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Monitoring soil salinity via remote sensing technology under data scarce conditions: A case study from Turkey

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ABSTRACT

Due to its negative impacts on land productivity and plant growth, soil salinization is a significant problem particularly in arid and semi-arid regions of the world. Among the natural factors of soil salinization, parent materials including high amount of salts and minerals in soil structure, known as primary salinization, can be addressed. Conventional irrigation techniques and poor drainage systems are predominant human-induced activities that result in secondary salinization. Countries with especially dryland environment, face difficulty in providing adequate food for their rapidly increasing population since each year lots of cultivated land are abandoned due to adverse effects of primary and secondary soil salinization. Therefore, monitoring, mapping and predicting soil salinization is of utmost importance regarding lessening and/or preventing further increase in soil salinity through some protective measures. The subject of concern becomes even more pronounced particularly in agricultural lands as is the case in the vicinity of Tuz (Salt) Lake Region in Turkey. This research focuses mainly on multi-temporal monitoring of Tuz Lake Region in order to track changes in areas of salty spots in years 1990, 2002, 2006, 2011 and 2015. A total number of 25 Landsat-5 TM and Landsat-8 images obtained between 1990 and 2015 were analysed in this study. Field electrical conductivity (EC) measurements for 322 soil samples in year 2002 were checked; and 28 of these samples were selected for generating salinity maps representing areas in the vicinity of the lake. All satellite images were radiometrically and atmospherically corrected prior to classification. Following the pre-processing step, five soil salinity indices were applied on all satellite images. 28 soil samples were then overlaid on images in order to extract the exact index values related to soil samples and regression approach was used to relate satellite image-derived salinity indices and field measurements. Linear and exponential regression analyses were conducted separately as the next step for all indices based on data gathered in 2002. Salinity index (SI) 1 = $\sqrt{B1 * B3}$ showed the best result with R^2 value of 0.93 and 0.83 for exponential and linear regression analysis, respectively. Salinity maps for years 1990, 2006, 2011 and 2015 were further produced utilizing the exponential and linear regression expressions attained for year 2002. Besides, this study detected land cover changes in the area from year 2000–2006, and from 2006 to 2012 by using CORINE land cover data to analyse the possible relationships between land cover change and salinity changes.

1. Introduction

Soil salinity negatively affects seed germination, crop productivity, soil and water quality specifically in semi-arid and arid regions of the world, resulting in loss of arable lands and soil degradation. It is ever-increasing at an alarming rate and is accepted as a widespread environmental problem endangering agricultural practices as thoroughly mentioned by scientists from various parts of the world at different time intervals (Zhu, 2001; Metternicht and Zinck, 2003; Zheng et al., 2009; Rongjiang and Jingsong, 2010). Generally, there are two main reasons for soil salinity. One relates to human-induced activities, and the other one is due to natural factors. Extent usage of poor quality irrigation water due to occurrence of extreme drought events combined with intense application of fertilizers are the main human-induced activities resulting in soil salinization (Perez-Sirvent et al., 2003; Barbouchi et al., 2014). Presence of parent materials and weathering of salt minerals by wind or water force are among the primary causes of soil salinization which is a common problem, and it becomes even more pronounced under high evaporation and less precipitation conditions (Metternicht and Zinck, 2008a). Mineral composition of

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soil, texture and its surface roughness are the core soil properties; whereby, physical properties of salinity varies by vegetation cover which is categorized as halophyte and non-halophyte plants (Metternicht and Zinck, 2003; Farifteh and Farshad, 2006). In fact, salt-affected regions could be differentiated from non-affected areas by the availability of halophytic plants indicating their characteristics of withstanding high soil salinity (Dehaan and Taylor, 2002; Fernández-Buces et al., 2006). Generally, photosynthetic activity of plants impact their spectral reflectance curve such a way that under less photosynthetic activity, plants have higher reflectance in visible and lower reflectance in near-infrared (NIR) portions of the spectrum from the vegetation, which is a case for crops facing salinity stress (Zhang et al., 2011).

Soil salinization is a process occurring dynamically with significant social and economic aspects; thus, for sustainable management of arable regions and natural ecosystems, proper and accurate information on spatial magnitude and variability in distribution of salinity is critical in order to timely monitor it and prevent further increase in salt-affected areas (Allbed and Kumar, 2013). Periodical monitoring of soil salinity is a necessity to properly manage soil and water resources; however, it is rather challenging to detect the required ground information in the regions impacted by salinity as referred by Gates et al. (2002) and Bilgili et al. (2011). United Nations Food and Agriculture Organization (FAO) have estimated that almost 397 million hectares of world's total land is covered by saline soil including nearly all continents (Koohafkan and Stewart, 2008).

