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Assessment of wind-erosion risk in the watershed of the Ningxia-Inner Mongolia Reach of the Yellow River, northern China

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ABSTRACT

The watershed of the Ningxia-Inner Mongolia Reach of the Yellow River (NIMRYR) suffers from serious wind-erosion hazard from several deserts distributed in this watershed. A mass of aeolian sediment is fed into the Yellow River directly or by its tributaries, which clogs the channel and causes major disasters in local regions. To prevent siltation of the Yellow River, it is urgent to understand the spatial variability and patterns of wind erosion in the NIMRYR watershed. For this purpose, the Integrated Wind-Erosion Modelling System (IWEMS) and the Revised Wind-Erosion Equation (RWEQ) were used to estimate the potential wind erosion rate (PWER) and to map wind-erosion risk in this watershed. In this study, the IWEMS model was used to calculate the PWER in non-arable lands, and the PWER in arable lands was estimated by the RWEQ model. The results show that the average PWER in the NIMRYR watershed ranged between 0 and 31440.4 t/km^2/a from 2001 to 2010. The areas with tolerable erosion, slight erosion, moderate erosion, severe erosion, very severe erosion, and destructive erosion occupied 31.04%, 38.13%, 22.89%, 6.46%, 0.93%, and 0.55% of the total watershed area, respectively. The assessment results showed that sandy lands have the highest wind-erosion risk and that the risk in arable lands is lowest. The average annual quantity of aeolian sediment blown into the NIMRYR was 15.87 Mt between 2001 and 2010, and that blown into the Ten Tributaries was 7.33 Mt.

1. Introduction

Wind erosion is an important environmental problem in arid and semi-arid regions (Buschiazzo and Zobeck, 2008; Stroosnijder, 2007), with approximately 28% of global land area experiencing this process (Oldeman, 1994; Callot et al., 2000; Prospero et al., 2002; Webb et al., 2006). Wind erosion significantly decreases soil productivity (Sterk and Raats, 1996; Visser and Sterk, 2007) and has a negative effect on the environment because fine particulates eroded from the surface become suspended in the atmosphere (Sharratt et al., 2007). Therefore, governments of arid and semi-arid countries now share the common objective of promoting sustainable land management by attempting to reduce wind erosion (O'Loingsigh et al., 2014). To control wind-erosion hazard, it is necessary to identify the distribution of wind-erosion areas and assess the wind-erosion risk in each region.

Identification and assessment of wind erosion began in the 1940s, when Bagnold (1941) proposed a cubic relationship between friction velocity and horizontal sand flux. Since then, various methods for estimating wind-erosion risk have been proposed by researchers. For example, Chepil and Woodruff (1963) proposed the concept of a soil wind-erosion index (SWEI) to assess wind-erosion risk and developed the first mathematical model to compute SWEI using wind speed, precipitation, evapotranspiration, and other variables. Burgess et al. (1989) proposed the Em model to predict the probability of sandstorm occurrence using the annual average effective soil moisture. By considering the effect of wind stress, McTainsh et al. (1990) improved the Em model into the Ew model. Later, McTainsh et al. (1998) developed the Et model, which could describe the interaction of wind speed and soil moisture in different periods using monthly meteorological data and enabled users to distinguish natural wind erosion from erosion by artificially accelerated means.

The assessment models described above focus on the probability of wind erosion and cannot calculate the potential wind-erosion rate (PWER). Quantitative wind-erosion models have more recently been used to assess erosion risk. For example, Coen et al. (2004) mapped the wind-erosion risk of agricultural land in Alberta, Canada using the Wind-Erosion Prediction System (WEPS). Using the Revised Wind-Erosion Equation (RWEQ), Mendez and Buschiazzo (2010) assessed wind-erosion risk in

