Review Paper:

The Disastrous Effects of Soil Salinity and pH on Environmental Systems

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Abstract

Soil salinity is a natural element of arid and semi-arid climates and it is becoming a growing concern in the soils across the world. When water-soluble salts build in a soil, it gets salinized. These salts contain chloride, sulphate, carbonate, bicarbonate and sodium in addition to potassium and magnesium. Due to shortage of oxygen, soil with a high salt level becomes incapable of supporting plant and animal life. This review discusses the causes of salinity, its impact on plant growth, their limits/standard in the environment systems and case studies of saline land. Besides this, salinity levels in streams and lands are generally rising as a result of rising groundwater levels. Most of the rural and urban communities have lost productive cropland and water supplies due to natural instability to these environments and human induced interferences.

Crop productivity, seed germination soil and water quality are adversely affected by soil salinity. A coastal region is also particularly vulnerable to climate change. There is a need to study soil salinization and its measures in detail for sustainable environmental systems.

Keywords: Plant stress, Salinization, Salt tolerant plants, Salinity-mitigation, Sustainable environmental systems.

Introduction

The beginning of the twenty-first century is characterised by a global shortage of water resources, environmental degradation and a rise in soil and water salinization that is nowadays recognized as a disastrous crisis[61]. Arid and semiarid regions are most commonly affected by soil salinity problems and crop production is reduced at different levels. A poorly drained soil is also highly salinized limiting crop yields[13]. In comparison to other environmental problems as a disaster such as global warming, climate change, water pollution, air pollution and deforestation, soil salinization is not as controversial; however, it should not be underestimated since many countries will not be able to produce enough food in the future if soil salinization continues at its current rate[28,29].

Salinity and sodicity both are associated with sodium. The term "sodicity" describes the salt content of soils. It comes about as a result of a process where sodium ions accumulate on the soil's exchange complex in preference to other soil cations, notably calcium. This process is typically accompanied by increases in soil pH and decreases in calcium and magnesium. Salinity, which is more commonly used, describes how much soluble salt is present in the soil. Salinity is influenced by water motions, unlike sodicity. The electrical conductivity (EC) and/or chloride concentration are used to determine the salinity of soil[36].

There are various mechanisms by which salinity can reduce plant performance and growth such as changing water relations in the plant, depletion of ions and toxicity[1,18,40,49]. A large percentage of irrigated land is affected by salinization due to the use of brackish water. The use of salt has damaged more than 45 million hectares of irrigated land worldwide and salt in the soil causes 1.5 million hectares to be out of production each year[12,49]. There are salts in all soils. All irrigation waters, whether from canals or underground pumps, even those of very good quality, contain some salts. Many salts are essential plant nutrients and are a common component of soil. Inorganic fertilizers, gypsum, composts, manure and mineral weathering contribute to the formation of salts[12,41].

There is a great deal of opportunity for study on the relationship between climate change and the drivers of soil salinity as a catastrophe at the global and regional scales. Soil salinization has been widely studied and documented in coastal regions with its disastrous impacts whereas inland areas have not yet been evaluated and monitored[21]. It has also observed that in dry and semi-arid regions, salinization and waterlogging are the two irrigated cultivation curses that negatively impact undeveloped fields' output. Setting up quick monitoring systems is necessary.

Comparing remote sensing to traditional ground techniques for mapping and monitoring soil salinity, there seem to be a number of benefits. The reflectance from bare soil or the salt crust may be used to map soil salinity while vegetation covering and health can be used to indirectly map soil salinity[39].

Causes of Salinity as a disaster

A soil becomes salinized when water-soluble salts accumulate. In addition to potassium and magnesium, there are chloride, sulfate, carbonate, bicarbonate and sodium in these salts. The process of sodium accumulation is also known as sodification. A soil with a high sodium content becomes incapable of supporting plant life and animal life due to a lack of oxygen[17,52,74]. Geological, hydrological and pedological processes are responsible for the development of most saline-sodic soils. These soils are formed mainly by intermediate igneous rocks known as phenolytes, basic

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igneous rocks known as basalts, undifferentiated volcanic rocks, sandstones, alluvium and lagoonal deposits. Salinization may be accelerated by water management and climate factors[59].

