Diagnostic Properties and Constraints of Salt-Affected Soils

Sanjay Arora

1 Introduction

Since time immemorial, the man has been relying on the soil for his sustenance for food, clothes, shelter and energy requirements. The pressure on this vital resource has increased to such an extent that the relationship between the living beings and the soil has become critical. A systematic and scientific appraisal of natural resources, especially soils and their database, is an important parameter, which may help to augment the food production. Soil resource inventory, therefore, is basic for rationalising land use according to its capability. Since no two soils are alike and have their own potential and/or problems and behave differently to management inputs, their use as per their capability is imperative for sustainable agricultural production (Yadav 2008). For sustained utilisation of soil resource, it is imperative to know the nature, characteristics and extent of different soils, their qualities, productive capacity and suitability for alternative land uses. Soil is defined as a naturally occurring body that has been evolved owing to the combined influenced of climate and organisms, acting on parent materials, as conditioned by relief over a period of time.

According to the Glossary of Soil Science Terms (Soil Science Society of America, 1970),

> "Soil is (1) the unconsolidated mineral materials on the immediate surface of the earth that serves as a natural medium for the growth of land plants, (2) the unconsolidated mineral matter on the earth surface that has been subjected to and influenced by genetic and environmental factors of parent materials, climate (including moisture and temperature effects), macro and microorganism and topography, all acting over a period of time and producing a product that is soil, that differs from the material from which it is derived in many physical, chemical, biological and morphological properties and characteristics".

S. Arora (✉)
ICAR-Central Soil Salinity Research Institute, Regional Research Station, Lucknow 226002, UP, India
e-mail: aroraicar@gmail.com

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2 Estimates of Salt-Affected Soils

According to the FAO Land and Plant Nutrition Management Service, over 6 % of the world's land is affected by either salinity or sodicity. The term *salt affected* refers to soils that are saline or sodic, and these cover over 400 million hectares, which is over 6 % of the world land area (Table 1. Much of the world's land is not cultivated, but a significant proportion of cultivated land is salt affected. Of the current 230 million ha of irrigated land, 45 million ha is salt affected (19.5 %), and of the 1500 million ha under dry land agriculture, 32 million is salt affected to varying degrees (2.1 %). In India, about 6.73 Mha of land is affected by salinity and sodicity problems.

2.1 Soil Resources of India

India's share in land resources of the world is only 2 %, on which 18 % of the world's population and over 15 % of the world's livestock survive. However, with its diverse agro-climate, topography and soil types, India is capable of producing a wide range of crops and vegetation. The land surface of the country is spread over an area of 329 Mha and is represented by different types of soils which are given in the Table 2. The Indian soils are broadly classified under eight soil taxonomic orders (Table 3).

Table 1 Regional distribution of salt-affected soils, in million hectares (Mha)

Regions	Total area (Mha)	Saline soils (Mha)	Saline soils (%)	Sodic soils (Mha)	Sodic soils (%)
Asia, the Pacific and Australia	3107	195	6.3	249	8.0
Europe	2011	7	0.3	73	3.6
Latin America	2039	61	3.0	51	2.5
Near East	1802	92	5.1	14	0.8
North America	1924	5	0.2	15	0.8
Total	12,781	397	3.1	434	3.4

Source: FAO Land and Plant Nutrition Management Service

Table 2 Major soil groups in India

Soils	Area (Mha)
Red and laterite soils	117.2
Black soils	73.5
Alluvial soils	58.4
Desert soils	30.0
Other soils {saline–alkali soils, forest and hill soils, peaty and marshy soils}	49.6

Table 3 Distribution of soils of India

Soil order	Area (Mha)	Percent
Entisols	80.1	24.37
Inceptisols	95.8	29.13
Vertisols	26.3	8.02
Aridisols	14.6	4.47
Mollisols	8.0	2.43
Ultisols	0.8	0.24
Alfisols	79.7	4.25
Oxisols	0.3	0.08
Non-classified	23.1	7.01
Total	328.7	100

The National Bureau of Soil Survey and Land Use Planning, Nagpur, has developed a detailed soil map of the country at soil suborder association level (totalling about 103 soil suborders). The soils were further classified following Soil Taxonomy up to family level.

