Chapter 9

Salt-affected Soils: Sources, Genesis and Management

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Abstract

The extent of salt-affected soils is proliferating because of different natural and anthropogenic factors like high temperature, low rainfall, poor quality of irrigation water etc. Different nature salts are being accumulated at the surface of soils and make environment difficult for plants to grow on such soils due to the reduced hydraulic conductivity and the low permeability. This leads to alter physical and chemical properties of soils making them non-productive for general cropping. Different management and remedial technologies are available to combat with the problem but the most striving concern is to opt the most economical and environment friendly technology. Different halophytic species can be used for the productive use of saline soils. Sodic and saline-sodic soils can be reclaimed using different amendments, which can provide soluble calcium to replace exchangeable sodium adsorbed on clay surfaces. There are two main types of amendments: those that add calcium directly to the soil and those that dissolve calcium from calcium carbonate already present in the soil. Studies demonstrated that under adverse conditions tree plantations may provide positive returns to investment and significant economic and social benefits to land users. These findings suggest that there is an opportunity for capital investment in afforesting abandoned salt-affected lands with multipurpose

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tree species. This chapter covers the introduction of salt-affected soils, associated aspects, management, and their reclamation.

Keywords: Salinity, Brackish Water, Root Zone Salinity, Reclamation, Management.

9.1. Introduction

Salt-affected is a general term used for soils which contain soluble salts or exchangeable sodium and/or both, in such amounts that can retard growth and development of plants. Such soils cause reduction in crop yield and are required to be managed and remediated for sustainable agriculture. Mostly salt-affected soils exist in arid and semi-arid regions but also found in some humid to sub-humid climatic areas, where conditions are favorable for their development. In Pakistan 6.67×10^6 ha area is under salt contamination (Khan, 1998) mainly due to unavailability of good quality water for irrigation. Ground water may supplement irrigation needs because of increased cropping intensity and competition from non–agricultural sectors for fresh water. At present, in Pakistan, more than 1.07×10^6 tube wells are pumping out 9.05×10^6 ha–m ground water (Anonymous, 2011) and 70-80 % of this water is unfit (Latif and Beg, 2004; Ghafoor et al. 2004) for agricultural crops having high electrical conductivity (EC), sodium adsorption ratio (SAR) and/or residual sodium carbonate (RSC) that have negative impacts for crop growth and development. In arid and semi-arid climatic zones use of low quality irrigation water has become a common practice to fulfill the needs of ever increasing population demands for food crops. (Qadir et al. 2007). Pakistan is situated in an arid to semi-arid region. As the fresh water supplies are getting short, farmers are pumping low quality (high EC, SAR and RSC) ground water for irrigation which is further aggravating the soil and ground water salinity and related hazards. These soils are adversely affecting the economic yields of crops and consequently leading to uneconomical crop production and rural poverty. In the suburbs of Indus Basin in Pakistan various research studies have been conducted and results reveal that almost 20-43% yield loss occur in salt affected fields as compared to normal ones. Qadir et al. (2014) reported that 36-69% yield loss with the average of 48% for rice crop occur due to salinity hazards. In this chapter, different aspects of salt-affected soils along with their management and remedial measures have been discussed.

9.2. Sources of Salts

Salts may originate from various sources acting either alone or in combination. However, the primary and major source of salts in soils and oceans is rocks and minerals present in the Earth crust which are weathering with the passage of time. Although the salts currently occurring in the ocean arise mainly from the weathering process of the rocks and minerals in Earth crust, now the ocean is functioning as an important “source” for the redistribution of salts.

9.2.1. Parent material and weathering process

As a result of in-situ weathering process, salts are released into soils and are accumulated or removed depending on the prevailing environmental conditions. Under humid conditions, salts leach through soils and are transported to the nearby streams and rivers resulting in formation of inland salt-affected areas. However, under arid to semi-arid climatic conditions, the weathering products accumulate in-situ and result in the development of salinity and/or sodicity. This process of formation of salt-affected soils as result of accumulation of salts released during weathering is called primary salination/sodication. In Pakistan salt-affected soils have been formed by: (i) deposition of physically transported salts along with parent material (PM) such as NaCl and $CaSO_4$ in the salt range belt of Pakistan; and (ii) mineral weathering in-situ, i.e., transformation of soil mineral and dissolution of sparingly soluble salts deposited along with PM as well as those formed later e.g. gypsum, lime etc.

