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Identifying change in spatial accumulation of soil salinity in an inland river watershed, China

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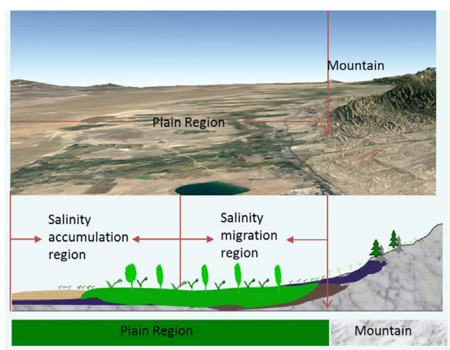
HIGHLIGHTS

- We investigated the spatial change of salt accumulation in soil.
- 56% of the studied area experienced changes in soil salt content.
- The Lorenz curve was applied to soil salinity accumulation across a watershed.
- Soil salt accumulation per unit area increased by about 16%.
- Results provide an insight into the spatial patterns of soil salinity accumulation.

GRAPHICAL ABSTRACT



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ABSTRACT

Soil salinity accumulation is strong in arid areas and it has become a serious environmental problem. Knowledge of the process and spatial changes of accumulated salinity in soil can provide an insight into the spatial patterns of soil salinity accumulation. This is especially useful for estimating the spatial transport of soil salinity at the watershed scale. This study aimed to identify spatial patterns of salt accumulation in the top 20 cm soils in a typical inland watershed, the Sangong River watershed in arid northwest China, using geostatistics, spatial analysis technology and the Lorenz curve. The results showed that: (1) soil salt content had great spatial variability (coefficient variation > 1.0) in both in 1982 and 2015, and about 56% of the studied area experienced transition the degree of soil salt content from one class to another during 1982–2015. (2) Lorenz curves describing the proportions of soil salinity accumulation (SSA) identified that the boundary between soil salinity migration and accumulation regions was 24.3 m lower in 2015 than in 1982, suggesting a spatio-temporal inequality in loading of the soil salinity transport region, indicating significant migration of soil salinity from the upstream to the downstream watershed. (3) Regardless of migration or accumulation region, the mean value of SSA per unit area was 0.17 kg/m^2 higher in 2015 than 1982 ($p < 0.01$) and the increasing SSA per unit area in irrigated land significantly increased by 0.19 kg/m^2 compared with the migration region. Dramatic accumulation of soil salinity in all land use types was clearly increased by 0.29 kg/m^2 in this agricultural watershed during the studied period in the arid northwest of China. This study demonstrates the spatial patterns of soil salinity accumulation, which is particularly useful for estimating the spatial transport of soil salinity at the watershed scale.

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1. Introduction

Soil salinization is a global issue, especially in arid and semiarid areas with low rainfall and high evapotranspiration (Butcher et al., 2016; Amundson et al., 2015; Li et al., 2014). Soil salinization influences soil quality and the sustainability of agriculture, and can decrease biodiversity, and reduce water quality and agricultural production (Cassel et al., 2015; Aragüés et al., 2014; Bui, 2013). An area of >930 million ha that occupies 7% of global land surface suffers from soil salinization, and the area is expanding (Rengasamy, 2006). Approximately 20% of irrigated land is salt-affected globally (Yeo, 1999), and the land area that has secondary soil salinization problems is as high as about 80 million ha in arid and semiarid regions (Ghassemi et al., 1997). Hence, it is crucial to mitigate and control soil salinity in agricultural lands, particularly where irrigation is used (Jalila et al., 2016; Singh, 2015). Understanding the process and spatial changes of salt accumulation in soil will improve ways to prevent soil degradation, and ameliorate soil quality for economic development (Salvati and Ferrara, 2015). This asks for accurate estimation of spatial variation of soil salinization at large scales (Daliakopoulos et al., 2016; Sheng et al., 2010; Benyamini et al., 2005).

Understanding the accumulation patterns and processes of soil salinity and its correlative factors is crucial to control soil salinization in arid environments. Previous studies showed that human activities and climate change are the primary controls on soil secondary salinization (Zhou et al., 2013; Foley et al., 2011). The conversion of natural land use (e.g. grasslands and forests) to cropland has dramatically affected soil properties as well as their spatial and temporal patterns. These changes often accelerate soil salinization (Abliz et al., 2016; Devkota et al., 2015; Ibrakhimov et al., 2011; Beltran, 1999). Generally, the spatial variation of soil salinity is substantially regulated by factors such as topography, climate and hydrological conditions (Yang et al., 2016; Wang and Li, 2013; Wang et al., 2008a). Soil salts are transported and redistributed with soil water, groundwater and irrigation water across the landscape. This process is significant in surface soils under conditions of little precipitation and high evapotranspiration in arid environments (Pankova et al., 2015; Zhang et al., 2014a; Cetin and Kirda, 2003). Therefore, better understanding about the spatial patterns of soil salinity could inform scientific strategies to control salinization for sustainable land management (Taghizadeh-Mehrjardi et al., 2014; Bennett et al., 2010; Qadir and Oster, 2004).

