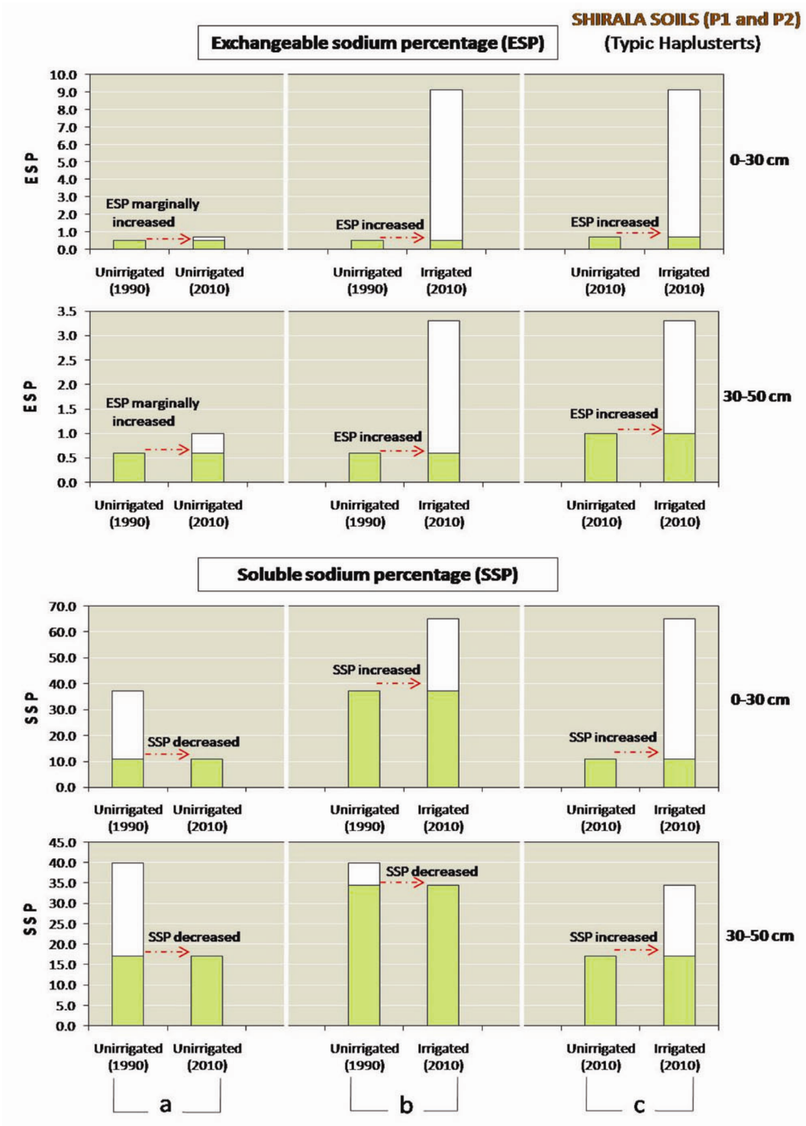

Figure 4. Changes in the chemical properties of soils in Amravati tehsil over the last 20 years (a) comparison in unirrigated soils (2010), (b) comparison in unirrigated (1990) and irrigated soils (2010) and (c) comparison in unirrigated and irrigated soils (2010) (During 1990 we did not find any reference of irrigation in this area and therefore irrigated black soils during 1990 and those during 2010 could not be compared.)

Influence of manure in dissolving carbonates and bringing calcium into the exchange complex to improve physical and chemical condition of soil is known. This along with the change in cropping pattern, viz. introducing legume (soybean, pigeon pea and gram) may have helped in maintaining the soil quality for the last two decades[42]. This good effect, however, was overshadowed wherever farmer used irrigation water. Thus, in spite of the effect of change in cropping system, irrigation resulted in significant decrease in sHC from 0.65 to 0.17 cm h^{-1} and from 0.67 to 0.22 cm h^{-1} in both the surface (0–30 cm) and subsurface (30–50 cm) layers. Additionally, a significant increase in BD was observed from 1.5 Mg m^{-3} to 1.7 Mg m^{-3} in the surface layer (Table 7).

