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Characterizing soil salinity in irrigated agriculture using a remote sensing approach

Akhtar Abbas [a,*,1], Shahbaz Khan [b], Nisar Hussain [c], Munir A. Hanjra [d], Saud Akbar [e]

[a] *Cooperative Research Centre for Irrigation Futures, Darling Heights Qld, Australia*
[b] *UNESCO Division of Water Sciences, Paris, France*
[c] *College of Agriculture, D.G. Khan, Pakistan*
[d] *Charles Sturt University, Wagga Wagga NSW, Australia*
[e] *Industry & Investment NSW, Richmond NSW, Australia*

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ABSTRACT

Managing salinity in irrigated agriculture is crucial for minimising its negative environmental impacts and for ensuring the long-term sustainability of irrigated agriculture. It demands establishing rapid monitoring systems that help develop sustainable management plans. Remote sensing offers several advantages over the conventional proximal methods to map and predict areas at salinity risk. This paper presents an integrated approach to characterize soil salinity using remotely-sensed data in the District Faisalabad, Punjab, Pakistan. The IRS-1B LISS-II digital data was acquired and analysed in combination with field data and topographical maps. Remotely-sensed data based salinity indices or band combinations were developed to monitor the occurrence pattern of salt-affected soils. Using supervised maximum likelihood classification, the images were classified into eight land use classes with an overall accuracy of around 90%. The classified images showed that 22.2% of the total area was under salt-affected soils in 1992. The occurrence pattern of salt-affected soils varied with positive and negative trends during 1992–1995 to a minimum of 10.6%. The delineation analysis into levels of saline soils revealed three types based on USDA classification (USDA, 1954). The slightly saline, moderately saline and strongly saline soils during 1992 were in the order of 15%, 3%, and 1% respectively. The interactive behaviour of salinity and sodicity and their combinations showed that saline-sodic soils occurred predominantly ranging from 6.9% to 17.3% of the salt-affected soils. The shallow watertable was found to be of hazardous quality in 28% of the study area. The relationship between salt-affected soils, waterlogged soils and groundwater quality revealed that 60–70% of the salt-affected soils occurred in shallow watertable areas during 1992–1995. The reuse of poor quality groundwater for irrigation and the failure of tile drainage system in the area are likely to further increase the risk of salinisation in the Indus Basin of Pakistan.

1. Introduction

Soil salinity in semi-arid regions where crop water requirements are augmented by irrigation supplies is a major concern for the sustainability of irrigated agricultural systems. It causes severe environmental degradation that impedes crop growth and overall regional production. Irrigation-induced salinity occurs in large and small irrigation systems alike. Salinisation is a worldwide problem, particularly in irrigated lands, which are extensively irrigated and are poorly drained. FAO (2007) reported that at the global scale more than 77 mha (million hectares) of land are salt-affected and about 43 mha are attributed to secondary salinisation. Estimates indicate that about one-third of the irrigated lands in the major countries with irrigated agriculture is badly affected by salinity or is expected to be salinised in the near future. Current estimates of the salt-affected soils as percent of the irrigated lands for different countries are: 27% for India, 28% for Pakistan, 13% for Israel, 20% for Australia, 15% for China, 50% for Iraq, and 30% for Egypt (Stockle, 2007). In only New South Wales (NSW) state of Australia, salinity is estimated to affect 15% of the irrigated land and, in recent years, many farmers have abandoned their rice fields due to the incidence of soil salinity. At global scale, soil salinisation is spreading at a rate of up to 2 mha per year, which offsets a significant portion of the crop production that is otherwise achievable by using the best management practices at a system level.

Pakistan has a total area of 79.6 mha, and 22 mha of cultivated land (GOP, 1999) with approximately 6 mha affected by the salinity within the irrigation areas (Mahmood et al., 2003). This environmental degradation is of staggering proportions and is one of the factors preventing the achievable potential of agricultural productivity. Geologically, the Indus plain, which is the major land for irrigated agriculture in Pakistan, was formed from alluvium deposited by rivers into shallow sea. The receding sea left residues of

* Corresponding author.
E-mail address: akhtar6@yahoo.com (A. Abbas).
[1] Formerly with CSIRO Land and Water, Canberra ACT, Australia.

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salts in soil profiles and aquifers. Minerals in parent rocks also released significant quantities of salts into the soil through weathering. Under historic climatic conditions, salts released through weathering were not leached out and consequently, accumulated within the soil profiles. Moreover, the irrigation systems (the most contiguous irrigation system in the world) introduced during the second half of the nineteenth century caused salt accumulation in the soil profile leading to the secondary salinisation (Abbas, 1999). A schematic representation of the development of the secondary salinisation is shown in Fig. 1.

Among all categories of salt-affected soils in Pakistan between 2 and 3 mha is understood as completely wasteland due to high level of salinity and sodicity (Qureshi et al., 1993). Estimates further show that 25% and 40% of the irrigated lands in the Punjab and Sindh are salt-affected respectively, and the livelihoods of about 10–20 million people are affected due to these salt-affected lands with impoverished productivity and increased threats to ecosystem (Barrett-Lennard and Hollington, 2006). Seepage from supply canals, extensive network of on-farm and near-farm watercourses; and flooded irrigated fields are known as primary causes of secondary soil salinity (Abbas et al., 2005; Kijne, 2006). Waterlogging and salinity have distressing social and economic effects on farming communities (Khan and Hanjra, 2008). Moreover, the increasing shortage of fresh water resources is likely to trigger increased environmental damage (Khan and Hanjra, 2009). The falls in river flows and reduced irrigation supplies due to persistent drought have disturbed the water ecosystems resulting into food insecurity and non sustainable farming systems (Hanjra and Qureshi, 2010; Thenkabail et al., 2010).

