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The correlation analysis on the landscape pattern index and hydrological processes in the Yanhe watershed, China

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SUMMARY

Yanhe watershed, as a typical and experimental district of Soil and Water Conservation District, has long been plagued by soil erosion due to severe human disturbances. Exploring the relationship between watershed landscape pattern and hydrological processes can find effective ways to solve soil erosion problems. At first, with remote sensing and GIS (Geographic Information System) technology and based on SWAT model, this paper analyzed and simulated ecological hydrological processes in Yanhe watershed. It is on subbasin scale that the runoff and sediment yields were simulated monthly in Yanhe watershed using SWAT model. Secondly, it quantified landscape pattern with landscape indices. The seven landscape indices at the landscape level were selected with principal component factor analysis, including Disjunct Core Area Density (DCAD), Radius of gyration (GYRATE_SD), Patch Cohesion Index (COHESION), Shannon's diversity index (SHEI), Total Core Area (TCA), Perimeter-Area Fractal dimension index (PAFRAC), Interspersion and Juxtaposition Index (IJI), etc. Thirdly, a new composite landscape index was constructed on the basis of eco-hydrological processes, which was closely related to soil erosion. The results are as follows: (1) Coupled analysis on the relationship of landscape indices and annual runoff as well as annual sediment yields in each subbasin, the correlation coefficient of seven selected landscape indices and runoff is very small, no passing all significant tests. But the correlation between sediment yields and the indices except for TCA and IJI is significant, and the absolute value of the correlation coefficient is between 0.3 and 0.5. (2) According to the "source-sink" theory of soil erosion, Slope-HRUs landscape index (SHLI) was built and can reflect the relationship between landscape pattern and soil erosion processes to a certain extent. The coupling relationship between Slope-HRUs landscape index (SHLI) and annual sediment yields in each subbasin is very clear, and correlation coefficient is −0.6, which is significantly negatively correlated.

1. Introduction

Watersheds are natural environmental and land management units. The sustainable management of watershed resources and the environment protection has challenged the hydrologist and water managers around the globe (Jones et al., 2001; Yasin and Clemente, 2014). The Loess Plateau in China has long been plagued by soil erosion due to severe human disturbances (Liu et al., 2003; Fu et al., 2005, 2014; Su et al., 2011), about 5000–10,000 t km^{-2} per year in most areas, and even higher than 20,000 t km^{-2} per year in some areas. Especially, Yanhe watershed is as the typical Soil and Water Conservation District in Loess Plateau. Average annual soil loss is between 5000 and 20,000 t km^{-2} per year, and the mean value is 14,460 t km^{-2} per year. Land use changes in a watershed can impact water supply by altering hydrological processes (Fu et al., 2005). Since the 1950s, the 'taking grain as the key link' policy, 'Grain-For-Green' (GfG project)(Su et al., 2011) and a number of ecological projects (Ouyang et al., 2010) have been practiced to increase grain yield to feed the mass population in starvation and curbed the continually deteriorating ecological situation. Thus, Yanhe watershed is the typical and important region in loess plateau. It is

Abbreviations: GIS, Geographic Information System; DCAD, Disjunct Core Area Density; GYRATE_SD, Radius of Gyration Standard Deviation; COHESION, Patch Cohesion Index; SHEI, Shannon's Diversity Index; TCA, Total Core Area; PAFRAC, Perimeter-Area Fractal Dimension Index; IJI, Interspersion and Juxtaposition Index; HRUs, Hydrological Response Units; SHLI, Slope-HRUs Landscape Index; PCA, Principal Component Analysis; SWAT, Soil and Water Assessment Tool.

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crucial to land use and water resource planning and management for the development of an integrated approach that can simulate and assess land use patterns and their effects on hydrological processes at the watershed level.

Landscape pattern indices can be used to quantify the spatial pattern (composition and configuration) of land cover features (Long et al., 2010). Landscape indices are useful in applying the concepts of landscape ecology in landscape monitoring and planning (Zhang and Wang, 2006; Uuemaa et al., 2007; Aguilera et al., 2011; Plexida et al., 2014), providing an objective description of different aspects of landscape structure and patterns (Wickham and Riitters, 1995; Herold et al., 2002; Kim and Pauleit, 2005). In the past, several studies have used factor analysis (FA) and principal component analysis (PCA) to reduce the multitude of available landscape pattern indices to a meaningful subset for the respective application (Arnot et al., 2004; Lechner et al., 2013; Liu and Weng, 2013; Fan and Myint, 2014). Many people defined some new landscape indices in different regions all over the world (Jackson et al., 2005; Borselli et al., 2008; Mayor et al., 2008; Hartel et al., 2010; Benedek et al., 2011; Brown and Reed, 2012), for example, index of connectivity (IC) and field connectivity index (FIC) (Borselli et al., 2008), flow length (FL) for quantifying the connectivity of runoff source areas (Mayor et al., 2008), connectivity indices and niche modeling (Hartel et al., 2010), and location-weighted landscape index (LWLI) (Chen et al., 2009).

