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Assessment and Management of Natural Resources of Coastal Gujarat towards Enhancing Productivity and Ensuring Food Security[1]

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Salinity of soil and water is a major constraint in enhancing productivity and ensuring food security. The Gujarat state is sharing the longest coastal line in the country *i.e.* 1600 km. Salinity problems are increasing at an alarming rate, more particularly in the irrigation command areas and coastal area. Out of 67.40 lakh hectares area affected by coastal and inland soil salinity/sodicity in the country, Gujarat has the largest salt-affected lands (21.05 lakh ha) which include 4.62 lakh ha coastal saline soils, 10.98 lakh ha inland saline soils and 5.45 lakh ha inland alkali soils. It is reported that Gujarat, in general received less rainfall during the period 1960–1990 compared to 1991–2008 and in particular Bharuch district received average annual rainfall of 753 mm during 1975-2011 as compared to 895 mm for the period 2000-2011. The average annual rainfall during the period 2000-2011 was increased by 19 per cent over long term average (1975-2011). It is also observed that the intensity of rainfall was more during later period of monsoon for 2000-2011 as compared to 1975-2011. Considering the climatic and edaphic factors, crops traditionally cultivated in Gujarat were highly appropriate. In Gujarat state the soils are ranging from sandy and saline to deep black clayey. Sand to sandy loam and saline soils are confined to the Kutch agro-climatic region and North Gujarat and partly to North Saurashtra. The soils predominantly found in Kutch are sandy and saline and receives the lowest rainfall in the state (346 mm per annum). The crops that have been traditionally cultivated in Kutch include pearl millet and sorghum. North Saurashtra has two dominant soil types: shallow to medium black and shallow to medium black calcareous. The average rainfall is about 633 mm per annum. While parts of North Saurashtra have medium black and poorly drained soils, South Saurashtra is completely covered with shallow to medium black calcareous soils. The average rainfall here is 877 mm per annum. Groundnut, sorghum, and pearl millet are the crops traditionally grown in South Saurashtra. Central Gujarat is covered with deep, medium black to loamy sand and sandy loam to sandy soil and average rainfall has been recorded at 822 mm per annum. The traditionally cultivated crops here are rice and cotton. South Gujarat, along with Southern Hills, characteristically comprises deep black clayey and deep black with coastal alluvial to medium black soils while the northern most region of South Gujarat is home to deep black to medium black poorly drained to loamy soils. The average rainfall in South Gujarat and the Southern Hills is 1207 mm per annum and 1819 mm per annum, respectively. The crops traditionally grown here include cotton, rice and sorghum. Gujarat witnessed an increase in groundwater extraction for irrigation purposes over the past two decades. This has been mainly caused by the shift in cropping patterns towards water intensive crops such as wheat, sugarcane, rice, and cotton. Seawater ingress besides marine influence creates huge salinity in the coastal regions. 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 undergroundwater or saline water irrigation. Dominant salts occur in coastal saline soils are sodium chloride and sodium sulphate with loads 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 been 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 salinisation in irrigation command areas decreased the productivity of arable farming. Technological knowledge generated till date has helped in solving the problems in large tracts of land in different regions to restore their full productive potential. However, new challenges 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 are 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 of adequate drainage, 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, etc. have to be ensured for enhancing the productivity of these soils.

*(**Key words:** Degraded land, Black soils, Secondary salinisation, Sea ingress, Bio-shield, Vertisols)*

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Agricultural productivity is declining due to various constraints in soil, climate and other natural resources. Salinity of soil and water is an environmental constraint affecting millions of hectares of land as well as the livelihood of farming communities. Coastal area salinity is due to marine influence, periodical inundation with tidal water, proximity to the sea and high water table with high concentration of salts in it. Saline soils in coastal areas are having predominance of sodium chloride and sodium sulphate salts 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 typical problems encountered in these areas are influence of tidal waves and periodical inundation by tidal water, shallow water table enriched with abundant salts, 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.

Agro-ecological condition of coastal Gujarat

Gujarat Agricultural University identified eight agroclimatic zones which have been further sub divided into Agro-ecological sub regions (Table 1). The major characteristics of agro-climatic zones including types of salt affected soils are given below.

