Ecological Engineering 94 (2016) 306–314

Contents lists available at ScienceDirect

Ecological Engineering

journal homepage: www.elsevier.com/locate/ecoleng

GIS-mapping spatial distribution of soil salinity for Eco-restoring the Yellow River Delta in combination with Electromagnetic Induction

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ARTICLE INFO

Article history:
Received 16 June 2015
Received in revised form 23 February 2016
Accepted 12 May 2016
Available online 18 June 2016

Keywords:
Soil salinity
Electromagnetic induction
Spatial distribution
The Yellow River delta
Eco-restoration

ABSTRACT

Soil salinization is one of serious ecological problems around the world, which seriously restricts the stability of ecosystem and the economic development of agriculture. Mapping and monitoring spatial distribution of soil salinity is important for management of ecology and agriculture. This study was carried out to explore the spatial distribution of soil salinity in the Yellow River Delta using the portable device EM38-MK2 with geostatistical analysis. Apparent soil electrical conductivities were measured under four kinds of measurement modes (0.5H, 0.5 V, 1.0H and 1.0 V, respectively). The results revealed that electrical conductivity of 1:5 soil to water extract (ECe) varied from 0.965 to 1.872 dS m^{-1} for all sampled soil profiles, and the salinity of topsoil was the highest, which indicated that soil soluble salts accumulated to the surface. The salinity in the top layer showed strong spatial variability while salinities of other layers were moderate. Soil salinity displayed a significant zonal distribution, gradually decreasing with the increase of distance to the coastline. The regions with high ECa values were located in the north and the east of the study area, whereas regions with low ECa values were located in the south and the west parts. The correlation coefficient showed that salinities of adjacent two soil layers reached a significant level of 0.01, and gradually decreased with increasing soil depth. The linear interpretation models with ECa as independent variables and ECe as dependent variables for each depth were with R^2 between 0.828 and 0.919. The interpretation models, taking ECa and ECe of 0- 15 cm depth as independent variables, and ECe of each layer in 15–100 cm depth as dependent variables, were with higher R^2 between 0.930 and 0.953. The mean error (ME) showed that there was small positive deviation in 40–100 cm whereas a high positive deviation in the topsoil (0–40 cm). The scatter plots also indicated that the models had better accuracy of salinity estimation in the top soil layers (0–80 cm). The results provides solid basis for eco-restoring in the Yellow River delta.

1. Introduction

Salt salinity is a common problem around the world, especially in arid and semi-arid areas (Wichelns and Qadir, 2014; Singh et al., 2013; Wang et al., 2008; Li et al., 2015) with low rainfall and high evaporation. Apart from the natural factors resulting in soil salinization, long-term irrigated agriculture with poor drainage system contributes to secondary salinization (Ouni et al., 2013; Qadir and Oster, 2004; Kitamura et al., 2006). Salt accumulation has detrimental effects on soil physical and chemical properties (Zhang et al., 2014; Shukla et al., 2011) and on enzyme activities and microbial and biochemical activities (Rietz and Haynes, 2003; Yuan et al., 2007; Karlen et al., 2008), thus inhibiting agriculture productivity (Rady, 2011; Ouni et al., 2014). Excessive Na^+ may cause high pH, changes in soil solution ions and nutrients, and destabilization of soil structure (Li et al., 2015). Also, salt toxicity influences plant growth significantly (Yan et al., 2013) from two aspects: hyperosmotic stress and hyperionic stress (Tang et al., 2014; Jiang et al., 2016). Saline soils are generally characterized by an electrical conductivity (EC) > 4 dS m^{-1}, pH < 8, and exchangeable sodium

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http://dx.doi.org/10.1016/j.ecoleng.2016.05.037
0925-8574/

percentage (ESP) < 15%, whereas in alkaline soils with EC < 4 dS m^{-1}, pH > 8 and ESP > 15% (USSLS, 1969).

Soil properties, such as cation exchange capacity (CEC), water-holding capacity and soil fertility are influenced by the soil texture. Geostatistical analysis has been one common method to depict spatial dependence and variability of soil properties. Cao et al. (2011) described the characteristics and spatial variability of soil organic matter and organic carbon around Qinghai Lake using the method called geostatistics. Cemek et al. (2007) also used the geostatistical method to assess spatial variability of soil properties related to soil salinity and alkalinity and to discuss the spatial distribution patterns in the Black Sea coastal region of Samsun. The results reported that there was strong spatial dependence in topsoil, whereas moderate spatial dependence in subsoil. Elbasiouny et al. (2014) conducted a survey about the spatial variability of soil carbon and nitrogen pools in north Nile Delta, which was significant to obtain a better understanding of biological process and was crucial to make good strategies and managements to develop sustainable agriculture by using ordinary Kriging method.

