ISSN: 2581-3749 (online) Advanced Agricultural Research & Technology Journal ▪ Vol. IV ▪ Issue 1 ▪ JANUARY 2020

Bio-shielding Coastal Saline Soils to Combat Climate Change in Coastal Areas: Coastal Region of Western India as a Case Study

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Abstract

Salinity in coastal soils, unlike that in inland soils is caused during the process of their formation under marine influence and subsequently due to periodical influence of saline water either through inundation or capillary rise from shallow underground water or saline water irrigation. Coastal saline soils are having dominant salts of sodium chloride and sodium sulphate with abundance of soluble cations with dominance of Na followed by Mg, Ca and K and chloride as the predominant anion followed by sulphate. The coastal land needs protection against tidal inundation through protective embankment like bio-shield for control of sea ingress, soil erosion and salinity. Monsoonal rainfall intensity has increased during later period of Monsoon in the Western Coastal region. Unsuitable climatic conditions, soil and water degradation, marine influence in the coastal areas and secondary salinization in irrigation command areas minimized the land suitable for arable farming. Technological knowledge generated till date has helped in taming the problem in large tracts of land in different countries to restore their full productive potential. However, new challenges are set to be faced either due to changing climate or land use anomalies, leading to exponential increase in the area under salinity. With the new challenges cropping up, soil salinity related stresses, particularly in coastal area can be more pronounced and more damaging to crop production. The productivity of these soils can be restored by management and reclamation using different available technologies. Providing adequate drainage, leaching out soluble salts below root zone, cultivation of salt-tolerant varieties (halophytic plants), bio-saline agriculture, and plantation of bio-shield including mangroves in coastal area have to be ensured for enhancing the productivity of these soils. For management and enhancing the productivity in coastal black soils of Gujarat, different interventions have been evolved. Coastal ecosystems being rich in a wide variety of natural resources offer large scope to develop alternate and sustainable farming packages.

Corresponding author: rcanil2014@gmail.com
Received Date: 3.9.2019; Accepted Date: 15.12.2019

Keywords: Coastal saline soils, black soils, secondary salinisation, sea ingress, bio-shield, Vertisols.

Introduction

Soil salinity in coastal areas is a common phenomenon. In the wake of climate change bio- shielding can be an acceptable proposition to save coastal ecosystem. The present work details a case study from the Western part of India.

Due to various constraints in soil, climate and other natural resources, the coastal areas of the country pose serious problems from agricultural productivity point of view. Salinity of soil and water is an environmental constraint affecting million hectare of land as well as the livelihood of farming communities. As per the compilation made on the soil resources and their potentials for different Agro-ecological Sub-Region (AESR) in coastal tract of India showed total 10.78 Mha area (Table 1) under this ecosystem (including the islands) which was the first scientific approach for delineation of the coastal ecosystem (Velayutham *et al.* 1999). Salinity in coastal area occurred during the process of their formation under marine influences and subsequent periodical inundation with tidal water and in case of low lands having proximity to the sea, due to high water table with high concentration of salts in it. Coastal saline soils are having dominant salts of sodium chloride and sodium sulphate with abundance of soluble cations with dominance of Na followed by Mg, Ca and K and chloride as the predominant anion followed by sulphate. The major problems of these areas are:

- influence of tidal waves and periodical inundation by tidal water;

- shallow water table enriched with salt contributes to increase in soil salinity during winter and summer months;
- heavy rainfall resulting in excess water during *Kharif* season;
- poor surface and subsurface drainage conditions;
- lack of good quality irrigation water and acute salinity during *Rabi*; and
- poor socio-economic conditions of the farming community limiting introduction of high investment technologies.

Agroclimate in coastal Gujarat

The eight agroclimatic zones identified by the Gujarat Agricultural University have been further sub divided into Agro Ecological Sub-Regions (Table 2). The coastal

Table 1. Extent and distribution of coastal area in India

States/Union territories	Area (km^2)
West Bengal	14,152
Orissa	7,900
Andhra Pradesh	35,500
Tamil Nadu	7,424
Kerala	7,719
Karnataka	7,424
Maharashtra	10,000
Goa	220
Gujarat	17,465
Andaman & Nicobar, Lakshadweep	26
Pondicherry and Karaikal	3
Total	1,07,833

Source: Velayutham *et al*. (1999)

Table 2. Major characteristics of coastal salt affected agro ecological situations of different agro climatic zones

Agro climatic zone	Soil type	Soil Texture	Rainfall (mm)	Principal agricultural Crops	Area ('000 ha)	Irrigation %
South Gujarat heavy rainfall	Salt affected	Clay to clay loam	1200-1500	Paddy, Sugarcane, horticultural crops	21	52
South Gujarat	Black cotton, salt affected	Clay to clay loam	900-1000	Paddy, Cotton, Sorghum, pulses	14	56
Middle Gujarat	Medium black, salt affected	Clay loam to silt loam	500-700	Paddy, Pearl millet, Cotton, Castor, Tobacco, Banana	26	78
North Saurashtra	Saline Sodic	Clay	500-600	Groundnut, Sorghum, Pearl millet, Wheat	187	22
	Coastal alluvial	Clay loam to clayey	300-400	Groundnut, Sorghum, Pearl millet	181	9
	Coastal alluvial	Silty clay	500-700	Groundnut, Sorghum, Pearl millet, Chick pea	299	22
	shallow black/ Coastal alluvial	Sandy loam to clay loam	300-400	Groundnut, Sorghum, Pearl millet, Sesamum	31	4
South Saurashtra	Low lying saline sodic with saline ground water	Clay	700-750	Cotton, Sorghum	50	10
	Mixed red and black and salt affected	Sandy clay loam to clay loam	750-1000	Groundnut, Sugarcane, Banana, Coconut, other horticultural crops	96	15
	Coastal alluvial	Sandy loam to silty clay loam	750-1000	Groundnut, Sesamum, Sorghum, Pearl millet, horticultural crops	286	18
Kutch	Hydro-morphic salt affected	Clay loam to silt loam	400-500	Cotton, Pulses, Sorghum, Cluster bean, Fruit crops	49	8
	Highly salt affected	Clay loam to silt loam	350-400	Cotton, Castor	--	--
Bhal	Sodic	Sandy loam to clay	550-650	Cotton, Sorghum, Wheat, Cumin, Dill seed	160	7

Source: NARP Status Report, GAU

agro-climatic zones which are salt affected and their major characteristics are detailed below.

