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Soil Salinity Prediction, Monitoring and Mapping Using Modern Technologies

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Abstract

In arid and semi-arid regions of the world, soil salinization is one of the most crucial environmental problems due to its adverse effects on agricultural productivity and sustainable development. Unconscious irrigation and old irrigation techniques extremely damage fertile land and accelerate water logging and salt accumulation in soil. In addition, some natural factors also exacerbate soil salinity. Therefore, it is an important concern to predict and monitor soil salinity in order to take protective measures against further deterioration of the soil. In this study, emphasis is given to the techniques used for predicting and monitoring soil salinity throughout the different regions of the world. Examples of soil salinity mapping will also be referred to alert especially the soil scientists and farmers. Traditionally, soil salinity prediction and monitoring are often carried out with intensive field work and sampling. Most previous studies have focused on differentiating salinized and non-salinized soil qualitatively by analysing the salinity distribution and monitoring its dynamics. Remote Sensing (RS), Geographical Information Systems (GIS) and modelling have recently outperformed the traditional methods. Mapping has progressed from qualitative to quantitative mapping via multiple-temporal and multi-spectral information obtained from RS observations. In zones of thickly vegetated soils, using vegetation indices in the evaluation, mapping of soil salinity have started to yield promising results; whereas indices have become the appropriate method in the case of exposed soils or soils with low scattered vegetation. This study reviews the application of various satellite images to delineate soil salinity maps by conducting either salinity indices generated by different spectral bands or vegetation indices.

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Keywords: Soil salinity; Remote Sensing; Salinity indices; Irrigation.

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1. Introduction

Soil salinization is a worldwide environmental issue that adversely affects plant growth, crop production, soil and water quality, and eventually results in soil erosion and land degradation (Zhu, 2001; Corwin and Lesch, 2003). Almost 3% of the world's soil resources are salt-affected (FAO, 2010). It is characterized by its development in both time and space due to accumulation of soluble salts at or near the surface of the soil (Schofield et al., 2001; Abbas et al., 2013). In especially arid and semiarid regions, it is becoming an important problem affecting agricultural production and sustainable utilization of land resources (Metternicht, 2003; Zheng et al., 2009; Rongjiang and Jingsong, 2010) leading to areal reduction of farmlands by 1- 2% per year (FAO, 2002).

Unconscious irrigation and practising old irrigation techniques, irrigating agricultural land with water rich in salt, land clearing and using fertilizer containing nitrogen and potassium salts are among the human-induced activities that cause soil salinity together with some natural factors such as parent material in soil structure, closeness of salty groundwater table to the surface, weathering of the parent rock and sea water cause soil salinity occurrence. Table 1 shows examples for outstanding reasons of soil salinity from different regions of the world.

Table 1. Common reasons of soil salinity problem in various regions of the world.

Item	Location	Reason of soil salinity problem	Main problems and effects	Remarks
1	Northeast of Brazil	25 to 30% of 5000 km^2 irrigated agricultural land is affected by salinization (Bouaziz et al., 2011).	Soil erosion due to salinization Loss of land productivity	Roughly 20% of irrigated agriculture worldwide is affected by salinization (Ghassemi et al.,1995)
2	West Texas, USA	Parent materials	Soil salinity constrains the growth of many agronomic crops (Aldabaa et al., 2015).	Variability of soil salinity is affected by parent material, soil type, and landscape position (Clay et al., 2001).
3	Saudi Arabia Al-Hassa Oasis	Inland sabkhas, topography, poor drainage, poor irrigation water quality and mismanaged agricultural practices (Allbed et al., 2014).	Decrease in productivity of date palms	These areas are often crusted with salts and occur on sand, silt or clay soils (Al-Amoudi, 1995).
4	Pakistan-Punjab	Shallow water table areas, alluvium deposited by rivers into shallow sea, Minerals in parent rocks (Abbas et al., 2013).	Salinity has distressing social and economic effects on farming communities.	
	North of Australia	Sea water intrusion	Extensive dieback plants such as: paperbark, grasses, and sedges (Bell et al., 2001).	Sea level intrusion/fluctuation and the effects of these on the wetland environments of the coastal plains are largely unknown (Eliot et al., 1999).
6	Morocco	Increased use of ground-and surface water coupled with the agricultural intensification are the major causes of soil degradation through secondary soil salinity and sodicity.	Loss of vegetation and agricultural productivity (Bannari et al., 2008).	
7	Mesopotamia, Iraq	Parent materials Due to slow drainage, salt accumulate in soils after evaporation and transpiration year by year	Most of the agricultural lands are abandoned and some decline in wheat production (Wu et al., 2014a).	