Soil salinity has high spatio-temporal variability; therefore, it is important to monitor and map its changes to predict some natural disasters such as desertification and mitigate drastic environmental, social and economic consequences specifically for semi-arid and arid regions of the world. Extreme field study and sampling is needed to monitor and anticipate soil salinity by using conventional methods. Monitoring soil salinity by knowing when, where, and how salinity and sodicity may occur is significant for optimizing land productivity as underlined by Al-Khaier (2003). Remote Sensing (RS) techniques have been widely used to assess soil salinity since 1960s; while black-and-white, and coloured aerial photographs were utilized to map salt-affected soils. RS technology 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 (Gorji et al., 2015; Fan et al., 2015; Scudiero et al., 2015). There are some constrains in monitoring soil salinization due to dynamic processes occurring at the saline soil surface; whereby spectral, spatial and temporal behaviour of the salt features are affected (Metternicht and Zinck, 2008a). Therefore, spatial resolution of the satellite imagery is an essential parameter that should be considered while monitoring and tracking soil salinity (Metternicht and Zinck, 2008b). Proper detection and quantification of soil salinity can be achieved by utilizing digital indices derived from different spectral bands of satellite images and relating them to ground-based electromagnetic measurements of soil electrical conductivity (EC) as referred by a couple of researchers (Dehaan and Taylor, 2002; Fernández-Buces et al., 2006; Farifteh et al., 2008). Rapid and non-destructive detection, wide regional coverage and possibility for relatively inexpensive long-term monitoring can be counted among the advantages of RS technology (Allbed and Kumar, 2013; Kumar et al., 2015). Even though rapid and accurate assessment of soil salinity via RS has been improved progressively in the last decades, expanding in the existence of soil salinization under different parameters and variables forced researchers to accelerate in modelling this phenomenon (Akramkhanov, 2005; Vasques et al., 2009).

The main objective of this study is utilizing Remote Sensing (RS) and Geographical Information Systems (GIS) techniques to generate soil salinity maps in Tuz (Salt) Lake Region, Turkey, in order to track and monitor the changes in salt-affected areas in years 1990, 2002, 2006, 2011 and 2015. Besides, this study utilizes CORINE data for identifying probable human-induced causes of soil salinization in the area by detecting land cover changes from year 2000–2006 and from 2006 to 2012. In fact, information about land-use/land cover changes (LULC) is required to monitor these changes at various time intervals in order to make proper decisions to mitigate negative effects of these alterations on environment (Das, 2009). Fig. 1 illustrates the soil salinity map of the world where Turkey may be observed as a country that is not considerably affected by soil salinity problem; therefore, limited studies on monitoring and mapping soil salinity exist. In that sense, this article may be regarded as one of the rare studies conducted in the country that represents a developing country with limited field data.

2. Materials and methods

2.1. Study area

The study area, Tuz Lake and its vicinity, is located in Central Anatolia between longitude 32°59′–33°39′ and latitudes 38°20′–39°10′. It is the second largest lake in the country with spe-

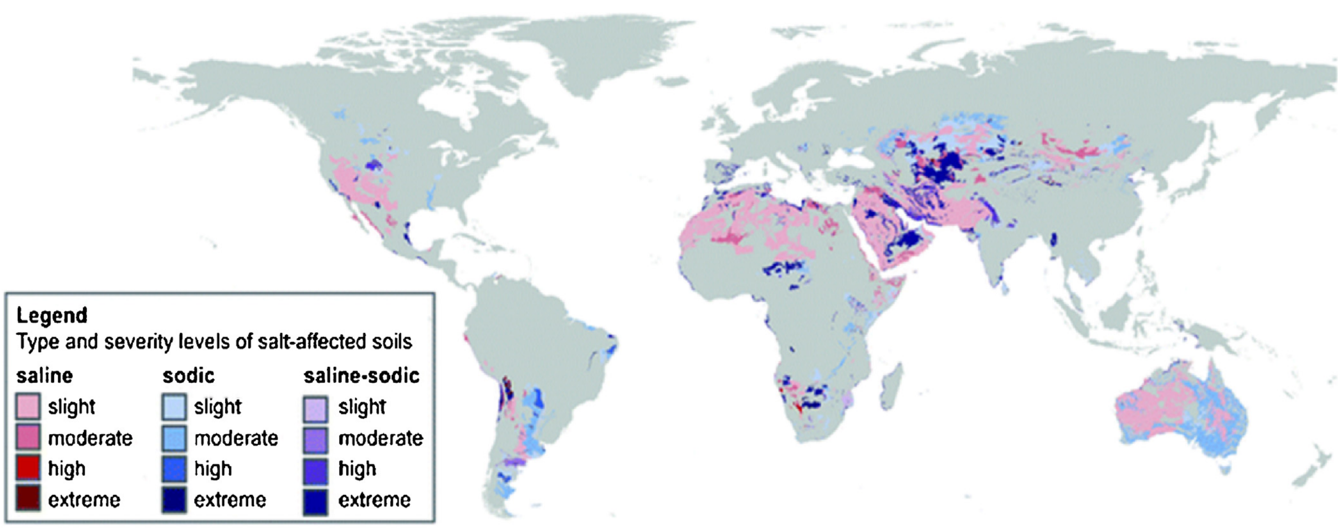

Fig. 1. Soil salinity map of the world (URL-1, 2016).