Rainfall analysis

Analysis of rainfall data for 36 years (1975–2011) and minimum and maximum temperature data for 18 years (1994-2012), collected from agro-meteorological station at Navsari Agricultural University, Tancha farm (near Samni) in Bharuch district Gujarat indicated that average annual rainfall during 1975-2011 was 753 mm compared to 895 mm for the period 2000-2011(Table 3). The average annual rainfall during the period 2000-2011 increased by 19 per cent over long term average (1975-2011). There was a notable shifting in monthly rainfall during the monsoon period. Rainfall in the month of June to August during 2000-2011 increased by 11 to 40 per cent while no change was observed in the month of September (Chinchmalatpure 2013). It is also observed that the intensity of rainfall was more during later period of monsoon for 2000-2011 as compared to 1975-2011. The water balance and length of growing period depends on the amount of rainfall and potential evapo-transpiration. Available water capacity and water holding capacity of soils play important role in determining the length of growing period. It is more affected in salt affected soils as the available water capacity is governed by the osmotic potential of these soils.

Soil Salinity

The salinity build-up in the coastal soils is mainly due to salinity ingress of ground water aquifers primarily owing to presence of high saline ground water table, excessive withdrawal of ground water from the coastal aquifers, sea water ingress, tidal water ingress, relatively less recharge of ground water, and poor land and water management (Burman *et al.* 2015, Bandyopadhyaya *et al.* 2011). Soil salinity of coastal area is having same nature as that of inland soils except for different salt compositions in the soils solution and specific toxicity of individual ions and their interacting effects observed in case of the former.

Table 3. Changes in average annual and monthly rainfall in Bharuch district

Period	Avg. rainfall for 1975-2011 (mm)	Avg. rainfall for 2000-2011 (mm)	Deviation percent
June	159	177	+11.32
July	232	293	+26.29
August	206	288	+39.80
September	120	120	0
Total	753	895	+18.85

Saline Soils

The electrical conductivity of the soil saturation extract was > 4 dS m^{-1}, the exchangeable sodium percentage <15 and the pH is < 8.5. Salts are composed of cations in order of dominance as sodium, magnesium and calcium and anions as chloride, sulphate, carbonates and bicarbonates. Specific ion toxicities and elevated osmotic stresses cause adverse effect on plant growth due to poor uptake of water and nutrients. With adequate drainage, the excessive salts present in these soils may be removed by leaching, thus bringing them to normalcy. Saline soils are often recognized by the presence of white crusts of salts on the surface. Owing to the presence of excess salts and the absence of significant amounts of exchangeable sodium, saline soils generally are flocculated and as a consequence, the permeability is equal to or higher than that of similar non-saline soils. The soils in *Bhal* region of coastal Gujarat are slight to moderately alkaline in nature (pH 7.5 to 8.2) and salinity of soils ranged from 1 to 132 dS m^{-1} (Nayak *et al.* 2000). The highest value of ECe is 132 dS m^{-1} observed in the area of Western Coast due to frequent tidal inundation, which leaves behind the salt with soil materials, hence concentration of soluble salts are more. In general, the salt content is decreasing with depth in coastal soils. The textural composition of soils, variation in depth and quality of ground water and proximity to the sea coast may be attributed to variation in the soil salinity in soils of coastal region.

Sodic Soils

Sodic soils have their exchangeable sodium percentage (ESP) > 15 which interfere with the growth of most plant, the electrical conductivity of soil saturation extract < 4 dS m^{-1} and the pH ranges between 8.5 and 10. The physical and chemical properties of these soils are greatly influenced by the exchangeable sodium content. As the ESP tends to increase, the soils have a propensity to become more dispersed. The soil colloids are usually in a deflocculating state. The dispersive effect of exchangeable sodium will be observed, however only if the electrolyte concentration in the soil solution is less than that required for flocculating the clay particles. Concentration of magnesium as compared to calcium is some times observed in some salt affected soil solution and due to which these soils behave differently in terms of physical and chemical properties primarily in respect of moisture and solute transport, aeration and thermal flux, thereby adversely affecting the plant growth. When soil pH in these soils exceeds 8.5, availability of some nutrients may be restricted resulting in nutrient disparity. Bicarbonate toxicities occur due to reduced iron and other micronutrient availability at high pH while sodium may lead to calcium and magnesium deficiencies (Arshad 2008).

Coastal salt affected soils of the Gujarat State

In South Gujarat deep black and coastal alluvial soils are predominant, medium black soils and calcareous medium black soil, respectively occur in Middle Gujarat and the Saurashtra peninsula and *Bhal* region has shallow to medium deep clayey soils and are extremely saline. Gujarat state is endowed with great diversity of ecosystems ranging from deserts, scrublands, grasslands, deciduous forests, wetlands, mangroves, coral reefs, estuaries and gulfs. About 33.5% of the State's geographical area is already subjected to varying degrees of soil erosion. The main causative factors for this are high intensity rainfall over short duration and in some places hilly terrains. Salinity ingress, sub-surface intrusion of sea water in regions of high ground water discharge affects about 13524 km^2 area. Over-extraction of ground water for highly intensive cropping practices also resulted in soil salinity. The heavy industrialization along the **"**Golden Corridor" i.e., Vapi to Mehsana belt and the concomitant release of effluents also affected the natural resources particularly, ground water, flora and fauna. A study conducted by ICAR-CSSRI, RRS, Bharuch (CSSRI 2016) in which out of 40 surveyed villages along the Amla Khadi, a tributary of the Narmada River, 31 are affected by heavy metal contamination. Across an area of 590.68 km^2, 22, 24, 15, 18 and 11 numbers of villages were affected by cadmium, cobalt, chromium, nickel and manganese respectively. Significant level of contamination of groundwater with Cd (0-1.81 ppm), Co (0-0.12 ppm), Cr (0-0.23 ppm), Mn (0-0.88 ppm), Ni (0.03-0.35 ppm), Zn (0.01-2.92 ppm) and Cu (0-0.25 ppm) was observed with values more than threshold level (ppm) of 0.01 (Cd), 0.05 (Co), 0.10 (Cr), 0.20 (Ni), 2.0 (Zn) and 0.2 (Cu). It is observed in the cluster analysis for grouping the villages based on severity of heavy metal contamination that villages concentrated within 2 km range in Amla Khadi were severely affected, village situated 5 km away were moderately affected and villages around 7 km away were not affected by heavy metals.