9.2.2. Irrigation water

All the natural waters contain dissolved salts. The expected effect (adverse or favorable) is highly dependent upon type and amount of salts and volume of irrigation water used. Canals of Pakistan contain best quality irrigation water as it contains salts varying from 120 to 200 mg L^{-1}. As an estimate, 10-cm deep irrigation with canal water in one hectare may add 120-180 kg salts. Other common source of irrigation and salts is ground water, which are mostly brackish in arid regions like Pakistan but the levels of EC, SAR and RSC in ground waters are quite variable. On an average, the ground waters in Pakistan contain up to 1250 mg salts L^{-1} (Ghafoor et al. 2004). A 10-cm deep irrigation using groundwater may add 1.2 Mg salts ha^{-1}. Such additions of salts in the soils highly depend upon depth of ground water table, volume of water used for irrigation, and type of salts as well as upon the evaporative demand of the atmosphere.

9.2.3. Flood waters and waste effluent

Flood water mostly redistributes the already present salts but may become important in some parts of the world such as during monsoon in Pakistan. Similar is the case with untreated sewage water as a source of salts, particularly in the Third World countries where it is used to irrigate crops, mainly vegetables, around cities or is disposed-off into the existing irrigation channels. Such irrigation waters are of particular concern with respect to heavy metals entry in the food chain of human beings and because of many pathogens as well as toxic organic materials.

9.2.4. Sea water

Sea water (EC > 4 dSm^{-1}, SAR > 50-55) intrusion as well as sea water sprays could contribute large quantities of salts but the action is a bit localized along coastal areas. Almost similar is the mode of inland saline seeps to contribute salts. However, importance of playas (Lakes having input but no output of effluent) need special consideration in some areas of the world. The soils in coastal areas are enriched with salts coming from sea through various ways, such as:

a) Striking of sea water high-tides with nearby surface soil;
b) Entry of sea water through rivers, estuaries, etc.;
c) Ground-water inflow; and
d) Salt-enriched sprays transported up to many kilometers inland from the sea coast and deposited as dry “fall-out” or “wash-out” by showers. Inland deposition of NaCl at a rate of 20-100 kg ha^{-1} $year^{-1}$ is quite common and values of 100-200 kg ha^{-1} $year^{-1}$ for nearby coastal areas have been reported. Although these amounts may appear small, but their regular deposition over long periods of time may lead to salinization of the soils.

9.2.5. Lacustrine and marine deposits

According to geological information, once whole of the Indian sub-continent was under sea. Gradually, sediments from Himalayas produced up-lands which were later developed for agriculture. Hence, some of the salts could be considered as fossil salts. Irrigation with low quality water reveals that salts already present in the soil profile are transported to the soil surfaces with irrigation which are left behind after evaporation. Thus, after a longer period of time salts that were previously evenly distributed in the whole profile may selectively accumulate on the soil surface and give rise to saline soils. Accumulation of salt-laden runoff water and its subsequent evaporation in the un-drained basin is also a cause of salinity in many low-laying areas.

9.2.6. Fossil salts

Salts accumulation in the arid regions often involves “fossil-salts” which are a consequence of earlier deposits or entrapped solutions in former marine or lacustrine deposits. Salt release may occur through natural as well as anthropogenic activities. An example of the former situation is the rise of salt bearing ground water through an originally impervious cap (which became permeable as a result of weathering process) overlaying saline strata. Examples of latter scenario are assembly of canals along with water works within the saline strata and use of ground water for irrigational purposes. In Rajasthan, India, a canal built on an underlying gypsum layer has resulted in development of salinity in the area within only a few years of its construction. This has been due to perched water table and contribution of salts from the underground gypsum layer.