3 Threats to Soil Resources

The massive post-independence development of irrigation has brought sufficient water for crops in millions of farms in India. Irrigation development, though a major factor in India's ability to enhance food production in irrigated areas and attain self-sufficiency in cereal grain production, in many canal commands, a rise in water table has been noticed consequent leading to the degradation of soils through water-logging and secondary salinisation.

3.1 Soil Degradation

The primary cause of degradation is the demographic pressure on land, resulting in loss of vegetal cover through deforestation. The land degradation occurs mainly due to uncontrolled deforestation followed by agricultural/farm activities. Hence, planning for productive land use is necessary to meet the growing challenges of food security since the land resource is not expandable physically.

It is estimated that in India, about 174.4 Mha of land is potentially exposed to various degradation forces like water (153.2 Mha) and wind erosion (15.0 Mha). About 40.0 Mha is subjected to floods and 22.0 Mha is not reclaimable for agricultural use. Loss of vegetal cover results in huge run-off, lowered recharge of groundwater and subsequently development salinity**.** Salt-affected soils occur at a tune of

6.73 Mha in our country. Salinisation, or soil degradation caused by increase of salt in the soil, is caused by incorrect irrigation management or intrusion of sea water into coastal soils arising from overabstraction of groundwater (Rao et al. 2014). It is severe on irrigated lands of the dry zone. It reduces crop yield and in severe cases causes complete abandonment of agriculture.

3.1.1 Salt-Affected Soils

In India salt-affected soils are mainly confined to the arid and semiarid and sub-humid (dry) regions and also in the coastal areas. The salt deposits are of sodium carbonate, sulphate and chloride with calcium and magnesium.

- These soils vary in nature from saline to nonsaline sodic.
- In coastal regions, saline soils are most predominant. They have high soluble salts (EC >4 dS/m) of chloride and sulphate of sodium, calcium and magnesium, low ESP and have pH value less than 8.2.

3.1.2 Extent of Salt-Affected Soils in India

The National Remote Sensing Agency (NRSA), Hyderabad, in association with other national and state level organisations like the Central Soil Salinity Research Institute, Karnal; National Bureau of Soil Survey and Land Use Planning, Nagpur; All India Soil Survey and Land Use, Delhi; and state government agencies conducted survey and used remote sensing data to prepare the maps of salt-affected soils of India in 1996. The Landsat satellite images were used in mapping salt-affected soils at 1:250,000 scale. Satellite images were interpreted for broad categorisation of different types of salt-affected soils; sample areas for field verification were identified and surveyed for soil sampling and characterisation. The salt-affected soils were classified according to norms for pH, electrical conductivity (EC) and exchangeable sodium percentage (ESP). The statewise extent of salt-affected soils in India is given in Table 4. It shows that maximum area of salt-affected soils occur in Gujarat followed by Uttar Pradesh and Maharashtra which account for about 62.4 %. Due to the limitation of small scale, some very small and isolated patches of salt-affected soils occurring in the states of Delhi, Jammu and Kashmir and Himachal Pradesh could not be detected. The salt-affected soils account for 6.727 Mha equivalent to 2.1 % of the geographical area of the country.

Out of the total 6.727 million ha of salt-affected soils, 2.956 million ha are saline and the rest 3.771 million ha are sodic. Out of the total 2.347 million ha salt-affected soils in the Indo-Gangetic Plain, 0.56 million ha are saline and 1.787 million ha are sodic.