Composition of the saturation extract of shrink-swell soils

The data on the composition of saturation extract of the soils are presented in Table 8. ECe of the irrigated soils increased compared to the unirrigated soils in view of the trend of electrical conductivity in irrigation water (ECiw). Bicarbonates, chlorides and sulphates were the dominant anions in the Shirala and Darapur soils (Amravati and Daryapur tehsils) (Table 8) with much higher concentration than the unirrigated soils. Wathoda soils (Bhatkuli tehsil) under irrigation had very high values of chlorides and sulphates (12.9 and 11.8 $mmol_c l^{-1}$) compared to unirrigated soils (1.2 and 0.8 $mmol_c l^{-1}$). Temburkheda soils under irrigation show more HCO_3^{-1} ion

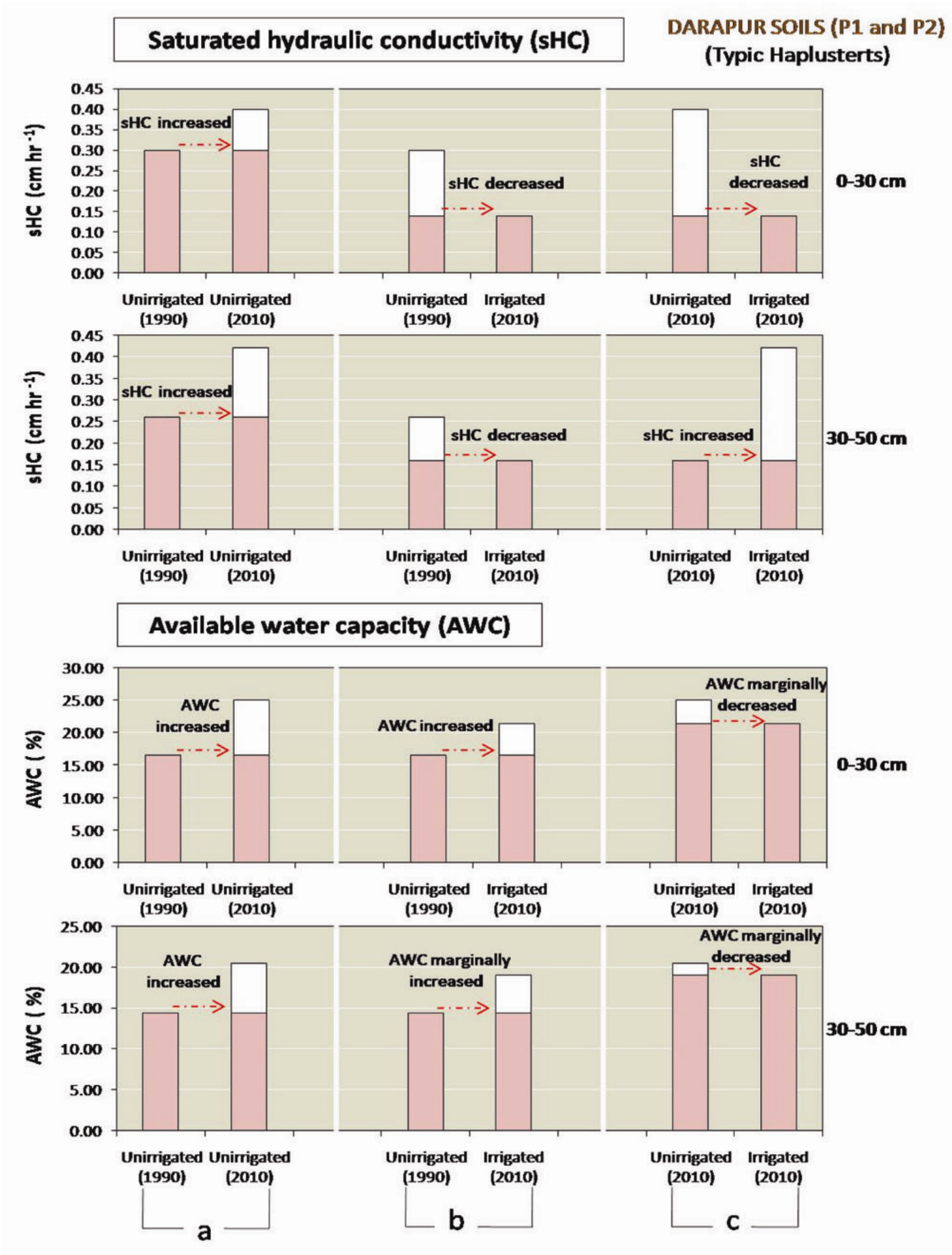

Figure 5. Changes in the physical properties of soils in Daryapur tehsil over the last 20 years (a) comparison in unirrigated soils, (b) comparison in unirrigated (1990) and irrigated soils (2010) and (c) comparison in unirrigated and irrigated soils (2010). (During 1990 we did not find any reference of irrigation in this area and therefore irrigated black soils during 1990 and those during 2010 could not be compared.)

concentration in the surface layers than the unirrigated soils (Table 7). Among the soluble cations, sodium shows dominance in the soils of Amravati and Daryapur tehsils in all the layers and were too high when compared with the unirrigated soils. Wathoda soils under irrigated condition show increase in values of soluble sodium and magnesium over the soils in unirrigated condition. Warud soils remained almost unaffected with only little increase of sodium in surface, may be due to good drainage conditions. Soluble Ca/Mg ratio decreased in all the irrigated soils when compared to the unirrigated soils.

Sodium adsorption ratio (SAR) of Shirala and Wathoda irrigated soils increased in the surface layers (6.1 and 6.6). The SAR of Darapur irrigated soils increased throughout the soil profile which was very high compared to the unirrigated soils. Temburkheda soils experienced