The objectives of this paper are to briefly discuss the common reasons of soil salinity, to introduce methods used to cope with this problem, and to review the current soil salinity detection, monitoring and mapping methods.

2. Soil salinity detection and monitoring

Monitoring is needed for taking proper and timely decisions towards modifying the management practices or undertaking reclamation and rehabilitation efforts. Monitoring salinity means identifying areas where salts concentrate and detecting temporal and spatial changes in its occurrence. Therefore, regular monitoring of soil salinity is essential for efficient soil and water management, and sustainability of agricultural lands as depicted by Bilgili et al. (2011).

Productive and fertile soils are a scarce resource in both arid and semi-arid environments. These areas suffer from scarce freshwater resources which necessitate the use of marginal quality water for agriculture. The main reason of salinity increase is forced intensification of agriculture for short-term benefits, ignoring long-term consequences for soil services to meet food demand, and poor management of soil and water resources. Indeed, assessment of salt affected soils begins with identification and continues by mapping and monitoring. Therefore, the use of traditional methods (laboratory analysis, field survey) for salinity monitoring is insufficient and unsuited to the rate of evolution of this phenomenon and is demanding high costs, contrariwise to the satellite imagery that can be a powerful tool for mapping and monitoring of the progression of salinity by its synoptic coverage and the sensitivity of the electromagnetic signal to soil parameters at the surface layer (Metternichet and Zinck, 2003; Farifteh et al., 2006).

2.1. Historical background of detection methods

Two main electrical conductivity (EC) methods were used for determining, monitoring and mapping soil salinity including determination from aqueous electrical conductivity and from soil-paste and bulk soil electrical conductivity (Rhoades et al., 1999). On the other hand, Remote Sensing (RS), Geographical Information Systems (GIS), modelling, geostatistics and advanced electromagnetic induction are the advanced technologies and tools for soil salinity assessment, mapping, and monitoring. There is a high correlation between soil reflectance and several soil properties such as mineralogy, organic matter content, moisture content, particle size distribution, iron oxide content, and surface conditions (Dematte et al., 2004). Ground observations and spectroradiometric measurements indicate that the main factors affecting the reflectance are quantity and mineralogy of salts, moisture content, colour, and surface roughness (Mougenot et al., 1993). Various analysts have conducted studies on mapping soil salinity utilizing different soil salinity indices and distinctive Spectral Vegetation Indices (SVI). Despite the fact that vegetation and salinity indices are useful for assessing soil salinity, no specific vegetation or salinity index could be utilized over every natural condition with proper results. These indices change with various natural conditions, soil types, vegetation cover and density. In general, the indices based on the visible spectral bands were found to be more sensitive to soil salinity in a recent study of Lhissou et al. (2014). In terms of vegetation indices, Normalized Difference Vegetation Index (NDVI) is considered as an uncertain indicator for soil salinity assessment due to possibility of growing of various plants in different levels of salinity. In addition, the existence of halophytic plants may confuse soil salinity detection based on the NDVI due to mixing with the spectral signature of salt, which then will lead to classification errors (Sethi et al., 2010). Hence, to overcome this issue and remove classification errors to some degree, the Soil Adjusted Vegetation Index (SAVI) and other indices and enhancement models have helped to separate soil and vegetation signals (Allbed and Kumar, 2013). Furthermore, Generalized Vegetation Index (GDVI) developed in recent years has shown a remarkable result for soil salinity assessment. In the study of Wu et al. (2014b), the predicted salinity of the study area by models using GDVI was evaluated with the ground measured data, and the results demonstrated predictions with a high accuracy of $R^2 = 0.86$.