Table 4 Extent of salt-affected soils India (ha)

State	Saline	Sodic	Total
Andhra Pradesh	77,598	196,609	274,207
Andaman and Nicobar Islands	77,000	0	77,000
Bihar	47,301	105,852	153,153
Gujarat	1,680,570	541,430	2,222,000
Haryana	49,157	183,399	232,556
Karnataka	1893	148,136	150,029
Kerala	20,000	0	20,000
Madhya Pradesh	0	139,720	139,720
Maharashtra	184,089	422,670	606,759
Orissa	147,138	0	147,138
Punjab	0	151,717	151,717
Rajasthan	195,571	179,371	374.942
Tamil Nadu	13,231	354,784	368,015
Uttar Pradesh	21,989	1,346,971	1,368,960
West Bengal	441,272	0	441,272
Total	2,956,809	3,770,659	6,727,468

Source: NRSA & Associates (1996)

Table 5 Properties of saline, saline–alkali and nonsaline–alkali soils

Properties	Saline soils	Saline–alkali soils	Nonsaline–alkali soils
Electrical conductivity (dS m^{-1})	>4.0	>4.0	<4.0
pH	<8.5	>8.5	>8.5
Exchangeable sodium per cent	<15	>15	>15

3.2 Characteristics of Salt-Affected Soils

The term ‘soil’ is considered to be a three-dimensional piece of landscape having shape, area and depth. Saline and alkali soils are defined and diagnosed on the basis of EC and SAR determination made on soil samples, and the information thus generated contributes substantially to the scientific agriculture based on USDA classification given in Table 5.

3.2.1 Natural or Primary Salinity

Salinity primarily results from the accumulation of salts over long period of time, in the soil or groundwater, which is generally caused by two natural processes:

- Weathering of parent materials breaks down rocks and releases soluble salts of various types, mainly chlorides of sodium, calcium and magnesium and, to a lesser extent, sulphates and carbonates. With sodium chloride as the predominant soluble salt.

- The deposition of oceanic salt carried in wind and rain forms the second cause.
- Rainwater contains from 6 to 50 mg kg^{-1} of salt, the concentration of salts decreasing with distance from the coast to the inland areas.
- The amount of salt stored in the soil varies with the soil type, being low for sandy soils and high for soils containing a high percentage of clay minerals. It also varies inversely with average annual rainfall.

3.2.2 Secondary or Human-Induced Salinity

Salinity occurs through natural or human-induced processes that result in accumulation of dissolved salts in the soil water to an extent that inhibits plant growth. Secondary salinisation results from human activities (anthropogenic) that change the hydrologic balance of the soil between water applied (irrigation or rainfall) and water used by crops (transpiration). The important causes for secondary salinisation are the following:

(a) Land clearing and the replacement of perennial vegetation with annual crops
(b) Use of salt-rich irrigation water
(c) Lands having insufficient drainage

3.2.3 Sources and Causes of Accumulation of Salts

The main causes of salt accumulation include:

- Capillary rise from subsoil salt beds or from shallow brackish groundwater
- Indiscriminate use of irrigation waters of different qualities
- Weathering of rocks and the salts brought down from the upstream to the plains by rivers and subsequent deposition along with alluvial materials
- Ingress of sea water along the coast
- Salt-laden sand blown by sea winds

Lack of natural leaching due to topographical situation, especially in arid and semiarid conditions.

Saline Soils These soils will have electrical conductivity (EC) of the saturation extract more than 4 dS m^{-1} and the exchangeable sodium percentage (ESP) less than 15 and the pH is less than 8.5. With adequate drainage, the excessive salts present in these soils may be removed by leaching thus bringing them to normalcy. Saline soils are often recognised by the presence of white crusts of salts on the surface. The important soluble salts in these soils are cations sodium, calcium and magnesium with low amounts of potassium and anions, chloride, sulphate and sometimes nitrate. 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 nonsaline soils.