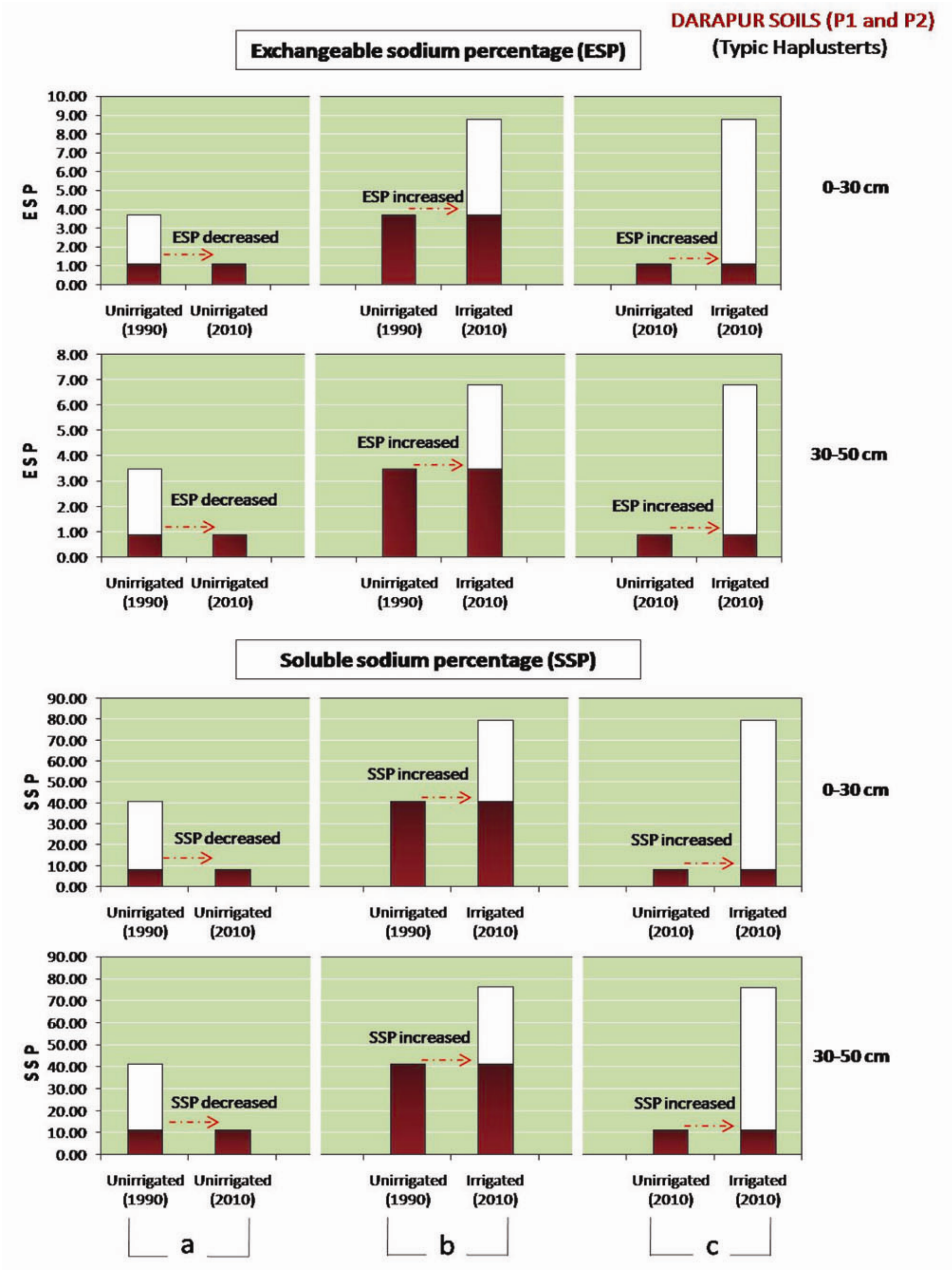

Figure 6. Changes in the chemical properties of soils in Daryapur tehsil over the last 20 years (a) comparison in unirrigated soils, (b) comparison in unirrigated (1990) and irrigated soils (2010) and (c) comparison in unirrigated and irrigated soils (2010) (During 1990 we did not find any reference of irrigation in this areaand therefore irrigated black soils during 1990 and those during 2010 could not be compared.)

rise in SAR values in the first 100 cm depth. Soluble sodium percentage (SSP) increased in all the irrigated soils rendering these soils sodic. In spite of using poor quality irrigation water, the sHC of Warud irrigated soils was higher (4.5–9.8 mm h^{-1}) than other soils in the district, which may be due to the presence of Ca-zeolite favouring building up of lower ESP, SAR, SSP and Na^+ concentration (Table 9).

Conclusions

The quality of soils in the Amravati district of Maharashtra has deteriorated, as indicated by impaired soil drainage, following irrigated agriculture. An exception to this situation is the irrigated soils at Warud tehsil where the drainage did not deteriorate due to the presence of Ca-zeolite. Although for the last several years farmers are