***Table 1**. Major characteristics of coastal salt affected agro ecological situations of different agro climatic zones (Source: NARP Status Report, GAU)*

Agro climatic zone	Soil type	Soil Texture	Rainfall	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 and banana	26	78
North Saurashtra	Saline Sodic	Clay	500-600	Groundnut, sorghum, pearlmillet, 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, pearlmillet, chick pea	299	22
	Shallow black / Coastal alluvial	Sandy loam to clay loam	300-400	Groundnut, sorghum, pearlmillet, 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 and other horti-cultural crops	96	15
	Coastal alluvial	Sandy loam to silty clay loam	750-1000	Groundnut, sesamum, sorghum, pearl millet, and horti-cultural 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
	Highly saline	Sandy loam to clay	600-700	Forestry	-	-

Rainfall analysis

The rainfall data for 36 years (1975–2011) have been analysed which revealed that average annual rainfall was 753 mm during 1975-2011 compared to 895 mm during 2000-2011 (Table 2). It was observed that average annual rainfall during the period 2000-2011 increased by 19 per cent over long term average (1975-2011). There was notable shifting in monthly rainfall during the monsoon period. Rainfall during June to August for 2000-2011 increased by 11 to 40 per cent while there was no change in 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.

Causes and types of 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 (Bandyopadhyay *et al*., 2011; Burman *et al*., 2015). Soil salinity of coastal area is having same nature as that of inland soils except for different salt compositions in the soil solution and specific toxicity of individual ions and their interacting effects observed in case of the former.

The soils with electrical conductivity of soil saturation extract (EC_e) is more than 4 dS m^{-1}, exchangeable sodium percentage (ESP) less than 15 and pH less than < 8.5 are categorised as saline soils. These soils are having the dominant cations in order of preference 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. Excessive salts present in these soils may be removed by leaching with provision of adequate drainage, thus bringing them to normalcy. These 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 ranging from 1 to 132 dS m^{-1} (Nayak *et al*., 2000a). The highest value of ECe is (132 dS m^{-1}) observed in the area of western coast which is due to frequent tidal inundation which leaves behind the salt with soil materials, hence concentration of soluble salts is 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.

The soils with exchangeable sodium percentage is more than 15, the electrical conductivity of soil saturation extract is less than 4 dS m^{-1} and the pH ranges between 8.5 and 10 are categorised as sodic soils. 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 more inclination towards becoming more dispersed. The

Table 2. *Amount of average annual and monthly rainfall in Bharuch district and its deviation*

Period	Average rainfall for 1975-2011 (mm)	Average 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

soil colloids are usually in a deflocculated state. The dispersive effect of exchangeable sodium will be observed, however only if the electrolyte concentration in the soil solution is smaller than that required for flocculating the clay particles. Higher concentration of magnesium as compared to calcium has been sometimes observed in soil solution of some salt affected soils. Due to which these soils behaves differently in terms of physico-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 are found in middle Gujarat and the Saurashtra peninsula and the 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 in 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 nos. 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 found which is 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 is alkaline at all the depths. While at some pockets the salt accumulation is found at the surface, at some other locations it tends to increase with the depth. The sodicity (ESP) does not show any regular trend with the depth. In Bharuch district, the coastal soils are reported to be heavier and clay in texture throughout the depth. The pH ranges from 8.6 to 9.5 and the EC_2 from 0.22 to 8.1 dS m^{-1}. The latter tends to increase with depth. The ESP varies from about 5 to about 18, with an increasing pattern with depth. The Bara tract area of coastal Gujarat in Bharuch district lies 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 with smectite as the dominant clay mineral. High shrink-swell potential has been exhibited by these soils 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 permeability 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 3). The soils of Bara tract are subjected to varying degrees of salinisation. 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 found 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} (Fig. 1). Whereas, 10 per cent of the sub-soil are having salinity less than 2 dSm^{-1}, 15 per cent between 2-4 dS m^{-1} and 75 per cent greater than 4 dS m^{-1} (Fig. 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 salts and/or with low sulphates are seen. 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).