Table 6 Indian system of classification

Soil characteristics	Saline soils	Alkali soils
pH	<8.2	>8.2
ESP	<15	>15
ECe	>4 dS m^{-1}	Variable, mostly <4 dS m^{-1}
Nature of soluble salts	Neutral, mostly Cl^-, SO_4^{2-}, HCO_3^- may be present but CO_3^{2-} is absent	Capable for alkaline hydrolysis, preponderance of HCO_3^- and CO_3^{2-} of Na^+

Saline–Alkali Soils These soils will have electrical conductivity of the saturation extract more than 4 dS m^{-1} and the exchangeable sodium percentage greater than 15 and the pH is seldom higher than 8.5. These soils form as a result of combined process of salinisation and alkalisation. As long as excess soluble salts are present, these soils exhibit the properties of saline soils. On leaching of excess soluble salts downwards, the properties of these soils will become like that of nonsaline alkali soils. On leaching of excess soluble salts, the soil may become strongly alkaline (pH reading above 8.5), the particles disperse, and the soil becomes unfavourable for the entry and movement of water and for tillage.

Nonsaline Alkali Soils These soils will have their exchangeable sodium percentage greater than 15, the electrical conductivity less than 4 dS m^{-1} and the pH range between 8.5 and 10. The exchangeable sodium content influences significantly the physical and chemical properties of these soils. As the ESP tends to increase, the soil tends to become more dispersed.

In addition to the parameters proposed by the USDA, Indian scientists considered the nature of soluble salts. Further, the pH value of 8.5 is too high, as isoelectric pH for precipitation of $CaCO_3$ at which sodification starts is 8.2, and mostly the pH is associated with the ESP of 15 or more. The classification of salt affected soils according to the Indian system is presented in Table 6.

4 Constraints

- Excess sodium on the soil exchange complex and/or soluble salts in the soil reduces the productivity of these soils.
- Soil physical condition, particularly soil structure, poses problem of water and nutrient availability.
- These soils show micronutrient deficiency.

4.1 Saline Vertisols

Vertisols and associated soils cover nearly 257 million ha of the earth's surface of which about 72 million ha occur in India. This shows that nearly 22 % of total geographical area of the country is occupied by vertisols. In the central part of India known as the Deccan Plateau, the soils are derived from weathered basalts mixed to some extent with detritus from other rocks. In other areas, particularly in the south, the soils are also derived from basic metamorphic rocks and calcareous clays. Similarly, in the western region, these are derived from marine alluvium that account for nearly 19.6 million ha. Of this about 1.12 million ha are affected by salinity and waterlogging problems. These soils are generally deep to very deep and heavy textured with clay content varying from 40 to 70 %. Further, these are also low in organic carbon content, high in cation exchange capacity, slight to moderate in soil reaction and are generally calcareous in nature. Vertisols, when kept fallow during *kharif* season, are exposed to soil erosion hazards. Their inherent physico-chemical characteristics such as poor hydraulic conductivity, low infiltration rates, narrow workable moisture range and deep and wide cracks pose serious problems even at low salinity level. However, the vertisols of Bara tract in Gujarat are generally very deep (150–200 cm), fine textured with clay content ranging from 45 to 68 % with montmorillonite dominant clay minerals (Rao et al. 2014). The soils exhibit high shrink and swell potential and develop wide cracks of 4–6 cm extending up to 100 cm depth. The soils are calcareous in nature having calcium carbonate ranging from 2 to 12 % in the form of nodules, kankar and powdery form.

4.2 Waterlogged Soils

An area is said to be waterlogged when the water table rises to an extent that soil pores in the root zone of a crop become saturated, resulting in restriction of the normal circulation of the air, decline in the level of oxygen and increase in the level of carbon dioxide. The water table, which is considered harmful, would depend upon the type of crop, type of the soil and the quality of underground water. It may vary over a wide range from zero for rice, 1.5 m for other arable crops and more than 2 m for horticultural and forest plantations. From practical point of view, a working group constituted by the Ministry of Water Resources has suggested the following norms:

Depth to water table (m)	Nomenclature
<2	Waterlogged
2–3	Potentially waterlogged
>3	Safe

Table 7 Extent and distribution of waterlogged and salt-affected soils in India (000' ha)

