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Monitoring and evaluating spatial variability of soil salinity in dry and wet seasons in the Werigan–Kuqa Oasis, China, using remote sensing and electromagnetic induction instruments

Jianli Ding [a], Danlin Yu [a,b,*]

[a] School of Resources and Environment, Xinjiang University, 14 Shengli Rd, Xinjiang 830046, China
[b] Earth and Environmental Studies, Montclair State University, 1 Normal Ave., Montclair, NJ 07043, United States

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A B S T R A C T

In arid and semi-arid regions, soil salinization is one of the most critical environmental problems due to its severe effects on agriculture productivity and long-term sustainable development. Monitoring, evaluating and predicting soil salinization are of utmost importance in those regions. The current study proposes an evaluating and predicting approach that is based on remote sensing (e.g., Landsat TM images) and near sensing technologies (e.g., electromagnetic induction device, EM38). We investigated seasonal and spatial changes of soil salinity in a Delta Oasis between the Werigan and Kuqa River in the northern rim of Tarim Basin, Xinjiang, China. Preliminary analysis suggests that apparent soil electrical conductivity obtained from EM38 is highly correlated with soil salinity, which is obtained from post-sampling laboratory tests. The study hence uses the apparent electrical conductivity as a surrogate for soil salinity to understand the spatial pattern of the latter. To understand soil salinity distribution pattern in the study region, we integrated spectral information derived from two Landsat TM images (acquired on April 15, 2011 for the dry season and September 22, 2011 for the wet season), and applied universal kriging, spectral index regression and regression–kriging approaches to obtain the pattern. Results suggest that regression–kriging with nested spherical model produces the closest fit of the observed soil apparent electrical conductivity. Since most previous studies often employ either one or the other approaches in soil salinity monitoring and evaluation, the study suggests that combining remote and near sensing technology provides a rapid and relatively accurate assessment of soil salinity in arid and semi-arid regions, which would be essential to manage and prevent further soil salinization and re-salinization.

1. Introduction

Oasis is a unique ecologic unit in the arid/semi-arid area with its availability of water and potential for agriculture, which makes it one of the most intensive human–land interactive regions. Due to increased intensity of human activities in oasis regions, soil degradation and desertification often threaten the sustainable development of oasis ecosystems and future agriculture development. Among the many forms of soil degradation, soil salinization due mainly to irrigation and other intensified agricultural activities is one of the most severe problems (Akramkhanov et al., 2011; Zheng et al., 2009). Monitoring, evaluating and predicting the spatiotemporal changing patterns of soil salinity are essential for managing and preventing further soil salinization. This becomes an imperative task for agricultural productivity and oasis sustainable development.

Traditionally, soil salinity monitoring and prediction are often carried out with intensive field work and sampling (Amezketa, 2007; Farifteh et al., 2007; Urdanoz and Araguees, 2011; Yao et al., 2008). Due to limited amount of sampling sites (only 68 sites were sampled) and available funds and labor, the sampling might not be a good representation for large areas. Remote sensing technology, on the other hand, provides a viable alternative to traditional field work due to its large area coverage, multiple spectra information and nearly constant observation (Bell et al., 2001; Bierwirth and Brodie, 2008; Douaoui et al., 2006; Farifteh et al., 2007; Metternicht and Zinck, 2003; Mulder et al., 2011; Taghizadeh-Mehrjardi et al., 2014). This is especially true since higher resolution imageries become readily available. The majority of the studies, however, also suggest that soil salinity information cannot be derived from remote sensing imageries very accurately except for severely salinized regions (Farifteh et al., 2006; Jiang et al., 2008; Metternicht and Zinck, 2003; Peng, 1997). On the other hand, from a management and sustainable development perspective, it is the moderately and lightly salinized regions that often require immediate monitoring for soil management and prevention of further salinization (Gao et al., 2010; Rao et al., 1995; Zhang et al., 2009a).

* Corresponding author at: Earth and Environmental Studies, Montclair State University, 1 Normal Ave., Montclair, NJ 07043, United States.
E-mail addresses: ding_jl@163.com (J. Ding), yud@mail.montclair.edu (D. Yu).

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In addition, near sensing technology via an electromagnetic device (mostly EM38) has been applied in numerous soil studies to obtain soil electrical conductivity and soil salinity information in various scenarios (Doolittle et al., 2001; Lesch et al., 1998; Li et al., 2008, 2010, 2012; Triantafilis et al., 2000, 2001; Yao and Yang, 2010). For instance, Lesch et al. (1998) developed a statistical monitoring strategy that uses electromagnetic induction data and repetitive soil sampling to measure changing soil salinity conditions in saline irrigation district of Flumen, Spain. Li et al. (2008) measured soil apparent electric conductivity of salinized soil in reclaimed coastal regions, and produced a soil electric conductivity profile. Li et al. (2012) attempts to account the spatiotemporal changes in total soluble salt content (TS) in a typical arid region of South Xinjiang, China. Wu et al. (2009a) studied the spatial variation of soil salinity in Fengqiu, Henan Province combining EM38 and spectral indices. Li et al. (2010) established a soil salinity interpretation model based on electromagnetic induction. In those studies, an electromagnetic induction device (EM38) was linked with a data logging system and a GPS unit to create a mobile electromagnetic sensing system. This system can then be used to obtain soil electric conductivity and salinization information fairly quickly and accurately comparing to traditional field work and ensuing laboratory measurement (Liu et al., 2003; Zhang et al., 2009c). More importantly, unlike traditional sampling strategy that can only produce salinity information of a specific sampling point, the EM38 device can obtain soil apparent electrical conductivity information for a series of sampling points relatively quickly and easily. This renders the measurement more representative than information obtained from a single sampling point. The majority of these studies often focus on the measurement and prediction of soil profile electrical conductivity and the heterogeneous nature of the spatial distribution of soil salinity. Except for a few studies, e.g., Wu et al. (2009b), seldom was this type of information combined with remotely sensed information to monitor the spatial and seasonal variation of soil salinity in large area.