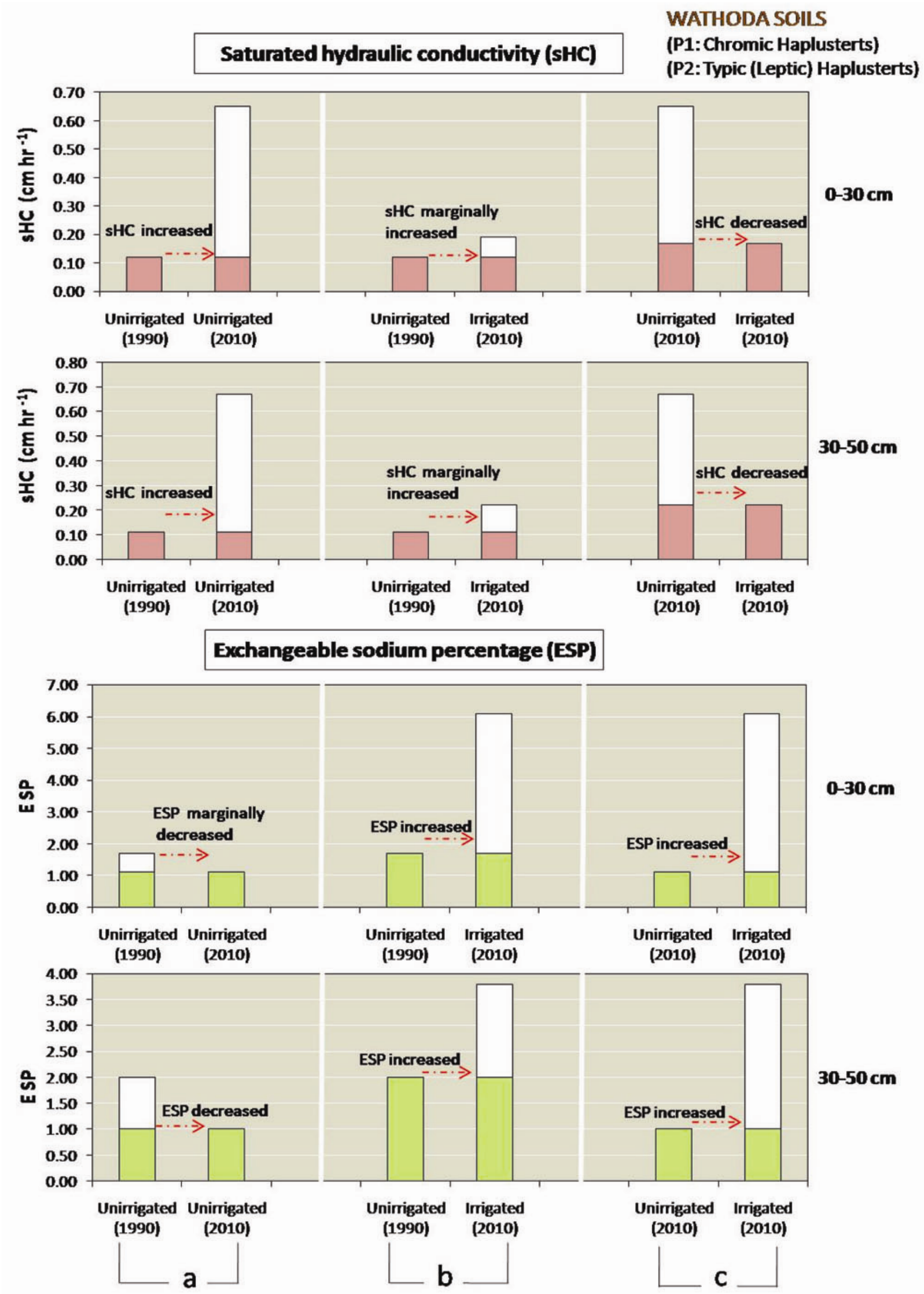

Figure 7. Changes in the properties of soils in Bhatkuli tehsil over the last 20 years (a) comparison in unirrigated soils, (b) comparison in unirrigated (1990) and irrigated soils (2010) and (c) comparison in unirrigated and irrigated soils (2010) (During 1990 we did not find any reference of irrigation in this area and therefore irrigated black soils during 1990 and those during 2010 could not be compared.)

using various irrigation water as protective for raising *kharif* and *rabi* crops in the highly clayey and smectitic soils, such anthropogenic activities have rendered these soils unsuitable for future agriculture. The present study demonstrates that similar soils under unirrigated conditions do not suffer from any serious degradation and thus