The coastal salt affected soils in Valsad and Surat districts are medium to heavy in texture and greyish to dark brown in colour. Their permeability is low to very low. The pH tends to increase with the depth and alkaline at all the depths. While at some pockets the salt accumulation occurs at the surface and at some other locations it tends to increase with depth. The sodicity (ESP) does not show any regular trend with depth. In Bharuch district, the coastal soils are clayey in texture throughout the depth. The pH ranges from 8.6 to 9.5 and the ECe from 0.22 to 8.1 dS m^{-1}. The latter tends to increase with depth. The ESP varies from about 5 to about 53, which increases with depth. The Bara tract area (covering 3 talukas *viz.* Vagra, Jambusar and Amod of Bharuch district of coastal Gujarat lying between 21°40' to 22°13' N latitude and 72°32' to 72°55' E longitude) are dominated by Vertisols and associated soils which are deep to very deep, fine textured and clay per cent ranging from 45-70 and having smectite as the dominant clay mineral. High shrink-swell potential is exhibited with development of 4-6 cm wide and 100 cm deep cracks. The water holding capacity is high but permeability is slow to very slow and drainability is imperfect to poor. The organic carbon content is 0.4 to 0.6 per cent with low to medium in available phosphorus and high to very high content of available potassium. Soils of Bara tract have significant concentration of soluble salts in sub-soils, although the concentration in surface layer is low (Table 4). The soils of Bara tract are subjected to varying degrees of salinization. The salinity of surface soils varies from 0.46 dS m^{-1} to 21 dS m^{-1} with a mean of 3.19 dS m^{-1} (SD = 3.56). In Bara tract, it was observed that only 40 per cent of surface soils are free from salinity (<2 dS m^{-1}), 49 per cent soils are saline (2-4 dS m^{-1}) and only 11 per cent soils are having salinity greater than 4.0 dS m^{-1} (Figure 1). In the sub-surface10 per cent have salinity less than 2 dS m^{-1}, 15 per cent between 2-4 dS m^{-1} and 75 per cent greater than 4 dS m^{-1} (Figure 2) (Chinchmalatpure *et al.* 2010). Salinity in Vertisols may be inherited from the parent materials or may be caused by over-irrigation. In coastal regions, Vertisols with high soluble (chloride) salts and/or with low sulphates are observed. The sub-soil salts are very difficult to leach down further because of very low saturated hydraulic conductivity and presence of high saline groundwater table condition in Bhal area, but it is possible to flush salts that have precipitated on the wall of cracks. In soils of low salinity, it was suggested to adopt appropriate irrigation strategies to restrict the upward movement of sub-surface salts (Chinchmalatpure *et al.* 2008).

In middle Gujarat coastal area (Gulf of Cambay), the soils are silty loam at the surface and are clay loam to clay at the sub surface. The ECe varies from 9 to 118 dS

Table 4. Physico-chemical characteristics of typical soil profile (Typic Haplusterts) of the Bara tract (Village Samni, Taluka Amod District Bharuch).

Horizon	Depth (m)	ECe (dSm^{-1})	pH	$CaCO_3$ (%)	OC (gkg^{-1})	Sand (%)	Silt (%)	Clay (%)	ESP	CEC cmol kg^{-1}
Ap	0.00-0.20	2.8	8.2	5.7	5.5	17.8	30.4	51.8	9.8	44.3
Bw1	0.20-0.44	2.7	8.0	5.7	3.7	22.0	25.8	52.2	10.5	45.4
Bw2	0.44-0.73	10.9	7.5	6.4	2.5	14.2	26.9	58.9	11.3	49.9
Bss	0.73-0.96	10.9	7.5	6.3	1.4	11.4	27.2	61.4	10.4	50.1
BC	0.96-1.25	10.5	7.7	6.4	2.3	21.8	26.8	51.4	5.7	44.4
C	1.25-1.50	11.4	7.7	17.7	0.1	37.2	18.0	44.8	4.7	36.2

Source: Chinchmalatpure *et al*. 2008.

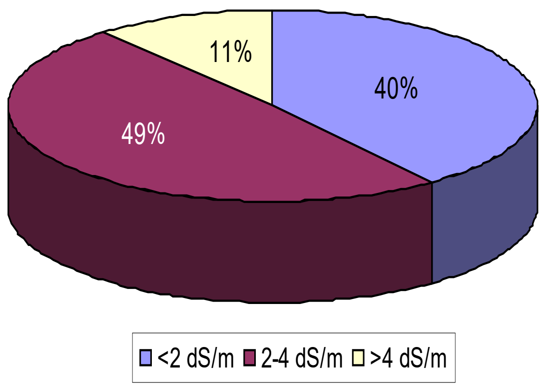

Fig. 1. Per cent area of surface soils of Bara tract affected by soil salinity.

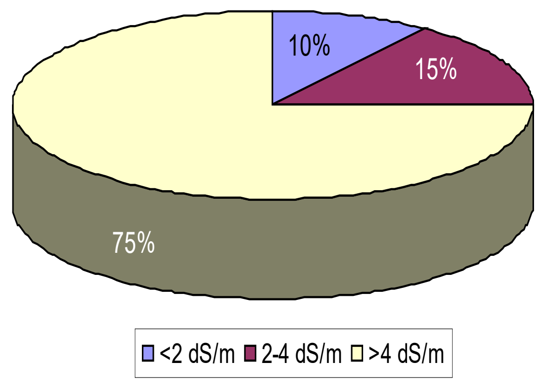

Fig. 2. Per cent area of Sub-surface soils of Bara tract affected by soil salinity.

m^{-1} and ESP from 10-81. The pH and ESP tend to increase with depth. But the salt accumulation shows a reverse trend indicating its accumulation at the surface through capillary rise. They are moderately calcareous and the saturated hydraulic conductivity ranges from 0.09 to 1.28 cm h^{-1}. The coastal salt affected soils of Saurashtra region clayey in texture with high amount of lime content. The pH ranges from 7.7 to 9.0 without much variation with the depth. The ECe also varies widely from 2 to as high as 20 dS m^{-1} with a tendency of reduction in salinity with depth. The ESP values are also generally high and values of around 50 is not uncommon. But there is no regular trend with depth at different locations. Soils of *Bhal* area due to their physiography differ widely in their salinity/ sodicity problems. The salinity variations are observed from 0.79 to as high as 282.5 dS m^{-1}, the ESP variations are from 11.3 to 30.0. Basically, these are clay to clay loam in texture and calcareous in nature with very poor permeability. In the Rann of Kutch, the surface layer of these soils is blocky with clay or silty clay in texture but becomes lighter with depth. The pH ranges from 7.8 to 8.4 and the salt does not show any regular pattern with depth.

