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Mapping soil salinity changes using remote sensing in Central Iraq

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ABSTRACT

Salinization is a common problem for agriculture in dryland environments and it has greatly affected land productivity and even caused cropland abandonment in Central and Southern Iraq. Hence it is of pressing importance to quantify the spatial distribution of salinity and its changing trend in space and time and ascertain the driving forces thereof. This study aims at such a diachronic salinity mapping and analysis using multitemporal remote sensing taking a pilot site, the Dujaila area in Central Iraq, as an example. For this purpose, field survey and soil sampling were conducted in the 2011–2012 period, and a multitemporal remote sensing dataset consisting of satellite imagery dated 1988–1993, 1998–2002, and 2009–2012 was prepared. An innovative processing approach, the multiyear maxima-based modeling approach, was proposed to develop remote sensing salinity models. After evaluation of their suitability, the relevant models were applied to the images for multitemporal salinity mapping, quantification, and change tracking in space and time. The driving causes of salinization in the study area were evaluated. The results reveal that the developed salinity models can reliably predict salinity with an accuracy of 82.57%, indicating that our mapping methodology is relevant and extendable to other similar environments. In addition, salinity has experienced significant changes in the past 30 years in Dujaila, especially, very strongly salinized land got continuously expanded, and all these changes are related to land use practices and management of farmers, which are closely associated with the macroscopic socioeconomic environment of the country.

1. Introduction

Salinity is a problematic issue for agriculture in the Mesopotamian Plain, Iraq since about 2300–2400 BC (Dieleman, 1963; Schnepf, 2004; FAO, 2011) and has become more severe in the recent decades. It is reported that approximately 60% of the cultivated land has been seriously affected by salinity, and 20–30% has been abandoned in the past 4000 years (Buringh, 1960; FAO, 2011) due to irrational land management (e.g., overirrigation and poor drainage) and other natural factors (e.g., flooding, drought, and impermeability of the underlying formation). It is clear that the arable agricultural land would further dwindle in Mesopotamia because of such land degradation, and might be exacerbated by climate change, and food security would face harsh challenge in the country. It is hence of prime importance to quantify the salt-affected land, assess its change trend in space and time, and understand the causes of salinization in order to provide relevant reference for the local and central governments for their sustainable agriculture development and land management in the future.

In regard of the salinization in Central and Southern Iraq, several authors, for example, Jacobsen and Adams (1958), Buringh (1960), Dieleman (1963), Al-Layla (1978), Al-Mahawili (1983) and Abood et al. (2011) have conducted studies and assessments. These assessments allow us to have a general understanding of salinity in the Mesopotamian Plain. International organizations such as FAO and UNESCO (United Nations Educational, Scientific and Cultural Organization) together with the Ministry of Agriculture (MoA) of Iraq have carried out soil classification and mapping in 1960 (Buringh, 1960). FAO (2008) investigated briefly the salinity severity in Western Asia including Iraq. However, the outdating of maps and their extremely low resolution (e.g., 4–10 km in pixel size) cannot meet the requirement of farm-level or household-level land management and for salinity control. Therefore, it is essential to produce salinity maps with higher resolution, higher accuracy and reliability to meet the urgent need of farmers and governments.

Salinity assessment and mapping are traditionally conducted by soil surveys and interpolation of analytical results of soil samples. However, such conventional means of soil survey requires a great deal of time (Ghabour and Daels, 1993) and funding investment. Fortunately, a significant progress has been made in this field thanks to the development of remote sensing technology in the recent decades, which offers a possibility for mapping and assessing salinity processes more efficiently and economically (Garcia et al., 2005). In fact, since the 1970s, a number of authors namely Hunt et al. (1972), Driessen and Schoorl (1973), Golovina et al. (1992), Steven et al. (1992), Mougenot et al. (1993),

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Rao et al. (1995), Metternicht (1998), Metternicht and Zinck (2003), Shao et al. (2003), Douaoui et al. (2006), Farifteh et al. (2006, 2007), Fernández-Buces et al. (2006), Brunner et al. (2007), Rodríguez et al. (2007), Eldeiry and Garcia (2010), Furby et al. (2010) and so on have investigated saline soil-related spectral features and radar signatures, and obtained a number of interesting results, for example, the relationships between vegetation indices and soil salinity (Steven et al., 1992; Huete et al., 1997; Garcia et al., 2005; Al-Khaier, 2003; Brunner et al., 2007; Lobell et al., 2010; Iqbal, 2011; Zhang et al., 2011). Some authors have argued for the possibility to assess salinity using the moisture content indicator, NDII (Normalized Difference Infrared Index, Hardisky et al., 1983), and the thermal band (Metternicht and Zinck, 1996, 2003; Goossens and van Ranst, 1998; Iqbal, 2011). Recently, Douaoui et al. (2006), Fernández-Buces et al. (2006), Farifteh et al. (2007), Eldeiry and Garcia (2010) and Hu et al. (2014) have proposed respectively the regression-Kriging method, combined spectral response index (COSRI) and best band combination including vegetation index for salinity classification and spatial variability modeling. Others have even discussed the potential to use SAR (Synthetic Aperture Radar) backscatter coefficients to characterize soil electrical conductivity (Singh and Srivastav, 1990; Singh et al., 1990; Taylor et al., 1996; Metternicht, 1998; Shao et al., 2003).

