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Assessment of soil quality indices for salt-affected agricultural land in Kurdistan Province, Iran

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ABSTRACT

Soil quality indices (SQIs) were an important tool for evaluating agro-ecosystems. Salinization and alkalization are major environmental problems that have threatened agricultural productivity since ancient times. The aim of this study is to assess soil quality in salt-affected agricultural land in Kurdistan Province, Iran, using three indices; the Additive Soil Quality Index (SQI_a), the Weighted Additive Soil Quality Index (SQI_w), and the Nemoro Soil Quality Index (SQI_n). Each of the soil quality indices were calculated using a Total Data Set (TDS) and a Minimum Data Set (MDS) approach. The TDS consisted of nine soil quality parameters measured on 150 samples (0–30 cm depth): pH, Electrical Conductivity (EC), Organic Carbon (OC), Cation Exchange Capacity (CEC), Carbonate Calcium equivalent (CCE), Exchangeable Sodium Percentage (ESP), Sodium Adsorption Ratio (SAR), Mean Weight Diameter (MWD), and bulk density (BD). Principal components analysis (PCA) was used to determine which indicators were to be included in the MDS. Indicator Kriging (IK) highlighted areas with a high risk of exceeding critical threshold values of EC, ESP, and SAR and having low soil quality. In non-salt-affected areas soil quality and the risk of exceeding critical threshold values and having low soil quality were lower and higher, respectively, compared to salt-affected regions. The MDS method showed a decrease in the area and proportion of grades with high and very high quality (I and II) and an increase in grades with low and very low quality (IV and V) compared to the TDS. The results of linear correlation, match, and kappa statistic analysis showed that soil quality was better estimated using the SQI_w compared to the SQI_a and the SQI_n. In addition there were higher values of agreement (match and kappa statistic) for the TSD than MSD. However, using the SQI_w index and MDS method can adequately represent the TDS (R^2 = 0.82) and thus reduce the time and cost involved in evaluating soil quality.

1. Introduction

Salinization and alkalization are the most important land degradation problems in arid and semi-arid regions (Farifteh et al., 2006). These processes are a major problem for agriculture in Iran and Mashali (1999) reported that, approximately 14.43% of Iran's total area has been seriously affected due to inappropriate land management such as over irrigation and poor drainage as well as issues related to other natural factors. Generally, salt-affected soils are categorized as saline, sodic or saline–sodic according to their electrical conductivity (EC) and sodium adsorption ratio (SAR) or exchangeable sodium percentage (ESP) (Richards, 1954). Saline soils are characterized as having high EC values (> 4 dSm^{-1}), whereas sodic soils have low EC (< 4 dSm^{-1}) and a high SAR (> 13) or ESP (> 15%) (Richards, 1954). Salt-affected soils can be highly degraded and very unproductive agriculturally due to the effect of salinity and sodicity on soil physical, chemical and biological properties. To manage these problems the effect of salinization and alkalization on soil properties and soil quality needs to be assessed.

A commonly used definition for soil quality is "the capacity of soil to function to sustain plant and animal productivities, to maintain or enhance water and air quality and to support human health and habitation" (Karlen et al., 1998). Quantifying soil quality using indices is common (Andrews et al., 2002a), because Soil Quality Indices (SQIs) are easy to use and flexible (Qi et al., 2009). SQIs can improve understanding of soil ecosystems and allow more efficient management

Abbreviations: SQI_s, soil quality indices; SQI, $_a$additive soil quality index; SQI_w, weighted additive soil quality index; SQI_n, nemoro soil quality index; TDS, total data set; MDS, minimum data set; PCA, principal components analysis; EC, electrical conductivity; OC, organic carbon; CEC, cation exchange capacity; CCE, carbonate calcium equivalent; ESP, exchangeable sodium percentage; SAR, sodium adsorption ratio; MWD, mean weight diameter; BD, bulk density; IK, indicator kriging

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(Qi et al., 2009; Wang and Gong, 1998). They have been successfully used at many scales and locations (e.g. Andrews et al., 2002a; Aparicio and Costa, 2007; Glover et al., 2000; Masto et al., 2008; Naderi-Boldaji and Keller 2016; Raiesi and Kabiri, 2016; Thomazini et al., 2015).