Conserving fertile lands and environmental stewardship have been indeed complementary goals for any land reclamation program in Pakistan agriculture. However, the solutions were neither

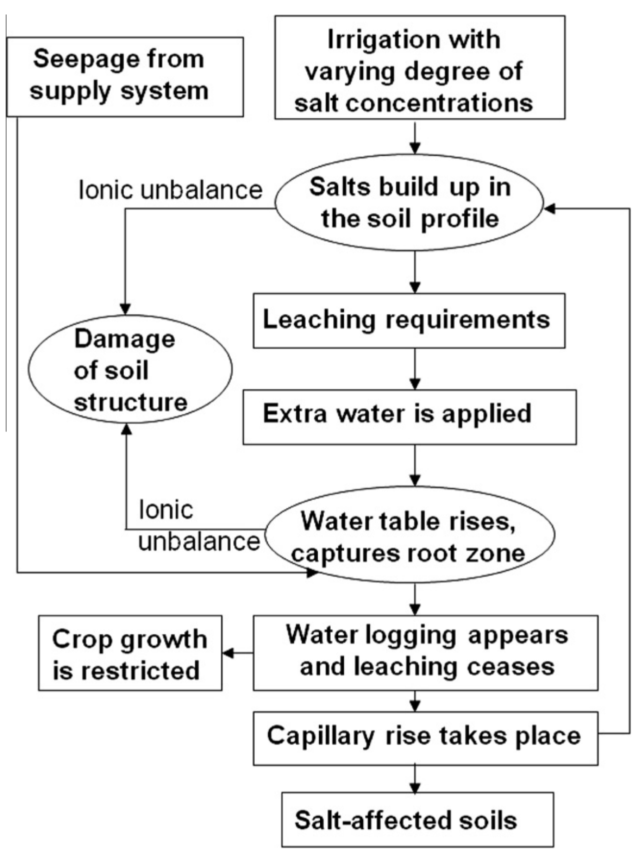

Fig. 1. Process of secondary salinisation in irrigated areas (modified from FAO, 2002).

cheap nor easy. For example, the suite of Salinity Control and Reclamation Projects (SCARPs) designed and implemented by Water and Power Development Authority (WAPDA) Pakistan failed to control salinity due to exorbitant costs and institutional failure. The key lessons learnt from this experience demanded for strong commitment in all jurisdictions plus the development of local land and water management plans (LWMPs) through effective stakeholders' engagement. However, such actions remain a dream and highly productive lands would further continue to retire unless reliable and updated information on the soil salinity and the linked impediments is not made available. Thus, monitoring the status of irrigated soil salinity in temporal and spatial extent is a primary concern for saving the productive irrigation systems.

The salinisation is inevitable and likely to expand because around 70% of the available surface water with varying degree of quality used for irrigation worldwide is continuously adding millions of tons of salts to productive lands. In future, to cope with the rapid population growth and increasing food demand, more dry lands will be put into agricultural production or cropping intensity must increase manifolds. Such extensive cropping will be mainly achieved through irrigation and thus accelerates the salinisation risks (Metternichet and Zinck, 2003). Monitoring and evaluation using visual interpretations, field surveys, and laboratory analyses have been in place since decades. However the question is, "do we have a simple tool for keeping track of continuous changes that help anticipate further degradation"? This paper builds on previous work (Abbas and Khan, 2007) and uses remote sensing data for characterizing salinity in a major irrigation district in the upper Indus Basin of Pakistan as a case example. The specific objectives of the paper are: (1) to develop a robust method for characterizing irrigated salinity based on remote sensing data; (2) to determine the temporal and spatial changes in salt-affected soils; (3) and to identify the association of occurrence of salt-affected soils with shallow watertable of varying quality.

2. Remote sensing for soil salinity – past perspective

What kind of information can remote sensing provide for managing salinity in irrigated agriculture? Remote sensing has the possibility to predict soil salinity, performance diagnosis, and impact assessment (Bastiaanssen et al., 2000). It saves labour, time and efforts when compared to conventional field measurements. The information derived from remote sensing tools is significantly objective, collected in a systematic way, and covers a wide area. Thus, remote sensing data has the ability to capture information on salt-affected soils in both spatial and temporal extents (Abbas, 1999). However, remote sensing based approaches for salinity mapping has met with limited success compared with the other applications in irrigated agriculture (Bastiaanssen et al., 2000; Metternichet and Zinck, 2003; Lagerloef, 2009). The development of methods to map salinity using remote sensing data in combination with field data have been the objective of several studies during the past two decades. Several algorithms and models have been developed to process satellite remote sensing data. Past research shows mapping and assessing of soil salinity using remote sensing tools like aerial photography, videography, infrared thermometry and multispectral scanners, RADAR and LIDAR imagery. For example, Dwivedi and Rao (1992) adopted a three-band combination of Landsat TM data for identifying salt-affected soils and the bands 1, 3, and 5 were found to be more informative. Tripathi et al. (1997) developed two indices using remote sensing data to monitor soil alkalinity in the Indo-Gangnetic plains. Dwivedi and Sreenivas (1998) demonstrated the potential of image transformations and described that the principal component analysis, image differencing and ratioing of the bands provided substantial information