Enhancement of productivity

Unsuitable climatic conditions, soil and water degradation, marine influence in the coastal areas and secondary salinization in irrigation command areas minimized the land suitable for arable farming. Technological knowledge generated till date has helped in taming the problem in large tracts of land in different countries to restore their full productive potential. However, new challenges are set to be faced either due to changing climate or land use anomalies, leading to exponential increase in the area under salinity. With new challenges cropping up, soil salinity related stresses, particularly in coastal area can be more pronounced and more damaging to crop production. It is well established that plant growth can be restricted or entirely prevented by increased levels of salinity and sodicity in the soil. The productivity of these soils can be restored by management and reclamation using different technologies available with the ICAR-Central Soil Salinity Research Institute. The processes of accumulation of salts and build-up of ESP have to be reversed. To achieve this, provision of adequate drainage, replacement of Na^+ ions from the exchange complexes, leaching out of soluble salts below root zone, cultivation of salt tolerant varieties/ halophytic plants, bio-saline agriculture, plantation of bio-shield including mangroves in coastal area need to be ensured for enhancing the productivity of these soils. Using the several technological options available for reclamation of salt affected soils, India has reclaimed about 2.08 million ha salt affected land and the reclaimed area contributes 14-15 million tonnes of food grains to the National pool (Tripathi 2011). For management and enhancing the productivity in coastal black soils of Gujarat, the different interventions are evolved.

Management of secondary salinization in black soils of coastal region

Farmers of the Bara tract are practising irrigated agriculture using canal water and/or saline tube well water. The soils of Bara tract have significant concentration of soluble salts in the sub-soil, though the concentration is low in surface layer. Salt accumulation was observed in surface layer when saline tube well water was used for irrigation to cotton crop on saline Vertisols. The development of secondary salinization was observed in the soil profiles irrigated with saline ground water but at the same time when soils irrigated with fresh canal water, showed reduction in soil salinity. Although yield of crops grown in the study area showed improvement due to availability of good quality water from canal but excess and un-judicious use of canal water for irrigation leads to increase ESP of soils and formation of sub-soil sodicity in the lower horizon which indicated the initiation of pedogenic process *i.e.* sodification. The different properties of soils under rainfed as well as irrigated condition are given in Table 5. Bulk density of soils under canal irrigation (1.6 Mg m^{-3}) is higher than those of soils under tube well irrigation/ rainfed condition (1.4 Mg m^{-3}) (Chinchmalatpure *et al.* 2015). The hydraulic conductivity is drastically reduced in soils under canal irrigation. Therefore farmers of the Bara tract area are advised for judicious use of canal

Table 5. Variation in properties of *rainfed* cultivated, tube well water irrigated and canal irrigated soils in Vagra Taluka of Bharuch district, Gujarat

Soil properties		Tube well irrigated (n=25)	Rainfed cultivated (n=15)	Canal irrigated (n=25)
Clay content (%)	Range	55.0-72.0	54.0-72.0	52.0-73.0
	Mean	58.0	59.0	56.0
	SD	0.56	0.45	0.59
CEC, cmol(p^+) kg^{-1}	Range	36.4- 64.9	33.0-56.8	37.3-51.2
	Mean	45.2	42.0	46.0
	SD	0.40	0.52	0.58
Organic carbon (%)	Range	0.24- 0.48	0.12-0.51	0.24-0.43
	Mean	0.28	0.26	0.28
	SD	0.10	0.12	0.07
pH_2	Range	8.0-9.2	7.9-9.0	7.9-9.2
	Mean	8.2	8.4	8.6
	SD	0.42	0.39	0.40
EC_e, dSm	Range	0.6-3.3	0.52-1.76	0.26-1.72
	Mean	1.98	0.86	0.80
	SD	1.02	0.45	0.35
ESP	Range	1.5-10.3	2.2-13.9	2.27-18.50
	Mean	4.62	4.56	5.12
	SD	4.01	3.88	4.21
Bulk density (Mg m^{-3})	Range	1.3-1.5	1.34-1.45	1.4-1.8
	Mean	1.40	1.40	1.60
	SD	0.04	0.04	0.06

water. To avoid further sodification due to canal water irrigation on these saline Vertisols, suitable water and crop management practices like conjunctive use of saline water with canal water, cultivation of low water requiring crops, use of pressurised irrigation system are to be adopted. These saline Vertisols are potentially sodic if irrigation water of low salt concentration is applied because of clay dispersion. Hence at given ESP, the decrease in electrolyte concentration increases the soil dispersion, but at the highest level of electrolyte concentration, the soil disperses slightly regardless of the magnitude of ESP.