These studies illustrate not only the advantage, feasibility and great potential of remote sensing and GIS in salinity mapping and assessment but also challenges to which we need to pay attention. Firstly, salt concentrated in subsoil is not easily detected by optical remote sensing (Farifteh et al., 2006); even in the topsoil (surface), if the salt content is below 10–15%, it is difficult to be discriminated from other soil surface components (Mougenot et al., 1993); however, reflectance increases with the increase in quantity of salts at the terrain surface, and this is particularly true for the blue band, in which the interference caused by ferric oxides is masked (Metternicht and Zinck, 2003). In fact, salt-affected soils show relatively higher spectral response in the visible and near-infrared regions of the spectrum than non-saline soils, and strongly saline–sodic soils present higher spectral response than moderately saline–sodic soils (Rao et al., 1995; Metternicht and Zinck, 2003). Secondly, the moisture in soil contributes to the decrease in reflectance in the middle- and near-infrared bands (Epema, 1990; Mougenot et al., 1993), which can easily lead to misinterpretation of salinity if just based on reflectance or vegetation indices. Thirdly, halophyte vegetation and even salt-tolerant crops such as barley, cotton, and alfalfa can modify the overall spectral response pattern of salt-affected soils, especially in the green and red bands (Rao et al., 1995; Metternicht, 1998).

We understood from the above brief review that remote sensing is a promising tool, especially, for large-scale salinity assessment. The outcomes of other authors such as relationships established between vegetation indices, moisture index (e.g. NDII), land surface temperature (LST, from the thermal band) and soil salinity will be useful if they can be ascertained. However, care should be taken to work out a reasonable approach for salinity quantification by taking the above challenges into account. In this context, the main objectives of this study are to propose an integrated approach for soil salinity mapping and assessment, track the change trend of the salt-affected soils in space and time, and ascertain the role of anthropogenic land use practice and management in the salinization processes. The Dujaila site, a severely salt-affected area in Central Iraq (Fig. 1), was selected as a pilot site to demonstrate the development procedure of the integrated mapping approach and its application for salinity change trend tracking.

2. Materials and methods

2.1. Study site

The Dujaila area, located between the Tigris River (north) and the Gharraf River (southwest), and administratively in the Wasit Governorate (Fig. 1) in Central Iraq, is the site where the largest Land Settlement Project started in 1946 as a model and experiment in Iraq after the Second World War (Dieleman, 1963). The total project area is around 99,000 ha including irrigated and non-irrigated land which can be further divided into three zones: reclaimed, semi-reclaimed and non-reclaimed. In the beginning of the project, with the formation of the new irrigation network for reclamation, salinity became worse due to lack of drainage system (Dieleman, 1963). That is why a number of experiments on salinity control by drainage, leaching and cultivation of salt-tolerant crops were conducted in the 1954–1959 period (Dieleman, 1963) and the successful experience was implemented and extended to the whole area. Land reclamation was not stopped until 1983.

The soil in the study site is mainly alluvial silty loam (locally silty clay loam) containing about 26–27% of lime and 0.4–2.5% of gypsum (Dieleman, 1963). According to its origin, the soil is Fluvisols; however, most of the soil is salinized, and locally, strongly salinized, and hence can be also classified as Solonchak or Solonetz in terms of the World Reference Base for Soil Resources (WRB). The measurements of Dieleman (1963) revealed that the surface soil (0–30 cm in depth) had a salinity of about 65 deci-Siemens per meter (denoted as dS/m in the following sections).

The Dujaila area belongs to a subtropical climate zone, characterized by short cool winter and long hot summer. Rainfall is concentrated in winter and spring from November to March with an average annual rainfall of about 141 mm in the past 60 years (measured at the adjacent station, Al-Hay). Winter is cool and short with a mean temperature of 12 °C from December to February. Summer is dry and hot to extremely hot with the maximum mean temperature of 45 °C in July and August.

The crops cultivated are wheat, barley and vegetables in winter and cotton, maize, millet, sorghum and sunflower in summer.

2.2. Field investigation and data

To map salinity, field survey is fundamental and essential. The survey campaign including soil sampling, measurement of EM38-MK2 (briefed as EM38, an electromagnetic instrument made by Geonics Ltd to measure soil electrical conductivity), land use/cover investigation and soil chemical analysis in laboratory was conducted during the October 2011 to June 2012 period. Soil samples included 15 surface (0–30 cm in depth) and 5 profile (0–150 cm) samples. Soil profiles were dug on October 19–21, 2011 and sampled at horizons of 0–30 cm, 50–70 cm, 90–110 cm, and 120–150 cm. Surface soil samples were obtained using auger in the places where EM38 measurements were also conducted on March 25–28, 2012 (4–6 days after rainfall events) and on June 28–July 04, 2012 (dry season after harvesting but before summer irrigation). The five profiles were revisited with EM38 measurements on March 25–28, 2012 due to the late arrival of the latter.

As designed, both vertical and horizontal EM38 readings (denoted respectively as EM_V and EM_H) were taken in plots (1×1 m^2) distributed at three corners of a triangle with a distance of about 15–20 m from each other. The averaged value of the three corner plots was regarded as the representative of the observation point in the center of the triangle. The objective of this treatment is to have more comparability between the field sampled data and the satellite images (with pixel size of 6.5–30 m). The electrical conductivity (EC) of 20 soil samples analyzed using 1:1 dilute method in laboratory and 62 pairs of EM_V and EM_H reading data were made available for this study.

The sampling locations (e.g., each triangle) were randomly selected depending on the accessibility but the variation of the field conditions such as salinity level, crop health and land use types was fully covered. The distribution of the sampling plots is shown in Fig. 2.

A multitemporal dataset mainly composed of Landsat TM (Thematic Mapper) and ETM+ (Enhanced Thematic Mapper Plus) images in the frame of 167-38 (Table 1), one scene of SPOT image dated March 28, 2010 and one RapidEye image dated April 22, 2012 were also acquired.