Soil quality indexing involves a three step procedure: (1) identification of the minimum data set of indicators/properties; (2) transforming indicator scores and; (3) integration of the all indicator scores into one SQI value (Andrews et al., 2004; Karlen et al., 2003). The most recent work on soil quality indices uses statistical functions to group indicators, so that the number of parameters is reduced by choosing those that best represent the soil quality (Anderson, 2003; Brejda et al., 2000; Sparling and Schipper, 2004). Factor analysis (FA) and principal components analysis (PCA) have been widely used to select the most important soil indicators and reduce dimensionality (Shukla et al., 2006; Wander and Bollero, 1999). The parameters are grouped into a Minimum Data Set (MDS) which is a collection of selected indicators able to measure soil state and function. Total Data Sets (TDS) and MDSs have been widely used to evaluate soil quality (Arshad and Coen, 1992; Blecker et al., 2012; Cheng et al., 2016; Doran and Parkin, 1994; Gregorich et al., 1994; Karlen et al., 1996; Larson and Pierce, 1991; Larson and Pierce, 1994; Martin et al., 1998; Nakajima et al., 2015; Sanchez-Navarro et al., 2015).

To quantify relationships between soil quality indicators and soil functions, the selected indicators are transformed using linear and non-linear standard functions (Larson and Pierce, 1994). Numerous SQIs have been used for specific purposes and to integrate dimensionless indicators into quality indices such as the Additive Soil Quality Index (SQI_a) (Andrews and Carroll, 2001; Askari, and Holden, 2014), the Weighted Additive Soil Quality Index (SQI_w) (Askari et al., 2014; Cheng et al., 2016; Karlen et al., 1998; Mukhopadhyay et al., 2014; Raiesi and Kabiri, 2016), and the Nemoro Soil Quality Index (SQI_n) (Qi et al., 2009; Rahmanipour et al., 2014). The SQI_a is a summation of the scores of indicators (Doran and Parkin, 1994). The SQI_w combines weighted values of all selected indicators into an index using an equation (Qi et al., 2009). The SQI_n model is based on the mean and the minimum indicator score, without taking account of their weight (Qin and Zhao, 2000). These three approaches have previously been used in agricultural lands (Qi et al., 2009; Rahmanipour et al., 2014; Raiesi and Kabiri, 2016; Andrews et al., 2003). Many papers have been published on SQI assessment, however, there has been little research into their utility in semi-arid environments, particularly areas with salt-affected soil. Mapping of soil quality is important in defining poor quality soils due to salinization etc. and therefore determining remediation efforts to try and deal with salinization problems which can be focused to the exact locations identified. The Ghorveh area located in Kurdistan province, Iran is one of the most agriculturally productive areas of Iran. Part of this area has suffered from salinization and alkalization and its agricultural productivity is threatened. Therefore, the main objectives of this study were: (i) to assess soil quality in salt-affected agricultural land of Kurdistan Province, Iran, using two methods of indicator selection (TDS and MDS) and three SQIs (SQI_a, SQI_w and SQI_n) and (ii) to determine the best SQI and method of indicator selection for this region.

2. Materials and methods

2.1. Site description

The study area is located in Kurdistan Province, about 20 km northeast of Ghorveh city, west Iran, and covers 309.62 km^2 (Fig. 1). The climate is semi-arid with distinct differences between the dry (July–September) and wet (Oct–May) seasons. Average annual precipitation and temperature are 369.8 mm and 10.8 °C, respectively. Soil moisture and temperature regimes are Xeric and Mesic, respectively. Elevation varies from 1750 m above m.s.l. to 2750 m below m.s.l. The main land use types consist of cropland (wheat and barley) which occupies approximately 85% of the total area. The major physiographic units are low lands, piedmont, plateau and hills with flat to steep slopes. The major soils of the study area (Soil Survey Staff, 2014) are Inceptisols (data not shown).