Management of waterlogged saline black soils

Subsurface drainage (SSD) is an effective technology for amelioration of waterlogged saline irrigated lands in India. The technology has been widely adopted and replicated in Haryana, Rajasthan, Gujarat, Punjab, Andhra Pradesh, Maharashtra and Karnataka and also most about 66,084 ha waterlogged saline soils have been reclaimed. Due to notable increase in crop yields, the technology results in 3-fold increase in farmers' income. The technology also generates around 128 man-days additional employment per ha per annum and also enhanced the crop intensity by 40-50 %, significant enhancement in crop yields (up to 45 % in paddy, 111 % in wheat, 215 % in cotton and 138 % in sugarcane) in different parts of the country, and farm income by 200-300 % leading to benefit cost ratio of 1.5 (Kamra and Sharma 2015, Chinchmalatpure *et al.* 2016, Thimmappa *et al.* 2015, Gupta 2013, Kaledhonkar *et al.* 2009). More than 1 million ha salt affected soils each in coastal and Vertisols regions of India have specific moisture stress and salinity problems. Technology such as SSD is beneficial in these regions for taking up preventive and curative management with gravity outlet and facility to discharge drain water. The performance evaluation study at heavy textured black soils at Mulad (Gujarat) indicated that soil salinity after SSD at different depths in 17 fields ranged between 0.47-3.9 dS m^{-1} which was quite below the permissible limit of 4.0 dS m^{-1} and initial salinity levels of 1.2-7.3 dS m^{-1} before installation of SSD (Chinchmalatpure *et al.* 2016). The reduction in the salinity of surface (0-30 cm) layer, part of effective root zone of crops, was much higher than in the deeper soil layers reflecting effective salt leaching from soil profile in all survey fields. The salinity of drainage water varied from 1.3 to 4.4 dS m^{-1} which is expected to reduce further with time to levels (< 2.0 dS m^{-1}) to make it utilizable for irrigation. The lowering of values of soil properties like ECe, SAR, pH and ESP of different soil layers in different blocks after introduction of SSD indicate the positive impact of the SSD on soil properties. It is observed that average sugarcane yield increased significantly from 40.2 t ha^{-1} before SSD to 95.9 t ha^{-1} after SSD leading to 138 % increase in yield (Table 6).

Table 6. Economics of sugarcane cultivation before and after SSD installation at Mulad village in coastal Gujarat

Particulars	Before SSD	After SSD	% Change
Yield (t ha^{-1})	40.23	95.92	138.4
Gross Income (₹ ha^{-1})	80460	191840	138.4
Cost of Cultivation (₹ ha^{-1})	78270	87698	12.1
Net Income (₹ ha^{-1})	2190	104142	
B:C Ratio	1.03	2.19	112.6

Integrated farming system

In coastal areas, the cropping system is predominantly mono-cropping, but the productivity is poor due to soil and climatic constraints. Diversified cropping through integrated farming system comprising crops, fruit trees, vegetables and multipurpose trees and staggered planting times provide subsistence income to the farming community, which also provide opportunities to offset the losses in the event of crop failures caused by aberrant climatic conditions. An integrated farming system model is developed for saline black soils region which includes crop components, fruit trees, vegetable crops, woody plants and farm pond. The data (Table 7) indicated that among fruit crops, higher amount of water i e., 953 mm was applied in Banana where as in papaya only 180 mm of water was applied. Among seed spices, Bishop's weed (*ajwain*: *Trachyspermum ammi*) was given lowest amount of water (44 mm) followed by *dill* (100 mm) and coriander (122 mm) and among vegetables, lowest amount of water applied to bottle gourd (134 mm) followed by tomato (110 mm) and brinjal (200 mm) (Rao *et al.* 2009). Water productivity of high yielding crops like banana is the lowest (0.931 kg m^{-3}), whereas papaya gave the highest water productivity (3.62 kg m^{-3}) (Table 7). Low water requiring spice crops and vegetable crops gave water productivity more than that of banana. Water productivity expressed in terms of monetary gains per unit of water applied indicated that Carom seeds (ajwain: *T. ammi*), due to its high cost had the highest water productivity followed by coriander, dill, papaya and vegetables. Banana, a high water requiring crop gave the lowest water productivity indicating its non-suitability for black soils of Bara tract with water availability as one of the constraints.

Benefit/cost ratios of spice and vegetable crops range from 5.28 to 3.48 whereas it is 2.15 for banana and 2.39 for papaya. Water productivity and B/C ratio given in table 8 indicate papaya among the fruit crops, bottle gourd among vegetables, and seed spice *ajwain/dill* followed by coriander are best suited for saline Vertisols of Bara tract region of coastal Gujarat.

Cultivation of halophytes

The halophyte plant species viz. *Salvadora persica*, *Salvadora oleoides* and *Suaeda nudiflora* having potential to remove salts from environment could prove to be helpful in remediating saline soils that are dominant in coastal and inland areas of Gujarat (Arora *et al.* 2013). These species grow well on saline black soils having salinity up to 55 dS m^{-1}. National Bank for Agriculture and Rural Development (NABARD), Mumbai in association with the RRS, Bharuch has developed a bankable model scheme for cultivation of *Salvadora persica* on salt affected black soils through a project sponsored by NABARD. Re greening of highly saline black soils with these halophytes helps to reduce salinity by 4th year onwards that enable to take up intercropping with less tolerant crops/forages (Rao *et al.* 2004)**.** Apart from this, the species provide a dwelling place for birds and enhances the environmental greening.

Cultivation of *Dill (Anethum graveolens)*

Non-conventional crop like dill can be grown using residual moisture resulting in 2.6 q ha^{-1} seed yield with net returns of ₹ 8000. This crop forms an ideal option for the State in general and the region in particular, which *by and large* faces water scarcity problems (Rao *et al.* 2001). Under saline water irrigation, crop would yield net returns of ₹ 16500 ha^{-1} with ₹ 6000 ha^{-1} as cost of cultivation. The benefit: cost ratio is 2.75. This crop thus would help farmers of the region to go for the second crop in the rabi season on lands, which hitherto remain fallow due to water and salinity constraints. Thus dill crop can be taken up using residual moisture and/or with saline ground water. The green can be used as leafy vegetable, an additional source of income.

Ground water recharge by Farmers

The ICAR-Central Soil Salinity Research Institute, Karnal along with its Regional Research Station at Bharuch, Gujarat has designed artificial groundwater recharge structure for better harnessing rainwater in Bharuch and Narmada districts mainly for cultivation purposes.