2.2. Multispectral satellite sensors

Broad exploration utilizing satellite imagery for mapping and monitoring soil salinity has been directed throughout the recent years with multispectral sensors. These incorporate Landsat Thematic Mapper (TM), Landsat Multispectral Scanner System (MSS), Landsat 7, Landsat 8, Landsat Enhanced Thematic Mapper (ETM), SPOT, Advanced Space borne Thermal Emission and Reflection Radiome (ASTER), IKONOS, MODIS and IRS (Allbed and Kumar, 2013). Landsat TM image was used for mapping soil salinity in Morocco by building up a semi-empirical model through utilizing optical remote sensing data and field measurements of EC. The 60% precision found between EC and spectral indices demonstrate that soil salinity could be well-evaluated utilizing spectral indices in the spatial estimation and mapping salinity in an irrigated land (Lhissou et al., 2014). A similar study of applying Landsat TM image for multi-temporal salinity mapping, quantification, and change tracking in space and time was conducted in Central Iraq by Wu et al. (2014a). The outcomes revealed that the created saltiness models can forestall saltiness with a precision of 82.57%, indicating that the mapping strategy is significant and extendable to other comparable situations. Another study-utilized satellite images IRS-1B LISS-II from 1992 to 1995 in Pakistan to develop a robust method for characterizing irrigated salinity. The highest correlation of 82% was found between EC and soil salinity indices (Abbas et al., 2013). Figure 1a and 1b illustrate the corresponding land-use and soil salinity distributions, respectively.

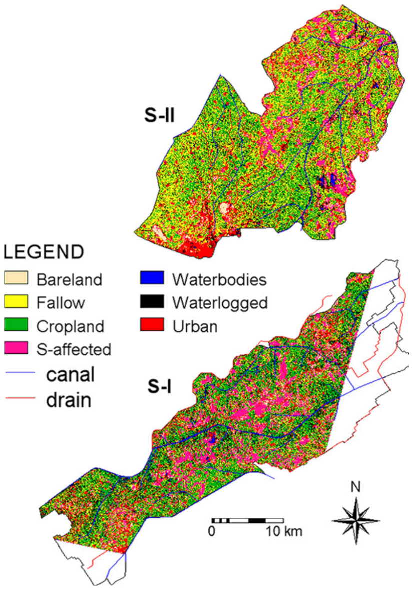

Figure 1. a) Land-use classification.

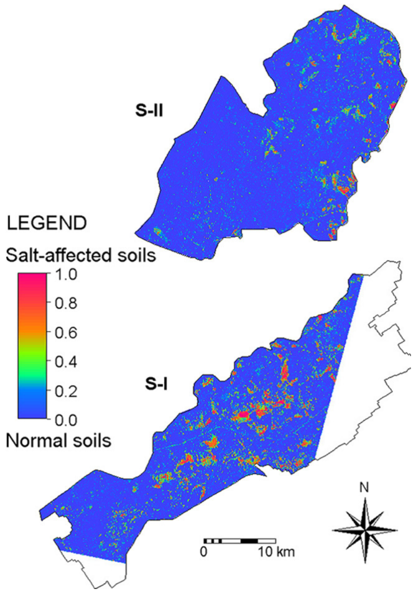

Figure 1. b) Distribution of soil salinity (Abbas et al., 2013).

Medium and low resolution multispectral satellite sensors have still been the favoured strategy for mapping and monitoring soil salinity. This is principally due to the low cost of the imagery and the capacity to map extreme surface expressions of salinity. Nevertheless, multispectral data has limited diagnostic capability because of its coarse spatial and spectral resolutions (Allbed and Kumar, 2013). The use of multispectral images for detecting salts is hindered by a set of factors. The quantity of salts concentrated on the soil surface is one of the important handicaps. Salts are difficult to discriminate from other soil surface component in case when the salt content is below 10–15% (Metternicht and Zinck, 2003). Significant restrictions may emerge through direct mapping of soil salinity with multispectral imagery especially when there are no salt attributes on the soil surface and where saline soils are dominated by halophyte plants as mentioned by Howari (2003).

