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Combined impacts of land use and soil property changes on soil erosion in a mollisol area under long-term agricultural development

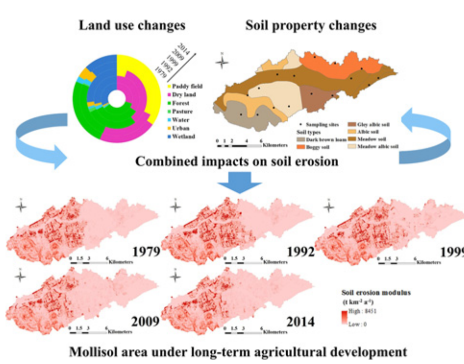
Wei Ouyang [a,*], Yuyang Wu [a], Zengchao Hao [a], Qi Zhang [a], Qingwei Bu [b], Xiang Gao [a]

[a] School of Environment, State Key Laboratory of Water Environment Simulation, Beijing Normal University, Beijing 100875, PR China
[b] Water Resources Research Institute of Shandong Province, Jinan 250013, PR China

HIGHLIGHTS

- Soil erosion characteristics under long-term agricultural development in a mollisol area were obtained.
- Paddy fields have a more significant impact than soil properties on soil erosion.
- The appropriate land use planning should be the priority to reduce soil erosion.

GRAPHICAL ABSTRACT



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ABSTRACT

Soil erosion exhibits special characteristics in the process of agricultural development. Understanding the combined impacts of land use and soil property changes on soil erosion, especially in the area under long-term agricultural cultivations, is vital to watershed agricultural and soil management. This study investigated the temporal-spatial patterns of the soil erosion based on a modified version of Universal Soil Loss Equation (USLE) and conducted a soil erosion contribution analysis. The land use data were interpreted from Landsat series images, and soil properties were obtained from field sampling, laboratory tests and SPAW (Soil-Plant-Atmosphere-Water) model calculations. Over a long period of agricultural development, the average erosion modulus decreased from 187.7 t km^{-2} a^{-1} in 1979 to 158.4 t km^{-2} a^{-1} in 2014. The land use types were transformed mainly in the reclamation of paddy fields and the shrinking of wetlands on a large scale. Most of the soils were converted to loam from silty or clay loam and the saturated hydraulic conductivity (K_s) of most soil types decreased by 1.11% to 43.6%. The rapidly increasing area of 49.8 km^2 of paddy fields together with the moderate decrease of 14.0 km^2 of forests, as well as K_s values explained 87.4% of the total variance in soil erosion. Although changes in soil physical and water characteristics indicated that soil erosion loads should have become higher, the upsurge in paddy fields played an important role in mitigating soil erosion in this study area. These results demonstrated that land use changes had more significant impacts than soil property changes on soil erosion. This study suggested that rational measures should be taken to extend paddy fields and control the dry land farming. These findings will benefit watershed agricultural targeting and management.

1. Introduction

Soil erosion is a direct consequence of agricultural exploitation, which may damage land resources and reduce soil quality, resulting in

* Corresponding author.
E-mail address: wei@bnu.edu.cn (W. Ouyang).

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environmental pollution problems that may lead to a series of threats to agricultural sustainability (Rickson, 2014; Guzman et al., 2015). Land use is an important factor affecting soil erosion and the process of sediment yield (Ouyang et al., 2010). Land use changes cause geomorphic responses that lead to an increase in areas vulnerable to high erosion rates (Pelacani et al., 2008). Previous studies have reported that landscape characteristics in watersheds could explain as much as 65.0% and 74.0% of changes in soil erosion and sediment yields (Shi et al., 2013). In addition, land use can influence soil losses by changing stream flow discharges (Serpa et al., 2015). Traditionally, it is considered that land uses such as grasslands and forests can produce less soil erosion hazards, and arable lands tend to accelerate erosion.

As a form of land degradation, soil erosion was also related to soil properties. Soil properties affect the transport of soil materials under the impacts of raindrop detachment and runoff scouring. Soil properties and related hydraulic parameters are important parameters that provide information for erosion studies (Schwen et al., 2014). Soil water retention, soil hydraulic conductivity and soil infiltration can also influence temporal variations in soil erosion (Durner and Iden, 2011; Wei et al., 2015). The water permeability of soil was taken as an index of its erosion resistance (Gee et al., 1976). The effect of soil properties on erosion is an important topic in environmental management in agricultural areas. However, changes in soil properties can be a long process. Hence, it is important to obtain long-term data to analyse changes in soil properties.