Impact of groundwater recharge on farm income

Table 7. Water productivity and B/C ratio of different components of the farming system on Saline Vertisols

Components	Fruit crops		Spice crops			Vegetable crops		
	Banana	Papaya	Ajwain	Dill	Coriander	Brinjal	Tomato	Bottle Gourd
Plot Area, m^2	190	225	480	1200	1600	120	160	200
Water applied, mm	953	180	44	100	122	200	110	134
Economic yield, kg $plot^{-1}$	887	652	40	102	116	280	240	440
Water productivity, kg m^{-3}	0.931	3.62	0.91	1.06	0.951	2.33	2.18	3.28
Water productivity, ₹ m^{-3}	3.58	19.25	72.70	31.60	33.28	18.70	12.20	17.60
Cost of cultivation, ₹	1590	1450	620	740	1120	500	280	560
Gross Income, ₹	5002	4916	3200	3180	5180	2240	1440	3520
Net Income, ₹	3412	3466	2580	2240	4060	1740	1160	2960
B/C Ratio	2.15	2.39	4.16	4.33	3.63	3.48	4.14	5.28

Net Income, ₹ ha^{-1} : 52258=00 (Under well managed conditions)

Table 8. Water productivity and Benefit:Cost ratio of different components of farming system

Component	Water Productivity, kg m^{-3}	Water Productivity, ₹ m^{-3}	B:C Ratio
Fruit Species	Papaya > Banana	Papaya > Banana	Papaya > Banana
Vegetables	Bottle gourd > Brinjal > Tomato	Brinjal > Bottle Gourd > Tomato	Bottle Gourd > Tomato >Brinjal
Seed Spices	Ajwain> Coriander > Dill	Ajwain> Coriander > Dill	Dill> Ajwain> Coriander

The groundwater recharge wells implemented in different villages of Bharuch district yielded improved groundwater regime in terms of groundwater quantity and quality. This resulted in improvement in farmers' income at all locations. Increase in crop yields and farm income from horticultural crops, Papaya and banana in Borebhata village and mango and soybean in Netrang village before and after implementation of recharge interventions are illustrated.

In Borebhata village the groundwater EC was 1.9 dS m^{-1} prior to monsoon which reduced to 0.35 dS m^{-1} due to groundwater recharging during monsoon indicating more than 80 % reduction in groundwater salinity. The average farm income of the farmer from drip irrigated banana prior to the installation of recharge well was ₹ 80,000 $acre^{-1}$ which increased to ₹ 1,10,000 $acre^{-1}$ representing 37.5 % increase. Similarly income from papaya increased from ₹ 1,40,000 $acre^{-1}$ to ₹ 160000 $acre^{-1}$ indicating 14.3 % increase in the first year after the installation of recharge well (Rao *et al.* 2010). In Netrang village, the water-table at 5.5 m depth, prior to the installation of recharge well rose to 3.2 m, indicating 2.3 m rise while the corresponding groundwater salinity reduced from 1.02 dS m^{-1} (pre-monsoon) to 0.14 dS m^{-1} (post-monsoon). Prior to the construction of recharge well, the yield of soybean was 10 q ha^{-1} which increased to 15.2 q ha^{-1}. The recharging of groundwater resulted in adequate groundwater resources enabling farmer to provide required irrigations as per needs of the crop. Mango being a sensitive crop to salinity responded well to the improved quality of pumped water being used with drip irrigation, highlighting the beneficial effects of ground water recharge.

Cultivation of forage grasses on saline black soils

Gujarat state has one of the largest dairy industries in the country. As the fodder produced on arable lands and grasslands is not sufficient to meet the demands of the cattle population, cultivation of forage grasses, *Dichanthium annulatum* and *Leptochloa fusca* in a ridge-furrow planting system with 50 cm high ridge and 1 m between midpoints of two successive ridges was appropriate in saline black soils having salinity up to 8-10 dS m^{-1}. For maximizing forage production on saline black soils, *Dichanthium* on ridges and *Leptochloa* in furrows form right option. Cultivation of salt tolerant grasses like *Dichanthium annulatum* and *Leptochloa fusca* on moderate saline soils result in yield of 1.9 t ha^{-1} and 3.2 t ha^{-1}, respectively (Rao *et al.* 2011).

Cultivation of *desi* cotton on saline black soils (Vertisols)

Desi cottons are known for their short staple characteristics, deep root system, resistance to diseases and pests and drought. The ICAR-CSSRI, RRS, Bharuch has been working on improvement in salt tolerance of herbaceum and arboreum cotton and has screened and identified salt tolerant germ plasms of cotton. Studies conducted at the station has indicated that *desi* cotton line (G Cot 23) as salt tolerant and high yielding even at 11.2 dS m^{-1} salinity and identified as salt tolerant *desi* cotton variety. On-farm Trials were undertaken on farmers' fields in Bhal area (Rajpara village, Dholera taluka, Ahmedabad district) and Bara tract (Bojadra and Kalak villages of Jambusar taluka, Bharuch district), where G Cot 23 recorded yield of 1.8 to 1.9 t ha^{-1}. Field trials were also taken up on farmers' fields with G Cot 23 on saline Vertisols (EC ranging 9.4 to 10.2 dS m^{-1}) in four villages namely Rajpur, Mingalpur, Shela and Kamatalav in Dhandhuka taluka of Ahmedabad district indicated seed cotton yields in the range of 1.7-1.8 t ha^{-1}.

Conjunctive use of water

To practice conjunctive use of saline and fresh water, the available options are blending and cyclic mode. Blending is promising in areas where freshwater can be made available in adequate quantities on demand. Cyclic use is most common and offers several advantages over blending (Rhoades *et al.* 1992). Analysis of results from a large number of experiments showed at the same level of ECiw (Weighted average salinity of the irrigation water), the yields for different cyclic use modes were higher than the estimated yields for mixing (Minhas and Tyagi 1998). The cyclic strategy involves the use of saline water and non-saline irrigation water in crop rotations that include both moderately salt sensitive and salt-tolerant crops. The cyclic strategy requires a crop rotation plan that can make best use of the available good and poor quality waters, and takes into account the different salt sensitivities among the crops grown in the region, including the changes in salt sensitivities of crops at different stages of growth. Blending consists of mixing good- and poor quality water supplies before or during irrigation. Different water qualities are altered, according to the availability of different irrigation water qualities and quantities, between or within an irrigation event.