Table 9. Overall scenario of soil parameters and irrigation quality in Amravati district, Maharashtra

	Irrigated					Unirrigated				
Depth (cm)	pH	EC	sHC	ESP	EMP	pH	EC	sHC	ESP	EMP
Shirala										
0–30	8.4	0.28	0.08	9.1	22.3	8.2	0.15	0.71	0.7	35.9
30–50	8.2	0.24	0.22	3.3	14.8	8.3	0.17	0.48	1.0	24.2
50–100	8.1	0.21	0.26	2.2	19.3	8.3	0.16	0.41	1.0	10.3
Irrigated water										
C3S2 (poor)				Na	Mg					
pH, 8.4; EC-1.8; SAR, 11.8; RSC, 10.1				14.0	2.5					
Darapur										
0–30	8.7	0.27	0.14	8.8	4.0	8.0	0.21	0.40	1.1	1.1
30–50	8.6	0.26	0.16	6.8	2.6	8.1	0.26	0.42	0.9	1.0
50–100	8.4	0.36	0.19	8.7	1.7	8.2	0.36	0.46	0.9	1.4
Irrigated water										
C3S1 (bad)				Na	Mg					
pH, 8.5; EC-1.6; SAR, 9.0; RSC, 7.3				11.5	2.4					
Wathoda										
0–30	7.9	0.66	0.17	6.1	2.4	7.9	0.16	0.65	1.1	1.7
30–50	7.9	0.44	0.22	3.8	1.6	8.1	0.16	0.67	1.0	1.2
50–100	7.9	0.53	0.26	1.7	2.1	8.2	0.17	0.93	1.2	1.5
Irrigated water										
C4S1 (very bad)				Na	Mg					
pH, 8.3; EC-3.0; SAR, 7.8; RSC, –0.2				19.0	11.2					
Temburkheda										
0–30	8.3	0.19	0.98	2.8	35.5	8.3	0.17	1.63	1.5	27.0
30–50	8.3	0.18	0.71	2.9	27.1	8.3	0.18	0.72	1.2	32.5
50–100	8.5	0.18	0.47	3.6	28.6	8.4	0.18	0.78	4.5	32.1
Irrigated water										
C3S1 (average)				Na	Mg					
pH, 7.9; EC, 0.9; SAR, 2.2; RSC, 1.4				3.5	3.5					

provide a clue as to how these soils need to be put under rain-fed agriculture under improved management practices. Also, it would be prudent to monitor and assess the quality of irrigation water vis-à-vis soil quality regularly to maintain the quality of this precious natural resource.