Soil and water assessment tool (SWAT) was developed to predict the impact of land management practices on water, sediment and agricultural chemical yields in large complex watersheds with varying soils, land use and management conditions over long periods of time. In recent years, SWAT model has been applied worldwide and is the tool used for addressing complex processes of runoff and erosion in watersheds (Arnold et al., 2010; Easton et al., 2010; Thampi et al., 2010; Githui and Thayalakumaran, 2011; de Vente et al., 2013; Bonuma et al., 2014; Park et al., 2014; Yasin and Clemente, 2014). The "source-sink" theory is mainly used to study the influence of spatial dynamic balance of land use landscape types on ecological process, and also to pursue suitable landscape spatial pattern (Chen et al., 2008).

Using remote sensing and GIS (Geographic Information System) technology and combining with field research and mathematical statistical methods, firstly this paper researched land use change status in Yanhe watershed and simulated ecological hydrological processes in Yanhe watershed based on SWAT model. On this basis, this paper tried to define the landscape unit involving terrain, soil and land use change information and then described quantitatively land use change by landscape indices method. In terms of eco-hydrological processes, the change of landscape pattern in Yanhe watershed is an important affect factor. Especially those soil erosion influences factors such as the complicated terrain and soil types status should be fully considered. Therefore, we constructed a comprehensive landscape index, that is Slope-HRUs landscape index (SHLI) which closely related to soil erosion and reflected the coupling relationship between regional landscape pattern change and soil erosion.

2. Method

2.1. Study area

Located in the central Loess Plateau (Fig. 1), Yanhe Watershed covers an area of 7725 km^2. Characterized by a typical warm,

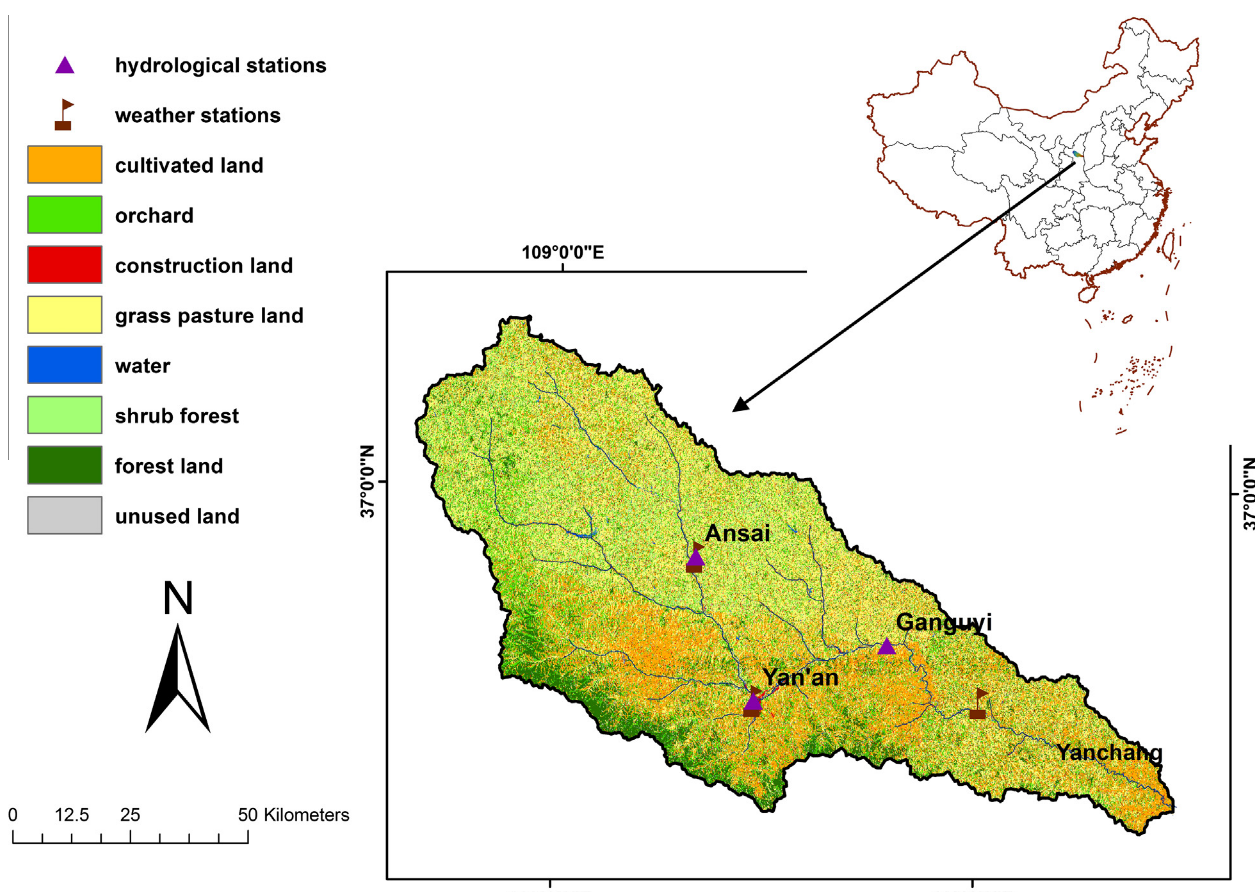

Fig. 1. The location map of Yanhe watershed.