Besides that, the cultivation of naturally salty lands, the increase in secondary salinity due to the inflow of mineralized groundwater from higher plateaus with intensive irrigation and the disposal of drainage water into irrigation canals increases the salt content of irrigation water[75]. It is widely acknowledged that salinity is one of the disastrous environmental factors limiting the productivity of crop plants as a result of its sensitivity to it, resulting from high salinity concentration in the soil and the fact that more and more lands are becoming impacted by it every day[57].

Disastrous Impact of Salinity on Environmental systems

The soil productivity has been impacted by a variety of environmental stresses including high winds, extreme temperatures, soil salinity, drought and flood. Soil salinity is one of the most catastrophic and disastrous environmental stresses, leading to significant decreases in crop productivity and quality[73].

Crop production around the world is adversely affected by salinity. Several factors can exacerbate this process including climate change, excessive groundwater use (especially in seaside regions), the use of low-quality water for irrigation and intensive farming practices associated with a massive increase in irrigation. Most vegetables, which are particularly sensitive throughout their entire ontogeny to soil salinity, suffer from low productivity due to soil salinity[40]. Due to the poor physical properties of the soil in saltlands, osmotic effects of salts cause poor aeration, nutritional imbalances and toxicities that limit plant development[72].

The effects of high salinity on plants are twofold: high concentrations of salts in the soil can inhibit root water absorption and high concentrations of salts within the plant itself can be toxic, inhibiting the uptake of nutrients and assimilation in the plants[34]. Salt stress significantly affects most glycophytes (salt-sensitive) crops. The stress caused by soil salinity is classified into three types: osmotic stress, ionic stress and secondary stress[6-8]. Salinity of soil is a natural feature of arid and semi-arid regions and it is becoming an increasingly important issue in undeveloped soils all over the world. The occurrence of salinity on a smaller scale is more common in temperate, moist climates, particularly in saltwater marshes, near highways and in effluent discharges containing salts.

In addition to causing damage to buildings, roads and rail links, salinity also damages sewage systems, telephone lines, gas lines and electricity grids[25,32]. On the other hand, plant growth is affected by salts due to soil osmotic pressure and nutrition interference. The osmotic or water-deficit effect of salinity refers to the reduced ability of plants to acquire water when there is a high salt concentration in soil solution. Increased salinity caused by either dry land salinization or saline water disposal schemes poses the greatest threat to lowland river systems also[33]. Even saline dust storms are really disastrous natural weather events that usually happen in arid and semiarid parts of the world[4].

Standard permissible limit of pH:
: According to WHO guidelines[68], the ideal pH range for aquatic life is between 6.5 and 9.0 whereas the range for drinking water is between 6.5 and 8.5. Water used for irrigation typically has a pH between 6.5 and 8.4.

Sodium change: The proportion of Na^+ is frequently used as a significant factor in determining whether water is suitable for irrigation. 200 mg/l of sodium is the recommended level for drinking water[26,68].

Prediction of soil salinity using Remote sensing: To map regional variation and forecast soil salinity, remote sensing data and multivariate analysis are essential techniques. The accuracy level is greatly increased by the salinity model that is produced using spectral parameter determination and cation lab analyses. According to abd et al[1], a regional area with variable soil salinity problems could be chosen for the application of the developed salinity model and testing the feasibility of using only remotely sensed data and its relevant spectral indices to investigate soil salinity problems with a larger number of sampling sites[1]. According to the current study, integrating remote sensing (pictures and spectral indices) with near sensing (EM38) technologies can result in quick, affordable and reasonably accurate methods of monitoring, assessing and forecasting soil salinity in relatively large dry and semi-arid regions[20].

In a research study of Kenli district of the Yellow River Delta, Li et al[44] have measured the soil salinity content in four seasons i.e. spring, summer, autumn and winter seasons —as well as four layers—surface layer (0–15 cm), superficial layer (15–30 cm), middle layer (30–45 cm) and deep layer (>45 cm). They used remote sensing monitoring of cultivated land salinization in the study area to study the problem of soil salinity. Landsat Images were used to extract the salinity index and vegetation index and a random forest technique was used to build surface salinity inversion models for various seasons[44].

Nowadays, it becomes possible to use machine learning to quickly monitor extensive spatial soil salinization. However, substantial training samples are frequently required for machine learning and gathering comprehensive data on soil salinization through field research is time-consuming and challenging[69].