1. Glanz, J. T., *Saving Our Soil: Solutions for Sustaining Earth's Vital Resource*, Johnson Books, Boulder, CO, 1995.
2. Lal, R., Soil carbon sequestration in India. *Climate Change*, 2004, **65**, 277–296.
3. Larson, W. E. and Pierce, F. J., Conservation and enhancement of soil quality. In *Evaluation for Sustainable Land Management in the Developing World* (ed. Dumanski, J.), Proceedings of the International Workshop, Chiang Rai, Thailand, 15–21 September 1991. Technical papers, vol. 2. Int. Board for Soil Research and Management, Bangkok, Thailand, 1991, pp. 175–203.
4. Sharma, K. L. and Biswapati Mandal, Soil quality and its relevance for sustainable agriculture. *J. Indian Soc. Soil Sci.*, 2009, **57**, 572–586.
5. Larson, W. E. and Pierce, F. J., The dynamics of soil quality as a measure of sustainable management. In *Defining Soil Quality for a Sustainable Environment* (ed. Doran, J. W. *et al.*), Soil Science Society America and America Society of Agronomy, Madison, WI, 1994, vol. 35, pp. 37–51.
6. Dudal, R., Dark clay soils of tropical and subtropical regions, FAO Agricultural Development, Paper No. 83, FAO, Rome, 1965.
7. Murthy, R. S., Hirekerur, L. R., Deshpande, S. B. and Venkat Rao, B. V., *Benchmark Soils of India*, National Bureau of Soil Survey and Land Use Planning (ICAR), Nagpur, India, 1982, p. 308.
8. Bhattacharyya, T., Sarkar, D. and Pal, D. K. (eds), *Soil Survey Manual, NBSS & LUP Publication No. 146*, NBSS&LUP, Nagpur, 2009, p. 400.
9. Mandal, D. K., Mandal, C. and Velayutham, M., Development of a land quality index for sorghum in Indian semi-arid tropics (SAT). *Agric. Syst.*, 2001, **70**, 335–350.
10. Sharma, K. L. *et al.*, Evaluation of long-term soil management practices through key indicators and soil quality indices using principal component analysis and linear scoring method in rainfed Alfisols. *Aust. J. Soil Res.*, 2008, **46**, 368–377.
11. Kundu, S. *et al.*, Assessing soil health of Vertisol of AESR 10.1 using selected physical, chemical and biological attributes of soils. *J. Indian Soc. Soil Sci.*, 2012, **60**, 281–287.
12. Ray, S. K. *et al.*, Soil and land quality of the Indo-Gangetic Plains of India. *Curr. Sci.*, 2014, **107**, 1470–1486.
13. Adyalkar, P. G., Paleogeography, nature and pattern of sedimentation and ground water potentiality of the Purna basin of Maharashtra. *Proc. Nat. Sci.*, 1963, **29**, 25–44.
14. Tanpure, V. D., A study of salinity in well waters of saline Tract of Vidarbha, M Sc thesis (unpubl.) Dr. PDKV, Akola, 1971.