State	Waterlogged area			Salt-affected area			
	Canal commands	Unclassified	Total	Canal commands	Outside canal	Coastal	Total
Andhra Pradesh	266.4	72.6	339.0	139.4	390.6	283.3	813.3
Bihar	362.6	NA	362.6	224.0	176.0	Nil	400.0
Gujarat	172.6	311.4	484.0	540.0	372.1	302.3	1214.4
Haryana	229.8	45.4	275.2	455.0	NA	Nil	455.0
Karnataka	36.0	NA	36.0	51.4	266.6	86.0	404.0
Kerala	11.6	NA	11.6	NA	NA	26.0	26.0
Madhya Pradesh	57.0	NA	57.0	220.0	22.0	Nil	242.0
Maharashtra and Goa	6.0	105.0	111.0	446.0	NA	88.0	534.0
Orissa	196.3	NA	196.3	NA	NA	400.0	400.0
Punjab	198.6	NA	198.6	392.6	126.9	NA	519.5
Rajasthan	179.5	168.8	348.3	138.2	983.8	NA	1122.0
Tamil Nadu	18.0	109.9	127.9	256.5	NA	83.5	340.0
Uttar Pradesh	455.0	1525.6	1980.6	606.0	689.0	Nil	1295.0
West Bengal	NA	NA	NA	Nil	NA	800.0	800.0
Total	2189.4	2338.7	4528.1	3469.1	3027.0	2069.1	8565.2

Note: NA means data not available; Source: Singh (1994)

The development of waterlogging and soil salinisation upon introduction of irrigation in arid and semiarid regions is a global phenomenon. It is estimated that about 10–33 % of irrigated lands in various countries have adversely been affected due to waterlogging and soil salinisation. It seems that since 1979–1980, the area under waterlogging and soil salinisation is increasing at the rate of 3000–4000 ha per annum. It is estimated that around 4.5 million ha area in India is affected by the problem of waterlogging (Table 7).

4.3 *Coastal Soils: Characteristics and Distribution*

Areas quoted under different soil groups do not appear to have been precisely made since the coastal plains are not yet well defined. Of the two coastlines in India, length of the east coast is higher than that of the west. The continental shelf is more stable than the coast. The continental shelf of 0–50 m depth spreads over 191,972 km^2 and that of 0–200 depth over 452,060 km^2 area. The shelf is wide (50–340 m) along the east coast. The exclusion of economic zone is estimated at 2.02 million km^2.

Practically, no systematic study was earlier made to demarcate the coastal soils based on well-defined scientific indices valid for the different sub-ecosystems in this country. Among the past works, some have suggested 3.1 million hectare area (including mangrove forests), while others suggested 23.8 million hectare under coastal salinity in India. The coastal saline soil has been used by various workers almost synonymously with coastal soil *per se* which is not correct since all coastal soils are not saline in nature. None of the above estimates appears to have been made on sound scientific basis. However, the latest compilation made by Velayutham et al. (1998) on the soil resources and their potentials for different agro-ecological subregions (AESR) of India show total 10.78 million hectare area under this ecosystem (including the islands) in India, which was the first scientific approach for delineation of the coastal soils.

4.3.1 Salient Features of Coastal Problem Soils

Coastal soils in a number of situations are constrained by various technological factors limiting the agricultural productivity and, therefore, merit attention. Salinity in the soils and groundwaters has, however, become a major environmental issue, and excessive salinity in the soil or irrigation water has been considered as the main limiting factor for the distribution of plants in natural habitats. The salient factors in the coastal plains are (1) excess accumulation of soluble salts and alkalinity in soil, (2) predominance of acid sulphate soils, (3) periodic inundation of soil surface by the tidal water and (4) eutrophication and hypoxia. All the above factors affect nutrient balance in soil and, in turn, plant growth.

Salinisation is a major form of land degradation in agricultural areas, including the coastal soils. Statistics about the extent of total salt-affected soils in the world vary. However, general estimates are close to 1 billion hectare, which represent about 7 % of the earth's continental extent. Salinity build-up in coastal soils takes place mainly due to salinity ingress of groundwater aquifers, for which the main factors responsible are (1) excessive and heavy withdrawals of groundwater from coastal plain aquifers, (2) seawater ingress, (3) tidal water ingress, (4) relatively less recharge and (5) poor land and water management.