According to Daliakopoulos et al[15], future studies on soil salinization should concentrate on the carbon dynamics of saline soil, further investigation of remote sensing of soil properties, remotely sensed data of saline lands and the harmonisation and enrichment of soil salinity maps to support policies and approaches for the protection of nations' soils[15].

In order to verify the accuracy of satellite images in mapping and monitoring salinity, field measurements are needed to validate the output. Salinization can be monitored using remotely sensed data. Keeping track of and monitoring salinity is vital to detecting further degradation and undertaking appropriate reclamation and rehabilitation measures in time to prevent further degradation[50].

Case studies of salinity /saline land

There has been an increase in salinity and sodicity over the past century. Over 25% of the total land and 33% of the irrigated land worldwide are affected by salinity and sodicity. As a result of soil salinity and sodicity, crops do not grow as well as they should because there are water logging problems, groundwater contaminations, losses in soil fertility and other adverse effects on ecosystems that depend on the soil. In addition to affecting food security, salinity and sodicity affect a significant portion of irrigated lands[47]. There is a wealth of data showing that drainage systems boost yields, which in turn raises rural incomes.

Egypt has one of the most extensive subsurface drainage programmes in the world[2]. A nationwide monitoring programme showed that the installation of subsurface drainage caused an average 30% decrease in the depth of the groundwater level, a 35 to 50% decrease in the areas affected by soil salinity and increased yields of all crops - beyond expectations - though different crops responded differently[3].

Recent investigations on soil characterization conducted in connection with the Central Queensland Sustainable Farming Systems Project have shown that many of the soils utilised for dry-land farming in the area contain high natural subsurface salinity and sodicity[36].

Most of the countries are facing the problem of soil salinity in their region. The most sensitive spectral bands are still unable to define vegetation indices (VIs), For this reason, previous vegetation indices (VIs) may not be capable of predicting salinization.

An investigation was conducted in the Yellow River Delta (YRD) of China to better understand the relationship between vegetation spectra and soil salinity by collecting hyperspectra of seven salt-sensitive/halophyte species and their root-zone soil samples[65].

Salinity and sodicity problems have significantly decreased Ethiopia's irrigated crop growing productivity, resulting in food insecurity, environmental degradation and lower yields. As a result of poorly managed irrigation water and a lack of drainage, salt-affected soil is likely to develop sooner, spreading to previously unaffected areas. Several approaches are suggested for tackling salinity and sodicity problems that summarize the knowledge of the causes, extent and effects of salt-affected soils on soil and crop production[14].

In another study, there is a negative impact of salinity on the productivity and profitability of farmland in the western San Joaquin Valley (WSJV). As a result of droughts, climate change and reduced water allocations, the salinity conditions may worsen. In order to develop mitigation strategies for soil salinity, it is critical to map it at the regional and state levels, but traditional soil sampling for salinity does not produce accurate large-scale maps[60]. Sea level rise, frequent cyclones, increasing salinity and altered seasonal patterns are some of the climatic stressors that have an impact on the Sundarbans. It is a very hazardous for bay of Bengal[58].

In coastal regions, salinity intrusion speed and distance are affected by different kinds of winds and their directions. The speed of salinity intrusion will be faster and the intrusion distance is longer if the wind direction is similar to the tide direction. However, the direction and effect of wind vary from place to place. Salinity intrusion disasters can be made heavier in Tanzhou and Shenwan of Zhongshan City and in Hongwan of Zhuhai City, whereas they can be made lighter in Sanzhao of Zhuhai City in the northeast[71].

The attempted study i.e. “Adaptation Strategy with Climate Induced Salinity Disaster in the Coastal Area of Bangladesh”, reveals into explanatory reactions to saline-water intrusion in Bangladeshi coastal regions, which are well-known for offering ecological and livelihood services[57]. Coastal population's livelihood, income generation and food security will be threatened by increasing salinity concentrations in future. Several measures have been implemented at the local and community levels to improve water supply including rainwater harvesting, water conservation, water treatment technology (such as pond sand filters) and groundwater use management, but the Government in the coastal countries has not prioritized the salinity issue in its disaster management plan so far[3].

