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Soil quality assessment in Yellow River Delta: Establishing a minimum data set and fuzzy logic model

Chunsheng Wu, Gaohuan Liu*, Chong Huang, Qingsheng Liu

State Key Lab. of Resources and Environment Information System, Institute of Geographic Sciences and Natural Resources Research, CAS, Beijing 100101, China

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ABSTRACT

The Yellow River Delta has abundant land resources, but the land exhibits heavy degeneration because of long-term exposure to harsh natural conditions and improper human activities, and the soil quality is poor in some areas. All these factors have adversely affected agricultural development and ecological protection in the Yellow River Delta. This study selected multiple physical and chemical indicators and used principal component analysis (PCA) to construct a minimum data set (MDS) to determine a comprehensive set of indicators for assessing soil quality in the Yellow River Delta. Moreover, a fuzzy logic model was used to assess soil quality and analyze the spatial distribution of the primary land use types in different soil quality grades. The results indicate that the MDS includes six soil indicators: total nitrogen (TN), available phosphorus (AP), available potassium (AK), soil organic matter (SOM), soil salinity (SS) and pH. According to the spatial distribution maps of the indicators, SS gradually declined from the coast to the inland areas, while TN and AP had opposite characteristics. AK and pH were evenly distributed around the study area, and SOM was highest in the center and gradually declined toward the edge of the study area. The soil quality was higher in inland areas than in coastal areas, and most of the study area was classified as grade III. Most of the farmland, forest, and garden plots were distributed in high-grade soil levels, but some of these plots were distributed in areas classified as grades V or VI. Many areas with high soil quality were unused, which indicated that the land resources of the study area should be planned reasonably.

1. Introduction

Soil is an important natural resource, and soil quality is a crucial attribute for food security, human health and the sustainable development of the ecological environment. However, a widely accepted concept of soil quality has not yet been defined (Gavrilenko et al., 2013). According to the existing concepts, soil quality is composed of three aspects: the ability of soil to improve biological production (soil productivity); the ability of soil to clear up environmental pollutants and germs (environmental quality); and the ability of soil to influence flora, fauna and human health (biological health) (Doran and Parkin, 1994; Karlen et al., 1997).

Soil quality assessment refers to the monitoring and evaluation of soil attributes, soil functions and soil conditions (Legaz et al., 2017). Soil quality assessments are difficult because of the heterogeneity and variability of the physical, chemical and biological properties in different soil areas (Arslan, 2017; Cheng et al., 2016; Lin et al., 2017), and the use of pesticides and fertilizers make assessments even more complex (Firdous et al., 2016). Therefore, scientifically selecting appropriate evaluation indicators is especially important, and physical, chemical and biological indicators should be considered simultaneously (Ashwood et al., 2017). In addition, the change in an indicator system at different spatial and temporal scales should also be considered when the assessment is managed over a series of time (Jose Sione et al., 2017; Mukhopadhyay et al., 2016; van Hall et al., 2017). However, acceptable guidelines or standards have not been established in indicator system construction and soil quality classification around the world until now (Biswas et al., 2017; Mukhopadhyay et al., 2016; Obade and La, 2016). Moreover, soil quality assessments and soil fertility assessments are easily confused because their selected indicators and evaluation methods are similar, which results in the inclination to evaluate soil fertility in soil quality assessments (Zuber et al., 2017).

The limiting factors of soil quality vary because of different land use types, ecological systems, locations and soil parent materials (Fu et al., 2003; Su and Zhao, 2003); therefore, selecting appropriate indicators is especially important for the results of soil assessments. Fortunately, establishing a minimum data set (MDS) makes the process of selecting indicators and assessing soil quality convenient (Andrews et al., 2002; Rezaei et al., 2006). On the one hand, an MDS can reduce data redundancy by selecting the most appropriate indicators among

* Corresponding author.
E-mail address: liugh@lreis.ac.cn (G. Liu).

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preselected indicators. On the other hand, the weights of the selected indicators can be generated when establishing the MDS, which is beneficial for the subsequent soil quality assessment, as it decreases the subjective anthropogenic influence (Rezaei et al., 2006). Several researchers have conducted soil quality assessments based on an MDS (de Lima et al., 2008). For example, Rahmanipour, F. completed a soil quality assessment of agricultural lands in Qazvin Province, Iran, and the result proved that the assessment based on the MDS was better than that based on the total data set (Rahmanipour et al., 2014). Other similar studies have also been carried out in coastal areas, forests, wetlands, and grasslands (Volchko et al., 2014; Wang et al., 2003). Some researchers have added macroscopic soil environment factors and land use status to indicator selection criteria to improve the establishment of an MDS, which has provided better results, but this method has not been widely utilized (Chen et al., 2013).

The Yellow River Delta (YRD), which was formed from sedimentation carried by the Yellow River over hundreds of years, has abundant land resources, but the salinized soil and frequent human activities have heavily stunted vegetation growth and degraded soil quality, which has threatened local ecological safety (Wu et al., 2017). Studies on the soil quality of the YRD have been rare until recently. There were two problems in the previous studies; first, many studies were conducted only using statistical data on the sample scale, and the results were not extended to the entire area (Zhang et al., 2016). Second, most research concentrated on some certain land use types and did not evaluate all the ecosystems in the study area (Guo et al., 2017; Yao et al., 2013).