Apparent soil electrical conductivity(ECa)has been widely used from 1970s (Rhoades and Ingvalson, 1971; Rhoades and van Schilfgaarde, 1976). ECa is an instant, easy and reliable way to obtain spatial characterization of soil salinity. Many factors affect ECa, such as water content, cation exchange capacity(CEC), sodium adsorption ratio (SAR) and texture (Friedman, 2005). The electromagnetic induction (EMI) is one of the fast methods to measure ECa, which has been applied in different regions. Farzamian et al. (2015) combined electrical resistivity tomography (ERT) and EM38 to measure moisture content variations and estimate saturated hydraulic conductivity in natural conditions. Sudduth et al. (2005) used ECa to reflect soil physical and chemical properties. Researchers found that electromagnetic methods are fast and reliable to delineate soil properties. This was the case that Heil and Schmidhalter (2012) characterized soil texture variability in the Tertiary upland hills with a digital terrain model and get the content of clay, silt and sand from ECa with EM38. The EMI method is widely used in monitoring soil salinity. Akramkhanov et al. (2014) used EMI system as an efficient and reliable method to monitor soil salinity in Uzbekistan. Ding and Yu (2014) conducted a survey to monitor and evaluate the spatial and seasonal changes of soil salinity using remote sensing and EMI, and found that spatial distribution of soil salinity differed from small horizontal or vertical distances, and soluble salts concentrated in the surface through capillary movement which aggravated the salt variability in arid and semiarid areas. It is important to monitor soil salinity in an effort to manage the irrigated land well. Herrero et al. (2011) conducted a survey with EMI system to get the detailed baseline data for soil salinity in Flumen irrigation district where the land had been irrigated more than 50 years, showing that the EMI system was suitable to evaluate soil salinity in irrigated areas. The information of ECa survey is used for mapping spatial variability of soil properties that are invaluable in ecosyetem and agriculture for assessing soil quality, planning land use, and determining the suitability of cropping patterns (Lesch et al., 2005; Corwin and Lesch, 2005; Yao et al., 2007; Urdanoz and Araguees, 2011).

Coastal districts are vulnerable to climatic changes, such as rising temperature caused by several environmental factors: sea level rises, seawater intrusion, changes in upstream river discharges, cyclones and erosion of coastal embankment contractions (Rawlani and Sovacool 2011). With the application of portable EM38, Barbiéro et al. (2001) studied salt distribution in the Senegal valley by obtaining the electromagnetic soil conductivity to understand variability and spatial arrangement. The results showed that saline areas were distributed as strips. EMI is also used to map soil salinity of individual plots (Amezketa, 2006).

Yellow River Delta (YRD), the largest delta in China, which covers the places alongside the Lower Yellow River, especially in the estuary formed by large amount of sediments carried by the Yellow River (Cui et al., 2009). The YRD plays an important role in global ecosystem because it provides an indispensable staging, wintering and breeding site for birds around Pacific migration route (Fan et al., 2011; Fan et al., 2012). However it is suffered primary and secondary salinization because the shallow saline groundwater and strong evaporation as well as human activities. The salinity of this area threatens food production and environment (Zhang et al., 2011; Fang et al., 2005; Ye et al., 2004). Mapping spatial distribution of soil salinity is important for ecology and agriculture arrangement and management as it reflects the use and the dynamics of soil and water resources, which provides basic knowledge for researches on restoration of saline land and farmland sustainability assessment (Adam et al., 2012).

The objectives of this paper are (1) to obtain optimal interpretation models between ECa and ECe for the reconstruction of profile soil salinity across the study area; (2) to map the three-dimensional variation of soil salinity using ordinary kriging approach based on 3D scatter data and 3D Mesh model in the study area for restoring the Yellow River Delta.

2. Materials and methods

2.1. Study area

The study area was the field of Dongying (including 5 counties), Shandong Province, China, which is the main field of lower Yellow River Delta (Fig. 1). The climate is characterized by continental monsoon in the North Temperate Zone with seasonal fluctuations in precipitation and temperature. The annual average precipitation is 580 mm, and the annual average evaporation/precipitation is 3.22. The soils are naturally saline due to very saline groundwater (average salinity of 30.1 g L^{-1}) and shallow depth (average depth of 1.2–2.4 m). Sandy loam is the predominant soil texture in this area.

2.2. Acquisition of data

2.2.1. Apparent electrical conductivity

In this study, the electromagnetic conductivity meter EM38-MK2 was used to measure apparent soil electrical conductivity. The instrument containing two coils, 0.5 and 1.0m, respectively, is based on the principle of electromagnetic induction. In Saline areas, apparent soil electrical conductivity is mainly associated with salt content whose contribution is generally greater than 80% and it will be higher with the increase of soil salinity.

In this study, we used mechanical distribution method with the grid of 4 km × 4 km and arranged a total of 259 measurement points. We measured the apparent soil electrical conductivity under four measurement modes (0.5H, 0.5 V, 1.0H and 1.0 V, respectively) at the measurement position, corresponding to three soil depths (0–0.6, 0–1.2 and 0–1.5 m, respectively). The apparent soil electrical conductivities were presented as $EC_{0.5H}$, $EC_{0.5V}$, $EC_{1.0H}$ and $EC_{1.0V,}$ respectively. The coordinates of each measurement position were determined by global positioning system, sampling date in May 2014.

2.2.2. Soil sample analysis

259 soil samples of 0–15 cm at the measurement point were collected. In order to obtain more detailed information about soil salinity, 84 random profiles among the 259 measurement points were selected, and 420 soil samples were collected in accordance with 0–15, >15–40, >40–60, >60–80 and >80–100 cm at the measurement positions. These soil samples were air dried, crashed and