An attempt was made to conduct a two-year field study based on qualitative data collection (semi-structured key informant interviews and focus group discussions) and a literature review (January 2011–December 2012). Based on preliminary key informant interviews, which were done to identify which natural disaster(s) will probably have or are already having the largest impact from climate change, the cyclones and salt water intrusion were selected as a focus in their research study.

Despite numerous recommendations, these two i.e. cyclones and salt water intrusion got the most attention.[30] As a result of increased salt levels, powerful winds and salt dust created by the wind in the region surrounding lake Urmia, the lands of the area are progressively salinized, leading eventually to desertification.

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Table 1
Case studies of saline land: India

Year of study	Location/Area	Methods used	Salinity Impact/ Causes	Major findings
2002	5000 ha in Gohana sub division of Sonepat District Northwest region of Haryana	For data collection, an area-random sample was taken using a grid of pre-determined density, in accordance with the grid scheme of the patwari maps.	Farming damage in Haryana is around Rs. 23,900/- per ha, with a potential yearly loss of Rs. 1669 million as a result of water-logging and salinity changes.	Cropping intensities and crop yields are found to decrease when soil salinity increases[16].
2007	The Damoda abandoned open cast mine of BCCL that has been filled with coal ash from the Chandrapura Thermal Power Station	The results of collecting samples were determined using atomic absorption spectrophotometry and a pH metre.	Near the research location is an ash field. As a result, researchers discovered a considerable quantity of heavy metal and monthly sample gathered data suggest that the PH value changes month to month.	The pH range recorded in the research region is 7.03 at the low end and 8.02 at the high end. The pH value is between the standard range[55].
2009	The Musi River drainage area is 2727 km^2 and is located near Hyderabad.	Samples obtained from a transect of nine sampling sites was created, six along the WIA and three locations outside of the WIA.	Because of the excessive wastewater mix-up in river water and tributaries, salinity is rising.	Salinity is most likely a cause in the declining rice yields in the Musi wastewater irrigated area[11].
2012	Tripalli, 425 ha gross area from Kerala.	The attempted study employs techno-social methods. The authors used the Salinity Participating Rural Approach technique to obtain salinity data.	The main reason for the rise in salinity is that canal water is directly exposed to sea water.	In this study location, salinity has the greatest influence on irrigated Boro crops. The benefitted area is 350 hectares[54].
2013	Pravaranagar has an area of 306 hectares and is located in the district of Ahmednagar, Maharashtra.	In all, 15 distinct soil samples (one kg each) were collected from chosen sites in the Pravara region at depths ranging from 0 to 15 cm.	Excessive and unplanned use of fertilisers and ground water for irrigation and agricultural production may arise. all micronutrient concentrations were present in adequate proportions. Soil, while rich, has an alkaline pH.	The pH of the soil in the Pravara region ranged from 8.04 to 9.10. As a result, the pH of all soil samples was alkaline[37].
2015	Dhapa has a land area of around 35 hectares.	The Leachate Technique is used to collect samples for examination.	All heavy metals were detected in leachate at levels below their respective allowable limits. The pH value indicates the biological stabilisation of the organic components.	The pH value of the collected leachate in this research region was substantially alkaline[46].
2021	Punjab's Malwa area in the south-west. In the districts, there are four blocks: Gidderbaha, Lambi, Malout and Muktsar, with a total size of 2656 km^2.	Portable devices (Eutech portable EC/pH metre) were used in the field to collect samples and conduct laboratory analyses.	As a result of excessive groundwater extraction. And the canal network in the study region is mostly responsible for the salinity increase.	Based on the d-excess values, four zones were formed in the region. The recharge sources and salinity levels distinguish these zones[42].