To this regard, the current study attempts to combine data obtained from both the remotely sensed imageries and the mobile electromagnetic sensing system for better soil salinity monitoring and possible prediction. We intend to study soil salinity and its spatial variation in the 0–10 cm soil depth during both wet and dry seasons in Werigan–Kuqa dealt oasis, Xinjiang, China. The data obtained via the mobile electromagnetic sensing system (near sensing) were combined with data derived from remote sensing imageries to produce soil salinity spatial prediction. Three interpolation approaches, i.e., universal kriging (without remote sensing information), spectral index regression (pure remote sensing) and regression–kriging (combined near and remote sensing information) are employed to test whether such combination would be effective. Apparently, more effective evaluation and monitoring means of soil salinization in arid and semi-arid regions would provide much needed tools for sustainable development.

2. Materials and methods

2.1. Study area

The Werigan–Kuqa River Delta Oasis is located in the Middle-Northern part of Tarim Basin of Xinjiang Uyghur Autonomous Region (henceforth referred to as Xinjiang). The actual study area is bounded between 82°10′E ~ 83°50′E longitude, and 41°06′N ~ 41°40′N latitude (Fig. 1). The study area has a typical temperate continental arid climate with large daily temperature difference (over 40 °C during the summer) and very limited precipitation (average 67.5 mm annually). Because of both the extreme continental climatic condition and ill-managed/irrational irrigation activities, soil salinization in the study area is common (Jiang et al., 2008; Li et al., 2012). Vegetation cover is very low and is dominated with desert species such as *Phragimites australis*, *Tamarix ramosissima*, *Allhagi sparisifolia*, *Karelina caspica*, and *Kalidium gracile* in relatively less salinized regions (Jiang et al., 2008). Salt efflorescence can be observed in severely salinized areas. In recent years, population increase and intensified extensive irrigation activities caused the study region to experience alarmingly rapid salinization and consequent desertification, which has generated great concerns across the government, scholars and the general public over the oasis's sustainable development in the long run.

2.2. Data acquisition via EM38

The EM38 is a widely used electromagnetic instrument for soil sensing developed by Geonics Ltd. (Ontario, Canada). The EM38 measures soil apparent electrical conductivity by inducing weak eddy currents in the soil (Lesch et al., 1998; Li et al., 2013; Ye et al., 2008). There are two dipole modes during the measurement using EM38, i.e., the vertical

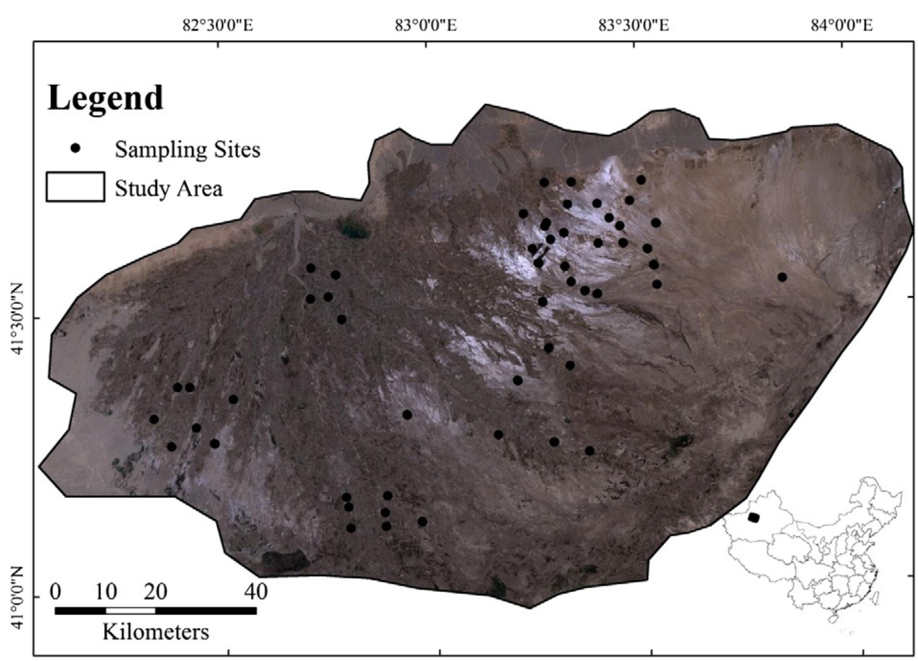

Fig. 1. Location of study area and distribution of sampling sites.