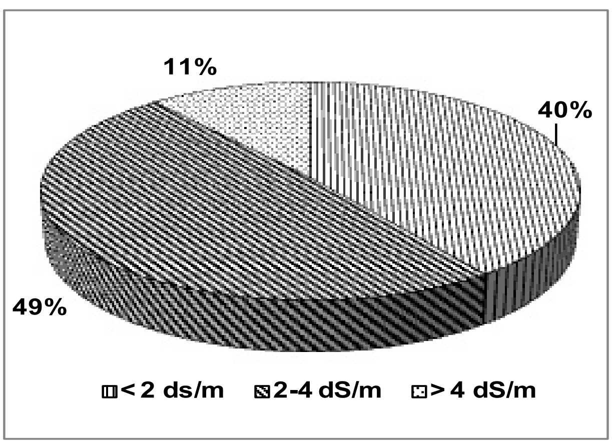

Fig. 1. *Per cent area of surface soils of Bara tract affected by soil salinity*

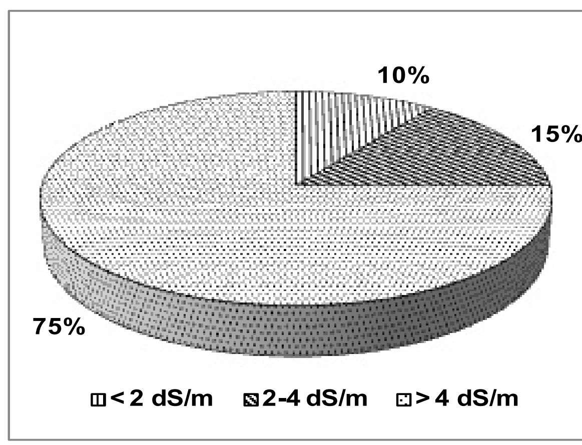

Fig. 2. *Per cent area of sub-surface soils of Bara tract affected by soil salinity*

Table 3. *Physico-chemical characteristics of typical soil profile (Typic Haplusterts) of the Bara tract (Village Samni, Taluka Amod District Bharuch)*

Horizon	Depth (m)	EC_e (dSm^{-1})	pH	$CaCO_3$ (%)	O. C. (g kg^{-1})	Sand (%)	Silt (%)	Clay (%)	ESP	CEC cmol (p^+) 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)

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 EC_e varies from 9 to 118 dS m^{-1} and ESP from 10-81. The pH and ESP tend to increase with the depth in the soil profile. But the salt accumulation shows a reverse trend indicating its accumulation at the surface through capillary rise. They are moderately calcareous and the hydraulic conductivity ranges from 0.09 to 1.28 cm h^{-1}. The coastal salt affected soils of Saurashtra region are clay in texture with high amount of lime content. The pH ranges from 7.7 to 9.0 without much variation with the depth. The EC_e 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. While the salinity variations are reported to be 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.

Productivity enhancement

Unsuitable climatic conditions, soil and water degradation, marine influence in the coastal areas and secondary salinisation in irrigation command areas minimized the land suitable for arable farming. To address such problems the technological knowledge generated has helped in large tracts of land 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, etc. 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.

Secondary salinisation in black soils of the coastal region

Farmers of the Bara tract are practising irrigated agriculture using canal water and/or saline tubewell 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 salinisation 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 exchangeable sodium percentage (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 the Table 4. 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), whereas hydraulic conductivity is drastically reduced in soils under canal irrigation. Therefore, farmers of the Bara tract area are advised for judicious use of canal water. To avoid further degradation of soil resources i.e.sodification due to irrigation using canal water having low salt concentration 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 the susceptibility to clay dispersion and

Table 4. *Variation in properties of rainfed cultivated, tubewell water irrigated and canal irrigated soils in Vagra Taluka of Bharuch district, Gujarat*

Soil properties		Tubewell 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
ECe, dSm^{-1}	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 (Mgm^{-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

other adverse effect. 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.