15. Puranik, R. B., Barde, N. K. and Ballal, D. K., Studies on some saline-alkali soils of Akola district, Maharashtra state. *Panjabrao Krishi Vidyapith Res. J.*, 1972, **1**, 51–58.
16. Balpande, S. S., Deshpande, S. B. and Pal, D. K., Factors and processes of soil degradation in Vertisols of the Purna Valley, Maharashtra, India. *Land Degrad. Rehabilitat.*, 1996, **7**, 313–324.
17. Magar, A. S., An appraisal of the nature of salinity and sodicity in black soils of the Purna Valley, M Sc thesis (unpubl.), Dr PDKV, Akola, 1990.
18. Nimkar, A. M., Deshpande, S. B. and Babrekar, P. G., Evaluation of salinity problem in swell-shrink soils of a part of the Purna Valley, Maharashtra. *Agropedology*, 1992, **2**, 59–65.
19. Kadu, P. R., Pal, D. K. and Deshpande, S. B., Effect of low exchangeable sodium on hydraulic conductivity and drainage in shrink-swell soils of Purna Valley, Maharashtra. *Clay Res.*, 1993, **12**, 65–70.
20. Van Wambeke, A., Calculated soil moisture and temperature regimes of Asia, SMSS Technical Monograph No. 9, Cornell Univ., Ithaka, New York, 1985.
21. Soil Survey Staff, *Keys to Soil Taxonomy* (Twelfth edition), United States Dept. of Agriculture, Natural Resource Conservation Service, Washington, DC, 2014.
22. Soil Survey Staff, *Soil Taxonomy: A Basic System of Soil Classification for Making and Interpreting Soil Survey*, USDA Handbook 436, US Government Printing Office, Washington, DC, 1998.
23. Pal, D. K., Genesis of sodic black soils (Vertisols). In International Conference on Sustainable Management of sodic lands, Lucknow, India, 2004, pp. 12–15.
24. Kadu, P. R., Physical and chemical properties affecting hydraulic conductivity of black soils of Purna valley, M Sc thesis (unpubl.) Dr PDKV, Akola, 1991.
25. Balpande, S. S., Characteristics, genesis and degradation of Vertisols of Purna Valley, Maharashtra. Ph D thesis (unpubl.), Dr PDKV, Akola, 1993.
26. Nimkar, A. M., Evaluation of physical and chemical characteristics of soils of the Purna Valley of Maharashtra, M Sc thesis (unpubl.), Dr PDKV, Akola, 1990.
27. Richards, L. A. (ed.), *Diagnosis and Improvement of Saline and Alkali Soils*, USDA Agriculture Handbook No. 60, US Government Printing Office, Washington, DC, 1954.
28. Elangovan, D., Reappraisal hydrological studies in parts of the Purna Alluvial Valley, Akola district, Maharashtra, Central Groundwater Board, Nagpur, 1985.
29. Muthuraman, K., Tiwari, M. P. and Mukhopadhyay, P. K., Salinity in the groundwater of the Purna basin – its genesis. *Geol. Soc. India J.*, 1992, **39**, 50–60.