Additionally, multispectral satellite sensors may lead to implicated reflectance, as non-saline soils may be confused by barren and extremely saline land. On the other hand, spectral resolution of Landsat becomes inadequate as the distinction between the spectra of saline and waterlogged land is highly weak to permit spectral separation (Fraser, 2009).

2.3. Hyperspectral Remote Sensing of soil salinity

The advancement of airborne and satellite-based hyperspectral sensors has partially overcome spatial and spectral restrictions of multispectral satellite imagery for both regional and local monitoring and mapping soil salinity. Hyperspectral sensors with an extensive number of narrow and contiguous bands are fit for giving sufficient data to distinguish and recognize between spectrally similar, but unique materials (Shippert, 2004). Hyperspectral airborne sensors offer an extensive number of spectral bands with high spatial resolution that permit the separation of halophyte plants from non-halophyte plants, and additionally the distinguishing proof of surface salt features in more detail than the multispectral sensors (Gupta, 2003; Dutkiewicz, 2006). Areas influenced by low to moderate soil salinity levels are commonly characterised by a good cover of salt-tolerant vegetation, an absence of salt-sensitive vegetation and minimal exposed soil. Such areas are more difficult to map, as there is a moderately slight contrast between the saline and non-saline areas. However, obtaining multi-temporal and periodic data to monitor soil salinity for large spatial domains is crucial and this might be costly and limited to using hyperspectral airborne systems.

3. Results and discussions

A wide range of mitigation strategies are required to cope with soil salinity impacts as it can be addressed as one of the most commonly observed agricultural and environmental problem. It is seen that use of saline water for agriculture is likely to increase with increasing water scarcity. Thus, it will be important to modify current soil, irrigation, and crop management practices to manage this inevitable salinity increases especially in the arid and semi-arid regions of the world. As stated by Ghassemi et al. (1995) and Metternicht et al. (2003) that almost 20% of the world's irrigated land is salt affected and this proportion displays an increasing trend even though considerable efforts are paid to land rehabilitation and reclamation practices. As the current situation is not that much promising in the sense of sustainability, monitoring of soil salinity on the already saline soil or on the soil that is prone to such a risk needs to be well monitored to secure land use management. Such saline affected areas cover huge land that makes it quite impossible to examine soil quality with field and laboratory data. With the today's advanced technology, the ground truth measurements must be coupled with especially remote sensing data to achieve best monitoring results. In the old days, ground observations were the only means of detecting salinity problems and levels; however, in parallel to the technological achievements and the ability to utilize modern technological tools of remote sensing with time make this issue quite controllable and manageable. Thus, best monitoring results are nowadays obtainable by integrating ground truth data including field and laboratory data with remote sensing data. Mougenot et al. (1993), Dematte et al. (2004) and Allbed and Kumar (2013) underlined the necessity linkage between ground observations and RS data in their research. Moreover, it is important to note that spatial and temporal changes may easily be detected with this integration to put forth the change detections. Another advantage of this coupling lies in the reality that large areas are usually concerned in salinity issues in many regions that make it difficult for the researchers and scientists to take frequent soil samples from the study areas. With the use of remote sensing data, one can be able to predict and foresee the sensitive areas and even can optimize the number of sampling stations. Apart from predicting and monitoring of saline affected land in a cost and time-effective manner through the use of remote sensing data, digitized mapping is also possible which is even equally important for the farmers and local authorities. By the use of the RS technology, early warning systems against soil salinity may be achievable, which is highly important for increasing crop productivity and even for selecting the appropriate crop pattern. Furthermore, salinity mapping should be preferred to alert people that if no protective measures are taken, the area will become even more saline which will then be more difficult to cope with.

4. Concluding remarks

Traditionally, soil salinity monitoring and prediction are often carried out with intensive field work and sampling. Most previous studies have nowadays focused on differentiating salinized soil and non-salinized soil, qualitatively analyzing the distribution of soil salinity and monitoring the dynamics of soil salinity. In recent years, Remote Sensing, GIS and modelling have become the preferred technological tools to map soil salinity due to large area coverage, which is of utmost importance both from the agricultural and environmental perspectives. Remote sensing data makes it possible to obtain multi-temporal data for varying spatial domains and conditions, which is a key element to monitor and detect soil salinity.

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