Integrated farming system for farm productivity enhancement

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 increase the likelihood of some species survive and provide subsistence income to the farming community of the coastal region and also provide opportunities to the farmers to offset the losses in the event of crop failures caused by aberrant climatic conditions. Farmers in this region are resource poor with low and insecure farm income. Thus, evolving appropriate technological interventions with special emphasis on enhancing the water productivity of crops using saline ground water to provide them a staggered income throughout the year is of immense importance. An integrated farming system model has been developed for saline black soils region which includes crop components, fruit trees, vegetable crops, woody plants and farm pond. The data (Table 5) 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, ajwain 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) (Gururaja Rao et al., 2009). Water productivity of high yielding crops like banana is the lowest (0.931 kg m^{-3}),

Table 5. *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
Cultivation cost, ₹	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)

whereas papaya gave the highest water productivity (3.62 kg m^{-3}). 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 ajwain, due to high cost of seed had the highest water productivity of ₹72.70 m^{-3}, and followed by coriander, dill, papaya and vegetables. Banana, a high water requiring crop gave the lowest water productivity of ₹3.58 m^{-3} 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 were found to be ranging from 5.28 to 3.48, banana had the B/C ratio of 2.15 and papaya 2.39. Water productivity and B/C ratio of these components indicate that papaya among the fruit crops, bottle gourd among vegetables, and seed spice ajwain/dill followed by coriander form ideal ones for this saline Vertisols of Bara tract region in coastal Gujarat.

Cultivation of halophytes

The halophyte plant species *viz*., *Salvadora persica*, *Salvadora oleoides* and *Suaeda nudiflora* having potential to remove salt 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 were found to grow well on saline black soils having salinity up to 55 dS m^{-1} and found to yield well. Based on the studies conducted at RRS, Bharuch the 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 the project sponsored by NABARD. Regreening of highly saline black soils that cannot be put under arable farming with these halophytes helps to reduce salinity by 4th year onwards that enable to take up intercropping with less tolerant crops/forages (Gururaja 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 (Gururaja Rao *et al*., 2001). Under saline water irrigation, crop would yield net returns of ₹16500/- ha^{-1} with Rs. 6000/- per hectare as cost of cultivation. The benefit: cost ratio works out to be 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.

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 fuscain* a ridge-furrow planting system with 50 cm high ridge and 1 m between midpoints of two successive ridges was found ideal 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 ideal proposition. Cultivation of salt tolerant grasses like *Dichanthium annulatum* and *Leptochloa fusca* on moderate saline soils result in 1.9 t ha^{-1} and 3.2 t ha^{-1}, respectively (Gururaja Rao *et al*., 2011).

Cotton on coastal salt affected soils

Desi cotton is known for its short staple characteristics, deep root system, resistance to diseases, pests and drought. 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. 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 (Gururaja Rao *et al*., 2012 and 2013). Higher amount of sodium was found in herbaceums when compared to hirsutums and B_t 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 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. Among the other cultivars, GJhv 374, followed by GBav 106, GBav 105 along with G. Cot. Hy 8 gave moderated 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 found to be 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, B_t hybrids and two checks irrigated with saline water of 4.2 to 11.8 dS m^{-1}. Highest seed cotton yield (productivity) was recorded in arboreum GBav 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 herbaceums and arboreums gave higher seed cotton yields over hirsutums and B_t hybrids. Based on seed cotton yield, herbaceums and arboreums were found to be superior over hirsutums and B_t hybrids. Herbaceums and arboreums, because of low water requirement, higher salt tolerance and better seed cotton yields had higher water productivity when compared to hirsutums and B_t hybrids. Biomass was found to be 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 B_t lines, which, however, need more irrigations. The efficacy of saline water irrigation is clearly seen in herbaceums and arboreums which thus form ideal species for saline agriculture on saline black soils both in inland and coastal regions of Gujarat.

Also 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 1.3 to 1.4 t ha^{-1}. Field trials were also taken up on farmers' fields with G. Cot 23 on saline Vertisols in four villages namely Rajpur, Mingalpur, Shela and Kamatalav in Dhandhuka taluka of Ahmedabad district indicated seed cotton yields in the range of 1.1-1.3 t $ha^{-1}$and the salinity ranged from 9.4 to 10.2 dS m^{-1} (Success Story-ICAR website 2015).