The objective of this study was to evaluate the soil quality of the YRD based on a synthetic MDS in 2014, which focused on the soil foundation, and soil types and all land use types were added as influencing factors to indicator screening process. A fuzzy logic model was used in the final soil quality assessment based on interpolating selected indicators and setting local indicator threshold. This study attempted to provide a new method for establishing an MDS by combining quantitative external soil environment attributes and internal soil attributes, and the results are useful for local land planning and ecological protection.

2. Materials and methods

2.1. Study area

The present study was conducted in the YRD, which is located in Dongying city of Shandong Province, China. The coordinates of the study site are from 37°22′–38°04′N and 118°14′–119°05′E (Fig. 1), and the total area is 5062.59 km^2. The study area has a gentle terrain with the elevation ranging from 0 m to 12.00 m above sea level, which gradually decreases from the southwest to the northeast. The micro-topographic features vary in the area as a result of alluviation from the Yellow River, and the features include depressions, flat grounds, tidal flats, and high lands. The study area has a temperate continental monsoon climate; rainy days are mainly from June to September, but the annual mean evaporation is greater than the annual mean precipitation. The main soil type is gleyic solonchaks with high salinization and a high sand proportion. The natural vegetation is widespread, especially herbaceous plants, such as bulrush, tamarix, cogon, and suaeda.

2.2. Data

2.2.1. Sampling and laboratory analyses

The surface soil was used as the study object and was sampled from May 14, 2014, to May 22, 2014 as this period was neither in dry season nor in rainy season, and it was also far from the stage of irrigation and fertilization, which made sure that the environmental noises and systematic errors of soil samples were removed as much as possible.

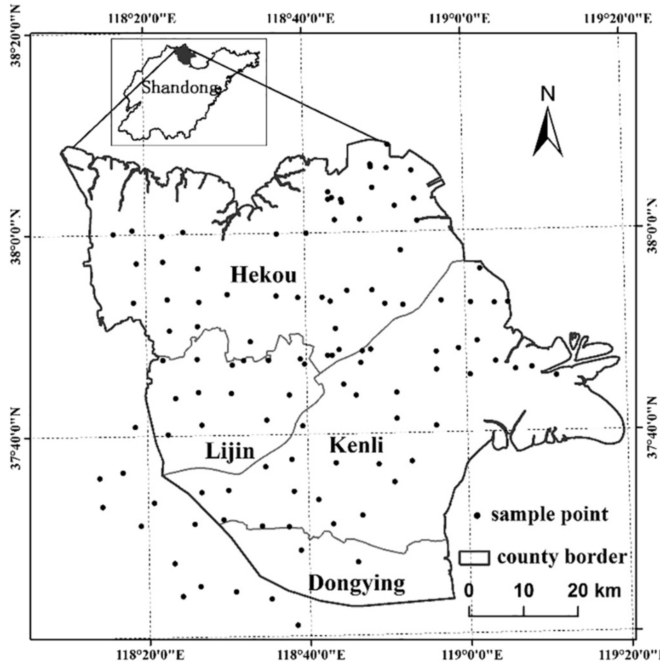

Fig. 1. Study area and sample points.

Combined with the land use types and soil types, a 6 km × 6 km grid arrangement was designed for sampling. Due to accessibility or operability limitations, some sample points were replaced with points near the originally designed locations. A soil drill was used to collect soil from 0 to 20 cm under the surface, and each specimen was placed in an aluminum box, which was then sealed. The location of each sample was recorded with a GPS, and a total of 98 samples were collected. A total of 14 samples outside the study area were added to guarantee the accuracy of the assessment results inside the study area. All soil samples were naturally air-dried and passed through a 2-mm sieve before physical and chemical analyses in the laboratory.

According to the advice from Xu Jian-ming (Xu et al., 2010) about the indicators for soil quality assessments, we selected 10 indicators in advance, including pH, total nitrogen (TN), available phosphorus (AP), available potassium (AK), soil particle composition (clay, silt, and sand), soil salinity (SS), soil organic matter (SOM), and soil humidity (SH) (measured by a soil parameter measuring instrument in the field). SS was measured using the conventional weight method, and the proportion of water-soil was set at 5:1 to extract the weight of soluble salt. A laser particle analyzer was used to detect the soil particle composition. The SOM was measured by the Walkley-Black method. TN was determined by the Kjeldahl digestion method. AP was determined by extracting samples with a 0.5 mol/L sodium bicarbonate solution and detecting with a spectrophotometer. AK was determined by extracting samples with a 1 mol/L ammonium acetate solution and detecting with a flame photometer. Soil pH was measured using the electrometric method on a soil/water suspension.

2.2.2. Auxiliary data

The auxiliary data, which were used as the influencing factors from the external environment in indicator screening process, included elevation, land use status, soil types, Landsat Thematic Mapper (TM) remote sensing images from the USA, and GF-1 remote sensing images from China. The land use status was generated by interpreting the GF-1 images from October 2014 using the land survey data of 2007, and the interpretation accuracy was 88.68%, which indicated that the results were credible. The unused land was classified as saline-alkali land. The spatial distribution of the rivers was extracted from the interpretation results. The NDVI was extracted from the Landsat TM remote sensing