Table 2
Case studies of saline land: Other Countries

Year of study	Location/Area	Methods used	Salinity Impact/ Causes	Findings/Remarks
2008	Inner Mongolia, China, It covers a total area of 1,100,000 ha, including 570,000 ha of agricultural land irrigated.	A study of soil salinity was undertaken using a remote sensing technology and images to compare the existing status of the soil to that of the past.	From 1973 to 2006, salt-affected cultivated area reduced by up to 42200 hectares	Due to the installation of a pumping station and an improved drainage system, the salinity of the soil has decreased[70].
2014	The actual study area Werigan–Kuqa Oasis, China, is bounded between 82°10′E ~ 83°50′E longitude and 41°06′N ~ 41°40′N latitude	Data acquisition via EM-38, Electrical conductivity from soil sampling, Remote sensing data and relevant indices, Spatial interpolation and comparison.	Surface irrigation is the primary source of soil salinization in this region.	According to the current study, combining remote sensing (pictures and spectral indices) with near sensing (EM38) technologies can result in quick, affordable and reasonably accurate methods of monitoring, assessing and forecasting in this study region because soil salinity is higher in dry and semi-arid regions than in wet regions[20].
2016	Wonji 6539 ha.	Remote sensing and GIS enabled spatial modelling, regression model and technique validation were used.	Moderate and slightly saline classes cover approximately 30% and 33.7% of the total area, respectively. None-saline class accounted for over 36% of the total area	Validation, verification, correlation and observation would be used to define 80% of the region as saline[9].
2021	Djilor that covers a total area of 444 km^2	The spatial distribution and LULC trends in salt-affected areas between 1984 and 2017 have found.	A stepwise regression analysis was applied where remote sensing indices (SI, SAVI, NDVI, elevation, distance to the river and TWI) were used.	According to changes in a certain parameter, there was a slight decrease in soil salinity between 1984 and 2017. Whereas growth in somewhat salinized and non-salinized regions were 42.14% and 7.85%, respectively, improvements in highly salinized areas were 23.47%.[67]
2022	Keneli District, Yellow River Delta, with a total area of about 2331 km^2	The authors have attempted to investigate the relationship between surface salinity and spectral indicators by developing a surface salinity inversion model and measuring samples such as NDVI, DVI, RVI, EVI, SAVI and ARVI and salinity indices such as SI, SI1, SI2, SI3, SI4 and SI5.	As soil layers get deeper, the average salt concentration rises, variability reduces and the saline soil area extends. Summer is the most salinized season for agricultural land in contrast to other seasons[8].	In the surface salinity model[43], the highest correlation coefficients between salinity index, vegetation index and soil salinity are 0.804 and -0.807.

It is possible to minimize the adverse environmental effects of salt dust in the dried areas of the lake, which is the main cause of this problem[23]. Tsunamis and typhoons have recently increased flooding and salinity in Japan's coastal lands. Southern Japan was affected by flooding following typhoon in 1999.

A few case studies of saline land for the Indian region and other countries also appear in table 1 and 2.

Managing salinity for sustainable Environmental systems

Soil salinity is a global environmental challenge to sustainable environmental systems that have grown over time. This could be because of the use of chemical fertiliser, soil erosion, or rising sea levels as a result of global warming[31,35]. Global food security and environmental sustainability are hampered by soil salinity in the recent era.

As a result, climate change accelerates soil salinity development, potentially spreading the problem to previously unaffected areas in the near future[48]. To develop effective management methods for the land productivity of salt affected region or coastal regions, particularly low-lying delta regions, which provide a source of livelihood for many millions of farmers worldwide, it is essential to understand the dynamics of salt transport in the soil. There are currently no numerical models that can account for soil salinity at both the regional and daily time scales[53].

The sustainability of the farming production system in irrigated drylands is under risk due to declining water quantity and quality, inadequate land, water and crop management practises, rising soil salinity, land degradation and desertification. In order to find the best mix of techniques that increases sustainability while reducing land and environmental damage, assessments of salinity dynamics and sustainability indicators are required[19].

As a result of its suitability for various purposes, groundwater quality is as important as its quantity. An important aspect of groundwater studies is water quality analysis. Geomorphological formations and human activities greatly influence the variation of groundwater quality in an area.

In groundwater, electrical conductivity reflects the total dissolved solids, so it can be used as a good indicator of salinity hazards[66]. Salinity stress is a major factor in reducing its growth and yield. As a result of high soil salinity, plants are subjected to osmotic and oxidative stress[6]. The scarcity of surface water supplies, the salinity of the groundwater and the condition of the salt-affected soil make it challenging to continue expansion in dry regions. The development of sustainability and expansion plans requires the application of systems thinking, taking into account the complicated feedback interactions between saline groundwater, salt-affected soil, plant growth, freshwater mixing with saline groundwater, irrigation systems and the use of soil amendments to alleviate the salinity impacts[63]. Scientific research is heavily focused on the environmental stress since it reduces plant productivity. Human activities have made this situation even worse. Stress from salinity has a negative impact. This happens as a direct result of how salt affects processes including photosynthesis, respiration, nutritional absorption, hormone imbalance etc.