Forage grasses on coastal salt affected soils

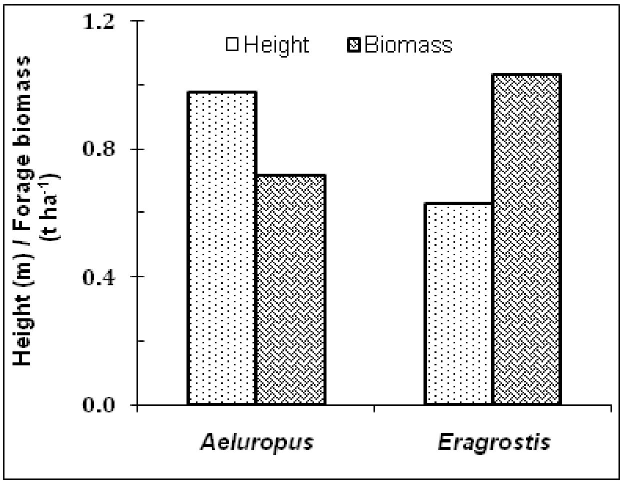

Fig. 3. Growth and forage yield of halophytic grasses on saline black soils of Gujarat

Wheat on coastal salt affected soils

At the experimental farm, Samni of ICAR-CSSRI, RRS, Bharuch is also working on screening of wheat genotypes for salt tolerance on saline Vertisols of coastal Gujarat. The wheat crop was being irrigated only 4 times with saline ground water (average EC_{iw} value is 10.5 dS m^{-1}) during the entire crop growth period. KRL 345, KRL 351, NW 6096 and KRL 378 were found promising entries. These genotypes were having better trait value for chlorophyll and K/Na ratio in leaf tissues. Wheat genotype KRL 370 was found salt tolerant with 3.88 t ha^{-1}grain yield at EC_e of 8.5 dS m^{-1}on salt affected Vertisols.

Farming production systems, which enable animal feed to be produced using salty water, will help farmers of the coastal region whose farms are affected by salinity or whose only source of irrigation is saline ground water. 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 (Gulzar and Khan 2003, Gulzar *et al.*, 2005; Gururaja Rao *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}given in Fig. 3 indicates that *Eragrostis spp*. showed higher forage yield under field conditions when compared to *Aeluropus lagopoides* even at salinity of 14.6 dS m^{-1}. Uptake and flux of Na^+ and Cl^- and thetotal 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 *Eragrostis spp*. though the increase was only marginal. Irrigation with saline water on Vertisols with high sub-surface salinity and further estimating the salt uptake by the halophytic grasses indicated that *Aeluropus* showed better salt removal when compared to *Eragrostis*. These grasses on saline black soils irrigated with saline ground water, showed higher efficacy in salt removal. This feature is highly useful in using these grasses under saline agriculture programmes for lowering the salinity, which over the years helps cultivation of lesser tolerant and more economically potential species.

Bio-shield to combat degradation in coastal area

Gujarat with 1600 km long coastline has the distinction of having longest coastline in the country. The region has economic significance due to huge industrial and infrastructure investment, substantial contribution to the GDP of the state as well as nation, 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, reccurring 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 is 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 hectares along the coastline of Jambusar taluka has been 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 kilometrelength 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*, *Suaeda 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 has been presented in Table 6. 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.

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 climate change. Soil salinity, waterlogging, soil erosion, and sea ingress are the major degradation problems that limit crop production in the region. Enhancing agricultural productivity of degraded coastal lands for improving food security and livelihood of the poor farmers under increasing demand of food for the country's burgeoning population, changing climate and declining land and water resources 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 climate change will be possible to mitigate the problems of land degradation, declining productivity and climatic constraints to a greater extent. To achieve this restoration there would be a need for the involvement of relevant stakeholders such as farmers, public institutions (research and extension institutions, other line Government Departments, KVKs, NGOs) for expansion, adoption and awareness about available technologies which not only help in restoring the productivity but also enhancing the productivity and directly or indirectly increase farmers' income.

Table 6. *Soil salinity (EC_2) in 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

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