Dill (*Anethum graveolens*: annual herb), a potential seed spice and aromatic oilseed crop can be grown during winter (rabi) season on saline black soils having salinity up to 4-5 dS m^{-1} with a seed yield of 3 t ha^{-1}

without any irrigation, which otherwise remained fallow during the rabi season. However, the conjunctive use of saline groundwater with surface water can improve the productivity manifold. In *dill*, if surface water is available for one time irrigation, it should be applied at the seed formation stage and saline water at the vegetative and flowering stages. If surface water is available for two irrigations, it should be applied at the time of flowering and seed formation stage and saline water at the vegetative stage. In areas with high groundwater table and lack of sufficient surface water, surface water up to 66 per cent can be saved by application of saline groundwater (4 dS m^{-1}) at branching and flowering stage and surface water at seed formation stage without further increase in soil salinity (Nayak *et al.* 2000b). This method can increase seed yield by 150 per cent over the yield obtained under un-irrigated condition.

In safflower, branching and flowering stages were sensitive to saline water irrigation. If surface water is available for one time irrigation, it should be applied at branching stage and saline water at vegetation and flowering stages. If surface water is available for two irrigations it should be applied at branching and flowering stages and saline water at vegetative stage. In safflower by applying saline groundwater (4 dS m^{-1}) at flowering and grain filling stages and surface water at branching stage, 86 per cent increase in yields over the yield obtained under unirrigated conditions (3.7 q ha^{-1}) can be obtained (Rao *et al.* 2001). In the absence of sufficient good quality of water, Indian mustard can be grown on saline black soils with saline ground water having EC of 4 dS m^{-1} in conjunction with the limited surface water. Flowering and pod formation stages are relatively more sensitive to saline water irrigation. In mustard, application of two saline water irrigations (4 dS m^{-1}) at branching and pod formation stages and surface water flowering stage resulted in yield of (5.59 q ha^{-1}) (Nayak *et al.* 2001). Flowering and pod formation stages are relatively sensitive to saline water irrigations. This method while saving 66 per cent surface irrigation water increases the yield by 123 per cent over the yield obtained under un-irrigated conditions (2.2 q ha^{-1}).

Saline water irrigation in cotton

Experiments conducted with different species of cotton viz., *herbaceums, hirsutums, arboreums* and Bt hybrids under saline water irrigation on saline Vertisols indicated *herbaceums* and *arboreums* as salt tolerant and superior to *hirsutums* and Bt hybrids (Rao *et al.* 2013a, Rao *et al.* 2012, Rao *et al.* 2013b). Higher amount of sodium was found in *herbaceums* when compared to *hirsutums* and Bt lines. Concomitantly, potassium was also found to be more in herbaceum, G Cot DH 7 and other herbaceums and arboreums, which makes these species maintain higher K/Na ratio. G Cot DH 7 gave higher seed cotton yield (Figure 3) of 119 g $plant^{-1}$ at 4 dS m^{-1} irrigation which was at par with the control. Even with the increase in salinity, G Cot DH 7 showed only 0.6, 6.1 and 15.1 per cent decrease in yield at 4, 8 and 12 dS m^{-1} salinity respectively, over the control. Other cultivars such as

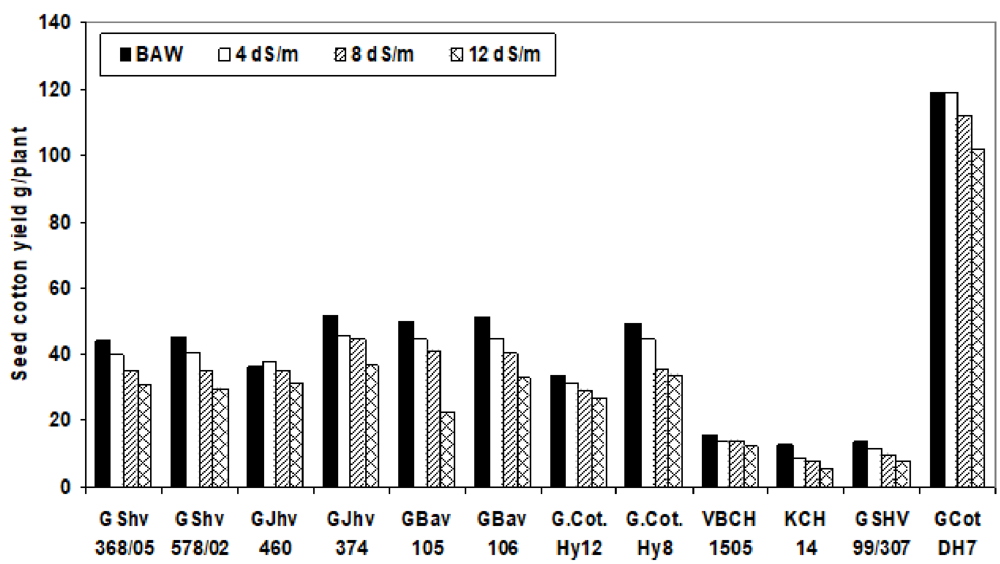

Fig. 2. Seed cotton yield of cotton species under saline water irrigation.

GJhv 374, followed by GBav 106, GBav 105 along with G Cot. Hy 8 showed moderate yield at 4 dS m^{-1} with further decline at 8 and 12 dS m^{-1} salinity levels. Lint yield and ginning percentage of herbaceums was more than that of arboreums. Based on the seed cotton yield at 12 dS m^{-1} saline water irrigation, the cultivars are placed in the order G. Cot DH 7 > GJhv 374 > GBav 106> GBav 105 > G.Cot. Hy 8. Field experiments at ICAR-CSSRI, RRS, Bharuch conducted with 36 accessions covering herbaceums, hirsutums, arboreums, Bt hybrids and two checks irrigated with saline water of 4.2 to 11.8 dS m^{-1}. Highest seed cotton yield was recorded in arboreum (G Bav 124) followed by herbaceum (GShv 297/07) which, in fact, yielded more than the checks G Cot Hy 12 and G. Cot Hy 8. Both herbaceum and arboreum yielded more seed cotton compared to hirsutum and Bt hybrids. Based on seed cotton yield, herbaceum and arboreum proved to be superior over hirsutum and Bt hybrids. Herbaceum and arboreum, because of low water requirement, higher salt tolerance and better seed cotton yields had higher water productivity when compared to hirsutum and Bt hybrids. Biomass production maximum in herbaceums, GBhv 290 (8.65 t ha^{-1}) and GBhv 291 (8.11 t ha^{-1}) followed by GBhv 283 (6.19 t ha^{-1}). Arboreums, GBav 124, 122, 109 and herbceums GShv 273/07, 297/07, 283 and 291 had higher water productivity under saline water irrigation. The higher water productivity of herbaceums and arboreums, thus clearly indicate their suitability to water scarce regions, unlike hirsutums and Bt lines.In view their good performance under saline water irrigation herbaceums and arboreums comes out to be ideal species on saline black soils both in inland and coastal regions of Gujarat.