The capacity of plants to develop and finish their life cycle on a substrate with high concentrations of soluble salt is known as salt tolerance. Halophytes are plants that can thrive and grow in rhizospheres with high salt concentrations[51]. Fertilization improves the efficiency with which nutrients are used and permit the application of fertiliser without significantly raising soil salinity.

By adding some nutrients, vegetable crops' resistance to salt can be improved (e.g. silicon, humic acid etc.). Additionally, biofertilizers may improve vegetable crops' tolerance to salt and lessen soil salinization[45]. The mechanisms that regulate salt tolerance are complex, taking into account osmoloregulation, hormonal control, osmotic adjustment, ion homeostasis and antioxidant protection[22]. Such accomplishments depend only on evaluation of the phenotypic expression of the relevant traits[10].

Mitigation strategies for the problem of soil salinity

One of the main causes of cultivated soils losing productivity is soil salinization. Although it can be challenging to determine precisely, there are more and more salinized soils on the earth. Irrigated soils are particularly affected by this phenomena. One-third of the world's agricultural land, or around 20% (45 million hectares), is thought to be salt-affected[45,65]. There are several abiotic stresses that limit plant growth and development including soil salinity. Saline soil conditions cause plants to experience a significant amount of high osmotic stress, ion toxicities and nutritional disorders, which lead to reduced soil properties and plant productivity. Physiological, biochemical and morphological changes occur in plants under salt stress.

To mitigate the adverse effects of soil salinity on plant growth and productivity, comprehensive management approaches that combine physiological and biochemical attributes with molecular tools, are required. To address the problem of soil salinity, recent reports have highlighted the importance of integrating a variety of advanced strategies[39]. In a saline environment, there are two main strategies for increasing and maintaining productivity: adapting the environment to the plant and adapting the plant to the environment. The former strategy has been tested more frequently.

Climate change may accelerate the development of high salinity worldwide, but especially in dry and semi-arid areas. The various mitigation strategies including amendments

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(gypsum, biochar, MSW, zeolites), salt-tolerant genotypes, subsurface drainage in waterlogged saline areas, micro-irrigation techniques (drip system), climate smart conservation agriculture, land shaping strategies, agroforestry and microorganisms, have the ability to reclaim salt-affected soils.

By enhancing the physico-chemical (pH, EC, bulk density, accessible soil nutrients) and biological (enzyme activity, MBC) characteristics of salt-affected soils across the world, these approaches can increase soil health and production[48].

Conclusion

In arid and semi-arid regions of the world, soil salinization has adverse effects on plant growth and productivity. These days, excessive fertiliser use and over-exploitation of cultivation with uncontrolled irrigation water are causing soil degradation. Lands in coastal areas turn into kharlands as a result of seawater intrusion. The biggest dangers to the coastal environment are this kind of land degradation and salinization, which can result in an agrarian catastrophe also. Salinity directly affects photosynthesis, respiration, nutrient assimilation. The primary salinization of soil is caused by high amounts of salts and minerals of parent materials. Human-induced salinization is primarily caused by conventional irrigation methods and poor drainage systems. It appears that salinity stress is one of the major constraints on the productivity of plants and crops.

One of the main risks to soil deterioration that most nations face is soil salinization. Numerous crucial ecosystem and non-ecological soil functions are affected by salinization. Determinants of salinization can be found within the natural and man-made environments with the climate and predicted climate change also playing a significant impact. Salt stress has a significant impact on crop productivity. Salinity, drought, cold and heat are abiotic stresses that negatively affect staple food crops' survival and yield.

On the global and regional scales, there is much opportunity to study how climate change influences soil salinity. Therefore, sustainability requires an in-depth study of soil salinization and its measures. Simultaneously, soil salinization can be predicted with remote sensing techniques during different seasons and for multiple soil layers. As a result, decision support can be provided for dynamic monitoring of land salinization as well as sustainable land use.

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