Current studies often estimate soil salinity change using indirect measurements, small-scale experiments or poorly defined periods of time (Herrero and Pérez-Coveta, 2005). Although single field investigations or observations can give some information about short-term changes in soil salinity (Scudiero et al., 2017), the changes in soil salinity are related not only among fields, but also irrigation regions and even the entire watershed (Scudiero et al., 2016; Zhang et al., 2014b). Clearly such limited information is inadequate to explain comprehensive soil–landscape relationships concerning transport and accumulation of soil salinity among irrigation regions, especially at the watershed scale. Quantifying the spatio-temporal variation of soil properties at larger scales is critical to adequately understand the extent of the environment problem (Corwin et al., 2006). However, it is a major challenge to quantify the spatio-temporal patterns of soil salinity accumulation (SSA) in heterogeneous soils.at the watershed scale.

Techniques and methods to monitor and map soil salinization have been a focus for research in arid and semiarid areas in recent years, because they are crucial for effective land management and utilization (Lal, 2015; Nurmemet et al., 2015; Cruz-Cárdenas, 2014; Ding et al., 2011; Fernandez-Buces et al., 2006). The appropriate mapping methods depend on the spatial scale of interest. Geostatistics, as an effective tool to study and predict the spatial structure of geo-referenced variables, has been commonly used to map soil salinization (Niñerola et al., 2017; Li H.Y. et al., 2015; Li Y. et al., 2015; Juan et al., 2011; Douaik et al., 2005; Pozdnyakova and Zhang, 1999). It was used to describe spatial variability for a number of natural indexes (Monestiez et al., 2010; Renard et al., 2005; Cambardella et al., 1994), as well as the temporal and spatial characteristics of soil properties over a large area (Tripathi et al., 2015). Therefore, identifying the spatial change of soil salt migration and accumulation is helpful to control soil salinization at the watershed scale. The Lorenz curve, defined by M.E. Lorenz (1905), is commonly used to describe the degree of inequality in social distribution of income and has become an effective statistical measurement for general equality analysis (Chakravarty, 1990). In recent years, this has gradually been introduced to resource and environment fields, and has proved effective in illuminating imbalances in distributions (Abell et al., 2013; Chen et al., 2009; Preston et al., 1989). The distribution of salt accumulation in soil is highly heterogeneous in the process of loading of soil salinity transport in the space of watershed. The Lorenz curve can be applied to soil salinity data to determine tradeoffs in the regions of soil salinity migration and accumulation, using the Gini coefficient as the criterion. Thus, the combination of information from the Lorenz curve and geostatistical analyses of soil salinity allows assessment of soil salinity accumulation in transport and accumulation regions, which advance our understanding of the spatio-temporal pattern of soil salinization during the long-term process of land use at the watershed scale.

The Sangong River watershed, a well-known inland river watershed in China's Xinjiang Province, was selected as a case study. This study aims (1) to quantify spatial variability of soil salinity at the watershed scale during 1982–2015, (2) to identify the boundary of soil salinity migration and accumulation regions using the Lorenz curve and (3) to assess the degree of soil salinity accumulation in different regions across land use types.

2. Materials and methods

2.1. Site description

The Sangong River watershed (87°49′–88°16′E, 43°50′–44°22′N) is located in the northern Tianshan Mountains and southern the Guerbantonggute Desert in northwest China (Fig. 1). The watershed covers mountainous region in the south and plains in the north. The plain region in this watershed is for agricultural use. It covers an area of 94,200 ha, and the north–south and east–west distances are 36.97 and 37.65 km, respectively; with the slope of only 2–2.5% downwards from south to north. The elevation varies from 710 m in the south to 440 m in the north (Fig. 1). The climate in the region is the arid continental climate, and the mean annual precipitation is <200 mm and mean annual temperature 7.3 °C with average maximum of 25.75 °C in July and average minimum of 15.7 °C in January. Based on long-term meteorological data (1965–2005), the mean annual pan evaporation is about 1533–2240 mm. In this area, irrigation is essential for agriculture due to little precipitation and high evapotranspiration. The dominant land use type is irrigated agriculture, with urban areas accounting for only a small percentage of the study area. The main soil classes are Solonchak, Haplic calcisols and Aquert, and they have been affected by agricultural practices for over 50 years. The crops in the region include wheat, corn, cotton, grapes and hops. This region has experienced intensive land exploitation since the 1960s and soil salinization has become a serious environmental problem during to irrigation (Wang et al., 2008b). Natural vegetation in the study region includes a variety of xeromorphic formations, e.g. *Reaumuria soongorica*, *Salsola nitraria*, *Ceratocarpus arenarius*, *Tamarix ramosissima*, etc.

2.2. Data source and processing

Soil salt content in 1982 and 2015 was obtained in two ways: we collected and measured soil salt content of 290 soil samples in 2015, and the other 145 data points in 1982 were from China's National Soil Inventory in the Sangong River watershed (Fukang Land Resources Administration, 1983). The locations of soil samples in 1982 were