2.2. Soil sampling and analysis

The conditioned Latin hypercube sampling (cLHS) method is efficient because it captures the variability of multiple input auxiliary variables (Minasny and McBratney, 2006) and has been applied to map soil properties and classes (Taghizadeh-Mehrjardi et al., 2016, 2015, 2014). In the study area, cLHS sampling was used and 150 soil samples were collected (0–30 cm depth) (Fig. 1). The soil samples were air-dried at room temperature and then, passed through a 2 mm sieve. Soil pH and electrical conductivity (EC) were measured in a saturated paste using a pH electrode (McLean, 1982) and conductivity meter (Rhoades, 1982), respectively. Organic carbon was determined using wet combustion (Nelson and Sommers, 1982). Cation exchange capacity (CEC) and exchangeable Sodium were estimated by the 1 N ammonium acetate (pH 7.0) method (Schollenberger and Simon, 1945; Sumner and Miller, 1996). Exchangeable sodium percentage (ESP) was estimated as the ratio of sodium, to CEC. Soluble calcium, magnesium and sodium were measured using the EDTA complex metric titration and flame photometric methods (Page, 1992; Jayachandran et al., 2012) then, Sodium Adsorption Ratio (SAR) was calculated using results from the saturated paste extracts of sodium, calcium, and magnesium. Calcium carbonate equivalent (CCE) and soil bulk density (BD) were determined by volumetric (Sparks et al., 1996) and core methods (Grossman and Reinsch, 2002), respectively. The method of Kemper and Rosenau (1986) was used to determine mean weight diameter (MWD) using the following equation (Eq. (1)):

$$MWD = \sum_{i=1}^{n} X_i W_i \tag{1}$$

where MWD is the mean weight diameter of water stable aggregates, X_i is the mean diameter of each size fraction (mm), and W_i is the proportion of the total sample mass in the corresponding size fraction after deducing the stone mass as indicated above.

2.3. Soil quality index assessment

2.3.1. Total and minimum data set

The nine measured parameters were used in a TDS and selected for their sensitivity in soil quality evaluation. The following soil properties: OC, BD, EC, CCE, CEC, pH, and MWD have been suggested by many authors as useful soil quality indicators (Arshad and Coen, 1992; Cheng et al., 2016; Doran and Parkin, 1996; Doran and Parkin, 1994; Harris et al., 1996; Karlen et al., 1996; Kay and Grant, 1996; Larson and Pierce, 1991; Mukhopadhyay et al., 2014; Qi et al., 2009; Papendick, 1991; Rahmanipour et al., 2014; Sanchez-Navarro et al., 2015; Smith and Doran, 1996). Some, CEC, OC, CCE, BD, and MWD were chosen due to their influence on soil fertility, supply of nutrients, pH, root growth, soil porosity, soil structure, and aggregate stability which in turn are largely a function of the plants growing in the area and soil ecology (Baldock and Nelson, 2000; Boix- Fayos et al. 2001; Grossman et al., 2001; Herrick and Wander, 1998; Tiessen et al., 1994) while EC, SAR, and ESP were added to specifically address the sodicity concerns of the region (Andrews et al., 2003; 2002a, 2002b; Gong et al., 2015; Vasu et al., 2016; Yao et al., 2014). The SQIs were computed by using a scoring function analysis framework (Andrews et al., 2004; Karlen et al., 2001). The MDS selection was determined to reduce dimensionality using PCA (Doran and Parkin, 1994; Qi et al., 2009). The PCs with high eigenvalues (> 1) (Andrews et al., 2002a) and those that explained at least 5% of the data variation were selected (Wander and Bollero, 1999). For each PC, soil variables with high factor loadings