9.2.7. Chemical fertilizers and waste materials

Utility of inorganic fertilizers is increasing and that of organic manures is decreasing in agricultural fields but their contribution to overall salt build-up in soils is insignificant. However, certain situations, such as dumping of cow’s dung slurry, sewage sludge or industrial by products such as press mud or pyrites, can contribute to excessive accumulation of certain ions those could limit soil productivity.

9.3. Genesis of Salt-affected Soils

The mode of soils-origin and/or the processes and factors involving in soil formation from un-consolidated parent material is defined as soil genesis, i.e., it is a process of developing soils from parent material. Genesis is a continuous but slow process that includes decreasing the particle size of the parent material, reordering of mineral particles, addition of certain materials such as organic matter and salts, changing the kinds of minerals, creating horizons, and producing clays.

9.3.1. Genesis of primary salt-affected soils

The following factors mostly contributed towards the genesis of salt-affected soils in Pakistan.

9.3.1.1. Salty parent material

Presence of primary minerals as the special constituent of parent material is the most important factor for genesis of salt-affected soils. Arid to semi-arid climatic zones of the world including Pakistan have more common soil salinity concerns due to low precipitation which is inadequate for leaching of salts below root zones. Under these circumstances soluble salts coupled with exchangeable Na^+ have accumulated over thousands of years during the process of soil formation. This is the case of primary/old/ancient salt-affected soils. These soils existed before the advent of the canal irrigation system in the Indus Plains of Pakistan.

9.3.1.2. Aridity and uneven distribution of rainfall

Most of the soils of Pakistan exist in arid to semi-arid climatic regions. Most of the rainfall occurs during monsoon (July-August) while during major part of the year the salts present in the soil tend to move upward with water through capillary action. The rainfall that is received (mostly < 500 mm annually) is not sufficient to leach down the salts away from the root zone. Moreover, the net upward movement of water in the soil along with evaporation at the surface provokes the accumulation of mineral salts in the surface soil.

9.3.1.3. Physiographic unevenness

Micro unevenness of the soil surface is generally not observable. This situation can be visualized from different depths of the standing water after a heavy rainfall. The rainwater flows from the convex parts over the sloping parts and is accumulated on concave parts. In parts where there is low effective leaching (convex and sloping parts), accumulation of salts takes place. Hence, patches of salts develop in an uneven soil. In Pakistan, the natural drainage is poor due to lower slope of 30 cm per 1609 m which promotes the salinization and sodication processes.

9.3.2. Genesis of secondary salt-affected soils

Introduction of canal water irrigation system in Pakistan is the major cause of evolution of secondary or man-made salt-affected soils. However, the extent of secondary salt-affected areas is very small than the primary salt-affected areas.

Several factors act alone or in combination to form secondary salt-affected soils. Insufficient or unequal application of irrigation water, imperfect soil drainage, waterlogging, brackish ground water, improper soil and water management, seepage from canals and water courses or combination of these factors are the principal causes for the formation of secondary salt-affected lands.

9.3.2.1. Sodication

Sodication can be defined as process of accumulation of exchangeable Na^+ content in the soil that results in the formation of poor soil structure along with unavailability of essential nutrients (Qadir et al. 2004). The salts of Na^+ Ca^{2+} and Mg^{2+} as well as Cl^- and SO_4^{2-} are present in excess under salt-affected soils while those present in smaller amounts are cations like K^+ and NH_4^+ and anions like CO_3^{2-}, HCO_3^- and NO_3^-. When salt concentration in soil is very high, a part of Ca^{2+} and Mg^{2+} precipitates as $CaCO_3$, $MgCO_3$, $CaSO_4$ and $MgSiO_3$. The precipitation of these salts results in the increased proportion of Na^+ in soil solution as well as on the exchange complex. In this way, saline soils can be regarded as responsible for genesis of sodic soils. For this reason, most of the moderately to strongly saline soils in Pakistan are generally saline-sodic/sodic as well. Sodication generally leads to deflocculation (dispersion), poor drainage and poor aeration in soil (Shainberg and Letey, 1984). In addition, severe nutrient imbalance results in these soils which may be in the form of deficiency as well as toxicity of certain vital elements. Such physical and chemical impairments lead towards low yield and production due to negative impacts on root growth activity coupled with soil micro-organisms. The color of sodic soils is most often dark that is due to deposition of discrete and suspended organic matter prevailing in soil solution at the soil surface. In such soils, after evaporation, darkening of the soil color is increased which may extend up to blackish in.