Changes in both land use and soil characteristics generally happen during agricultural development, which lead to hydrologic responses that have a synergistic effect on soil erosion. When tillage intensity increased, soil erosion resistance (e.g., soil erodibility and critical shear stress) would decrease (Wang et al., 2016). Moreover, land use changes can also affect soil properties. The conversion of natural grasslands to cultivated lands destabilized soil structure and reduced the soil saturated hydraulic conductivity (K_s) values (Shabtai et al., 2014), which modified infiltration and runoff processes. But the previous research also showed that in agricultural areas, although soil organic matter and permeability were close in pasture and forest restoration system, the difference in sediment yields between these two systems could be significant (4.55 kg ha^{-1} and 25.01 kg ha^{-1}) (Nacinovic et al., 2014). To estimate the annual soil loss in watershed on agricultural fields, the application of Universal Soil Loss Equation (USLE) and its revised version is suitable, which can benefit policy practices based on land use changes (Panagos et al., 2015).

Mollisol, which has the highest fertility and greatest potential for productivity, plays important roles in grain production and food security in China (Liu et al., 2012; Duan et al., 2012). The mollisol area in northeastern China extends across four provinces, with a variety of forms of soil and water loss that include water, wind and melt water erosion, of which water erosion on slope farmlands is the main factor that contributes to soil loss (Xu et al., 2010). There had been four great waves of agricultural development in this mollisol area since the 1950s, and agricultural transformation through farmland reclamation has been profoundly changing land use types, soil environments and hydrological conditions (Ouyang et al., 2013a). At the same time, the loss of soil organic matter had exerted an adverse influence on the agricultural development in this area (Yao et al., 2017). These changes influenced soil infiltration, runoff generation and in turn soil erosion (Mao et al., 2008). Changes in land use and soil characteristics led by long term agricultural development had made soil erosion exhibit special characteristics. With the agricultural development, soil erosion regulations under different farmland types should be investigated for agricultural planning.

Although cultivated lands generally accelerate soil erosion, understanding the combined effects of land use and soil property variations on soil erosion, especially in the area under long-term agricultural development, is a critical issue and is needed to assist watershed management and reduce soil erosion. Hence, the purposes of this paper are: (1) to identify the changes in land use types and soil water characteristics over the decades; (2) to obtain the temporal variation and spatial distribution of soil erosion by utilizing long-term agricultural development; and (3) to determine the combined impacts of changes in land use and soil properties on soil erosion in mollisol zones.

2. Methodology

2.1. Study area description

The study area is the Abujiao River Basin (Fig. 1), which is located in Bawujiu Farm in the mollisol area of northeastern China with an area of 142.5 km^2. The main river flows eastwards, and the altitude ranges from 38.0 m to 209 m. The mean annual temperature is 2.94 °C, and the annual average precipitation is 583.2 mm, which mainly occurs in summer from May to September (Ouyang et al., 2013b). Nearly 82.5% of total rainfall occurs in August and the rainfall intensity reaches the peak in this period. This area is in one of the most important crop production bases in China due to its long length of daylight, large daily temperature differences (Hao et al., 2012) and precious mollisol resources. It has experienced waves of agricultural development over decades and the main crops are maize, rice and soybean.

2.2. Data collection and land use types

The Digital Elevation Model (DEM) of watershed (30 m × 30 m) was provided by the Data Center for Resources and Environmental Sciences, Chinese Academy of Sciences (RESDC) (http://www.resdc.cn). The land use data were interpreted from Landsat images for five selective and representative years 1979, 1992, 1999, 2009 and 2014 (http://glovis.usgs.gov/). The images were selected mainly in growing or harvesting seasons of crops and free from clouds and snow cover to the fullest. Land use data were obtained by supervised classification method under the ENVI 5.1 operating platform (Ouyang et al., 2016; Huang et al., 2013) and was rectified manually according to field investigation throughout the study area. According to national land cover database scheme, 7 land use types were classified in Abujiao River Basin: paddy fields, dry land, forests, pastures, water, urban area and wetlands (Fig. 2). Paddy fields are for wetland rice planting and dry land is mostly cultivated with soybean, which were under temporary or permanent crops for annual field crops. Forest is a mixed forest type which includes naturally regenerated forest, planted forest and wooded land. Pastures contain meadow and pasture land cultivated with herbaceous forage crops. Water refers to inland water area including rivers and streams. Urban area in this study refers to residential area and wetlands have free water above surface permanently or during the major period of growing seasons.

2.3. Mollisol sample collection and determination of soil properties

According to soil type distribution, field and site investigation in the study area by remote sensing technique, a total of 16 sites of sampling covering all soil types were determined in 2014 (Fig. 3). The grid method (1.5 km × 1.5 km) was used for random sampling. Ridges, roadbeds, farmland and areas that were apparently disturbed were carefully avoided. Broken branches and leaves over the soil surface were removed. Three soil samples were collected from the top soil layer (0–20 cm) at each sampling site. To ensure the samples to be representative, 3 to 5 soil samples within 100 m near the middle site of each grid were first collected and then mixed uniformly. Quartering method was employed to take 1 kg soil sample from the mixed soil and then these samples were sealed in sterile polyethylene bags and kept in a portable refrigerator staying away from heat and light. The coordinates, latitude, longitude and surrounding topography were recorded during the sampling process.