30. Bhattacharyya, T., Pal, D. K. and Deshpande, S. B., Genesis and transformation of minerals in the formation of red (Alfisols) and black (Inceptisols and Vertisols) soils on Deccan basalt. *J. Soil Sci.*, 1993, **44**, 159–171.
31. Pal, D. K., Balpande, S. S. and Srivastava, P., Polygenetic Vertisols of the Purna Valley of central India. *Catena*, 2001, **43**, 231–249.
32. Pal, D. K., Bhattacharyya, T., Ray, S. K., Chandran, P., Srivastava, P., Durge, S. L. and Bhuse, S. R., Significance of soil modifiers (Ca-zeolites and gypsum) in naturally degraded Vertisols of Peninsular India in refining the sodic soils. *Geoderma*, 2006, **136**, 210–228.
33. Piper, C. S., *Soil and Plant Analysis*, University of Adelaide, Adelaide, 1950.
34. Jackson, M. L., *Soil Chemical Analysis*, Prentice-Hall Inc., Eaglewood Cliffs, New Jersey, 1958.
35. Klute, A., Water retention, laboratory methods. In *Methods of Soil Analysis Part 1* (ed. Clute, A.), 2nd edn, *Agron, Monograph 9*, Madison, Wisconsin, 1986, pp. 635–662.
36. Jackson, M. L., *Soil Chemical Analysis – Advanced Course*, University of Wisconsin, Madison, WI, 1979, 2nd edn.
37. Kanwar, J. S., Quality of irrigation water as an index of suitability for irrigation purposes. *Potash Rev.*, 1961, **18**, 1–13.
38. Eaton, E. M., Significance of carbonate in irrigation water. *Soil Sci.*, 1950, **69**, 123–133.
39. Wilcox, L. V., Determining the quality of irrigation water, US Dept. Agric. Information Bulletin, 1958, pp. 194.
40. Bhattacharyya, T., Pal, D. K. and Srivastava, P., Role of zeolites in persistence of high altitude ferruginous Alfisols of the Western Ghats, India. *Geoderma*, 1999, **90**, 263–276.
41. Padekar, D. G., Soil quality as influenced by landuse management with special reference to irrigation in selected tehsils of Amravati district, Maharashtra, Ph D thesis (unpublished), Dr PDKV, Akola, 2014.
42. Bhattacharyya, T., Chandran, P., Ray, S. K., Pal, D. K., Venugopalan, M. V., Mandal, C. and Wani, S. P., Changes in levels of carbon in soils over years of two important food production zones of India. *Curr. Sci.*, 2007, **93**, 1854–1863.
43. FAO, Water Quality for Agriculture. In *FAO Irrigation and Drainage* (eds Ayers, R. S. and Westcot, D. W.), Paper No. 29, Rev. 1, FAO, Rome, 1994.
44. Vaidya, P. H., Evaluation of shrink-swell soils and groundwater of the Pedhi watershed in Amravati district of land use planning. Ph D thesis (unpubl.), Dr PDKV, Akola, 2001, p. 167.

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