9.4. Classification of Salt-affected Soils

Salt-affected soils are usually characterized into three main groups 1) saline, 2) sodic and 3) saline-sodic.

9.4.1. Saline soil

Saline soil is referred as a soil that contains plenty of soluble salts that have adverse effects on plant growth but does not contain excessive exchangeable Na^+. Most of the soluble salts in saline soils are composed of cations Na^+, Ca^{2+}, and Mg^{2+} and of anions Cl^-, SO_4^{2-}, and HCO_3^-While in minute concentrations other cations such as K^+ and NH_4^+ along with anions including NO_3^-, CO_3^{2-} and BO_4^{2-} also occur in these soils. Saline soils have $EC_e \geq 4$ dS m^{-1}, SAR < 13 $(mmol\ L^{-1})^{1/2}$, ESP < 15and $pH_s < 8.5$.

9.4.2. Sodic Soil

Sodic soil can be defined as a soil that restrains adequate concentrations of exchangeable Na^+ that have serious impacts on plant growth and development but not having excessive concentration of soluble salts. Soil structure, aeration, and hydraulic conductivity are deteriorated by the excessive amount of exchangeable

Na^+. Sodic soils have EC_e < 4 dS m^{-1}, SAR > 13 (mmol $L^{-1})^{1/2}$, ESP > 15 and pH_s > 8.5.

9.4.3. Saline-sodic soil

Saline-sodic soil refers to a soil having both soluble salts as well as exchangeable Na^+ in sufficient amounts that cause harmful impacts on all type of crop plants Saline-sodic soils are characterized as the soils that have: EC_e > 4 dS m^{-1}, pH_s > 8.5, SAR > 13 (mmol $L^{-1})^{1/2}$ and ESP > 15.

In some literature, the term "alkali" is used in place of "sodic", i.e., for soils having excess exchangeable Na^+. Hence, the terms "saline-alkali" in place of "saline-sodic" and "alkali" in place of "sodic" are used. However, the use of the term "alkali" is being discouraged because of its ambiguity with the term "alkaline" which refers to the soils having pH > 7.0. According to an estimate (Khan 1998), the salt-affected soils of Pakistan cover on area of about 6.67×10^6 ha.

On global basis, the salt-affected soils exist mostly under arid and semi-arid climates in more than 100 countries covering about 9.55×10^6. These soils cover about 25% and 60 % of the world's irrigated and cultivated land, respectively. Overall, about 62% of the salt-affected soils of the world are saline-sodic/sodic while 38% are saline (Tanji 1990).

Table 9.1 Extent of soil salinity/sodicity problem in Pakistan

Province	Area (Million ha)
Punjab	1.234
Sindh	3.04
Balochistan	0.12
KPK	0.11
Pakistan	4.50

Source: WAPDA (2003)

Table 9.2 Salt-Affected Area (m ha) of Punjab, Pakistan

Year	Area Survyed	Salt Affected			
		Uncultivted	Cultivated	Total	%age
1945-46	4.84	0.42	0.49	0.91	18.80
1955-56	5.96	0.05	0.69	1.20	20.64
1965-66	6.88	0.44	0.68	1.12	16.28
1975-76	7.34	0.37	0.61	0.98	13.35
1985-86	7.57	0.30	0.58	0.88	11.62
2000-01	7.92	1.16	1.51	2.67	33.71

Source: Ahmad and Chaudhry (1997)