Attempts have been made on modelling of groundwater behaviour with respect to seawater intrusion. Salt water intrusion takes several forms. Horizontal intrusion occurs as the saline water from the coast slowly pushes the fresh inland groundwater landwards and upwards. Its cause can be both natural (due to rising sea levels) and man induced (say, by pumping of fresh water from coastal wells). Pumping from coastal wells can also draw salt water downwards from surface sources, such as tidal creeks, canals and embayment. This type of intrusion occurs within the zone of capture of pumping wells, which is local in nature, where significant drawdown of the water table causes induced surface infiltration. A third of intrusion is called 'upconing'. Upconing also occurs within the zone of capture of a pumping well, with salt water drawn upwards towards the well from the salt water layer or well existing in deeper aquifers.

Salt Accumulation Salt accumulation in soil affects plant growth in the coastal soil in much the same way as in inland soils except for the effects due to specific toxicity of ions under given situations. Three major types of salt-affected soils exist in the coastal plain.

Soil Fertility With regard to soil fertility, the coastal soils are usually rich in available K and micronutrients (except Zn), low to medium in available N and are having variable available P status. Major portion of the applied N fertiliser is lost through volatilisation.

4.3.2 Coastal Saline Soils

Of all the major ecosystems, which factor in agriculture or food production, 'coastal' has a significant role, wherein about 50–70 % of the global population lives within 100 km of the coastline covering only about 4 % of earth's land. Besides, the ecosystem is highly risk prone and vulnerable causing colossal damage to lives and properties, and this is further compounded due to climate change. Agriculture, on the coastal plain, is constrained by a number of technological, social or anthropological and climatic factors limiting the productivity (Rao et al. 2009).

Coastal saline soils occur along the 6100 km long coastline of India. Salinity problems in coastal areas 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. The coastal soils exhibit a great deal of diversity in terms of climate, physiography and physical characteristics as well as in terms of rich stock of flora and fauna (Rao et al. 2013). These soils comprise deltas, lacustrine fringes, lagoons, coastal marshes and narrow coastal plains or terraces along the creeks. About 3.1 million hectares of coastal soils are widely distributed in the coastal belt of West Bengal, Orissa, Andhra Pradesh, Pondicherry, Tamil Nadu, Kerala, Karnataka, Maharashtra, Gujarat, Goa and Andaman and Nicobar Islands. The coastal soils may be either saline or acid sulphate in nature. The saline soils are dominant with NaCl and Na_2SO_4 with abundance of soluble cations in the order of Na>Mg>Ca>K and chloride as the predominant anion. The major problems encountered in these areas are:

- These lands are subjected to the 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* season.
- Poor socio-economic conditions of the farming community limiting introduction of high investment technologies.

4.3.3 Inundation and Flooding of Soils

A flood is an overflow or accumulation of an expanse of water that submerges land. In the sense of 'flowing water', the word may also be applied to the inflow of the tide. 'Coastal flood' is caused by severe sea storms, or as a result of another hazard (e.g. tsunami or hurricane). A storm surge, from either a tropical cyclone or an extratropical cyclone, falls within this category. Coastal flooding is a problem wherever development has occurred adjacent to, or on, beach systems. The problems of maintaining these areas are accentuated by naturally rising sea levels due to global climate change. Floods usually occur when storms coincide with high tides. Very often the problem becomes much more severe with increase in salinity in the flood water caused by breaching or overflowing of the sea dykes, etc. Flooding thus causes significant change in soil properties depending on the soil, hydrological properties of the flood water and duration of flood. Among others, the most significant changes in soil properties of relevance to plant growth are silt deposition, accumulation of salts, erosion of top soil, organic C status in soil, depletion of soil oxygen resulting in lack of plant metabolic activities and overall reduced soil atmosphere causing significant change in soil nutrient dynamics.

Proper diagnosis and identification of contraints will help in successful remediation programme of the problem soils.

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