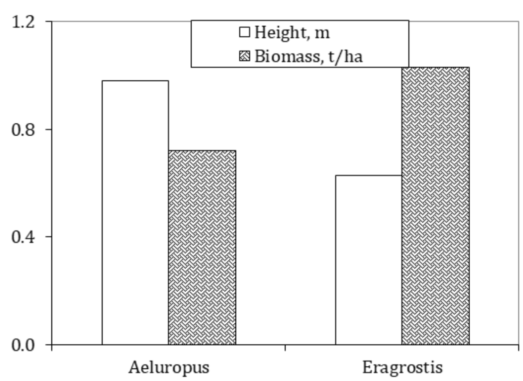

Fig. 4. Growth and forage yield of halophytic grasses on saline black soils of coastal Gujarat.

Forage production under saline water irrigation

Developing sustainable and productive management systems for halophytic grasses help farmers to live with salt and allow them to continue farming, improve productivity and expand cultivation on under-utilized soils like coastal salt affected black soils (Rao *et al.* 2005, Gulzar and Khan 2003, Gulzar *et al.* 2005). The green forage yield of these halophytic grasses under field conditions irrigated with saline ground water of EC 12.8 dS m^{-1} (Figure 4) indicates that *Eragrostis* sp. showed higher forage yield as compared to *Aeluropus lagopoides* even at salinity of 14.6 dS m^{-1}. Uptake and flux of Na^+ and Cl^- ions and the total Na^+ uptake showed a decreasing trend with increase in salinity of irrigation water in both the grasses. Among the grasses, *Aeluropus lagopoides* showed higher uptake than that of

Table 9. Soil salinity (dS m^{-1}) upto 5 km distance from sea side to land side

Distance (km) from sea towards land side	Soil Depth (cm)	Village along the sea coast in Jambusar taluka of Bharuch district				
		Tankari	Asarsa	Nada	Malpur	Neja Dahegam
0-1	0-30	18.5	32.0	10.3	13.9	18.0
	30-60	15.2	26.0	9.9	11.1	14.9
1-2	0-30	40.0	25.0	45.0	18.1	22.0
	30-60	34.0	17.8	35.0	19.0	20.0
2-3	0-30	6.0	17.3	14.3	0.26	1.21
	30-60	11.4	16.8	17.5	1.8	0.13
3-4	0-30	0.48	0.28	2.7	0.2	2.3
	30-60	0.32	0.25	2.7	0.2	2.3
4-5	0-30	0.22	0.19	0.31	0.17	0.17
	30-60	0.35	0.23	0.55	0.17	0.16

Eragrostis sp. though the increase was only marginal. Irrigation with saline water on Vertisols with high sub-surface salinity indicated that *Aeluropus* showed better salt removal when compared to *Eragrostis*. This feature is highly useful in using these grasses under saline agriculture programmes for lowering the salinity, which over the years would help cultivation of lesser tolerant and more economically potential species.

Creating bio-shield to combat climate change in coastal area

Gujarat with 1600 km long coastline has the distinction of having longest coastline in the country. About 25 % of the total population of the state living in 3,000 villages and towns and this distinction also has its challenges like heavy soil erosion, rapid salinity ingress, depleting green cover, reoccurring cyclonic storms. Among all Indian states, Gujarat has been identified as high-risk states due to long coastline. This puts valuable economic assets and human life on the coast at risk. The nature and scale of the problem demands attention and action from all concerned. Creating a bio-shield (*Sajeev Suraksha Kavach*) along the coast of Gujarat was conceived as a multi-layered, green belt comprising of mangroves, energy and fruit trees and fodder cultivation for protecting economic assets and human life against natural calamities, reducing salinity ingress, creation of "carbon sink" with increased access to food, fodder and fuel and enhanced livelihoods in primary and renewable energy sector. An NGO, VIKAS, Centre for Development, Ahmedabad has been working for 40 years with twin objectives as regeneration of natural resources and livelihood development. During last 10 years, the work on mangrove plantation covering about 1200 ha along the coastline of Jambusar taluka is completed. The need is to go beyond and build on the work carried out by creating a more comprehensive initiative in form of bio-shield. Currently, a pilot project with 200 meters width and one kilometre length is implemented at Tankari Village, Jambusar taluka of coastal Bharuch district. The green belt starts with plantation of mangroves towards the sea-side followed by *Casuarina equisetifolia*, *Suaeda nudiflora, S. maritima*, *Salvadora persica*, energy and fruit plantation and at the end fodder like *Dichanthium annulatum, Leptochloa fusca* plantation on the landward side. Present soil salinity status of the study area is presented in Table 9. Subsequently the project would cover entire length of Jambusar taluka measuring 60 km and connecting 12 villages - from Kavi in north to Tankari in south direction. The project would directly impact 25,000 persons dwelling in 12 coastal villages and protect 35,000 acres of agriculture land.

Conclusion

The coastal region plays an important role in providing livelihood opportunities to a vast section of rural people. However, the region suffers from various land degradation problems, productivity constraints and adverse impacts of natural hazards. Soil salinity, waterlogging, soil erosion, and sea ingress are the major degradation problems that limit crop production in the region. Enhancing agricultural productivity of less productive coastal lands for improving food security and livelihood of the poor farmers is the biggest challenge. With different interventions/technologies suited to local conditions in conjunction with appropriate soil, water and crop management following integrated nutrient management, salt tolerant crop varieties, efficient irrigation practices, creating bio-shield to combat unfavourable natural conditions will be possible to mitigate the problems of land degradation, declining productivity and climatic constraints to a greater extent. To achieve this restoration towards enhancing the productivity and increasing farmers' income, there would be a need for the involvement of relevant stakeholders such as farmers, and public institutions (research and extension institutions, other line departments of government, KVK, NGO) for expansion, adoption and awareness about available technologies.

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