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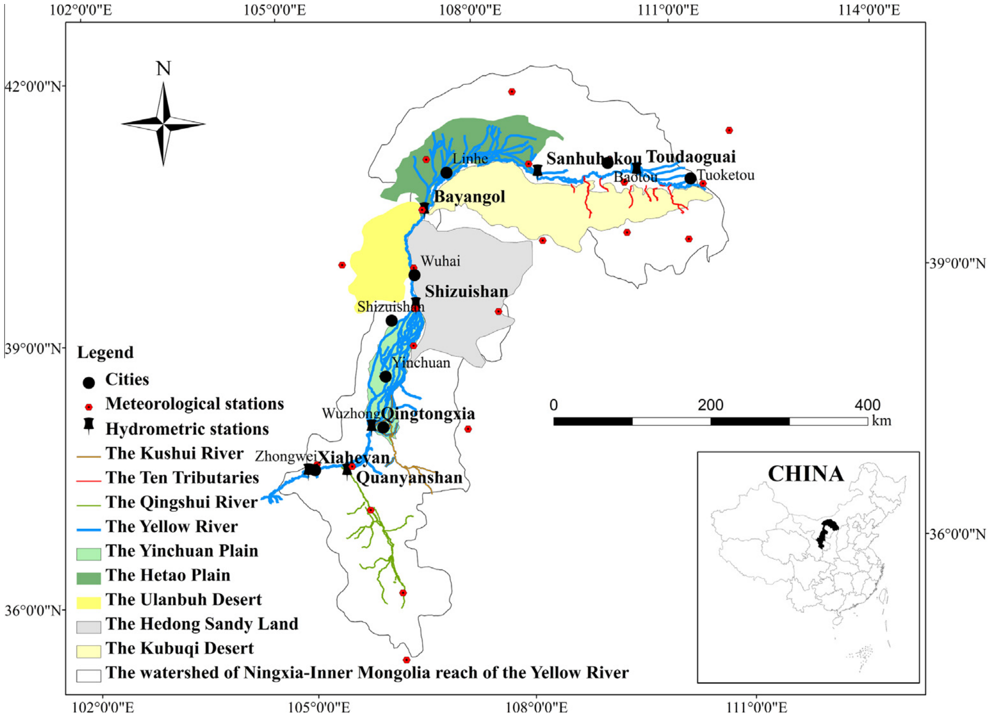

Fig. 1. Sketch of the watershed of the Ningxia-Inner Mongolia Reach of the Yellow River.

agricultural soils under different tillage systems in the Pampas of Argentina. Silenzi et al. (2012) identified the wind-erosion risk in an area southwest of Buenos Aires, Argentina using the WEQ (Wind-Erosion Equation) in a previous version of the RWEQ model.

The Yellow River flows through an extensive aeolian alluvial plain in Ningxia and the Inner Mongolian plateau in northern China, which extends from Xiaheyan in Ningxia Province to Toudaoguai in Inner Mongolia (Fig. 1). Frequent strong winds and erodible surfaces cause extreme wind-erosion processes in the watershed of the Ningxia-Inner Mongolia Reach of the Yellow River (NMRYR). A large amount of aeolian sediment feeds into the main stream and tributaries of the Yellow River by particle saltation and dune avalanches. It has been estimated that approximately 1.91×10^7 tons of aeolian sediment are blown into the Yellow River from the Ulanbuh Desert every year (Yang et al., 1987). The average annual amount of saltation sediment blown into the Yellow River from the Ulanbuh Desert was 5.56×10^6 tons from 2001 to 2010 (Du et al., 2014). Yao et al. (2011) determined the area of aeolian desert that entered into the Yellow River in the Ningxia-Inner Mongolia region by comparing sequential satellite imagery from 1977, 1990, 2000, and 2008, and they found that the total area of bank erosion from 1958 to 2008 was approximately 518.38 km^2. The previous estimates described above could either determine only approximately the quantities of sediment fed into the Yellow River over a period of time (Yang et al., 1987; Yao et al., 2011) or could describe the detailed wind-erosion process only along a tiny reach of the Yellow River (Du et al., 2014). Based on this situation, it is necessary to identify and estimate the wind-erosion risk in the NIMRYR watershed at accurate temporal and spatial resolution using appropriate wind-erosion models.

Although the WEPS model is presently considered as the most advanced wind-erosion model, it is not suitable for estimating wind-erosion risk in the NIMRYR watershed because it is complex, data-intensive, and beyond the capability of environmental scientists to adjust or modify to reflect regional variations. In this study, the Integrated Wind-Erosion Modelling System (IWEMS) proposed by Shao (2001) and the Revised Wind-Erosion Equation (RWEQ) developed by the United States, Department of Agriculture (Fryrear et al., 1998) were used to identify the wind-erosion area and assess the wind-erosion risk in this watershed because of the advantages of these two models, such as simple modeling processes, fewer input parameters, and easier integration with GIS databases. According to the PWER values calculated by the models, the quantities of aeolian sediment blown into the reaches and tributaries of the Yellow River with accurate temporal resolutions and locations were also computed. We hope that the results of this study can provide some references for preventing wind-erosion hazards in the NIMRYR watershed. The spatial and temporal distribution of PWER in this watershed is also expected to be interesting for environmental scientists.

2. Methods and scenarios

2.1. Methods

Because of the advantages of the IWEMS and RWEQ models described above, the IWEMS model was used to predict the PWER in non-arable lands, and the PWER in arable lands was calculated by the RWEQ model. The calculations will be described later in this paper.

2.1.1. The IWEMS model

The IWEMS model was proposed by Shao (2001) to predict wind-erosion processes at regional and national scales. In this model, three key parameters are needed: (1) the saltation threshold friction velocity, u_{*t}; (2) the streamwise saltation flux, Q; and (3) the sand deposition rate.

Considering the effect of vegetation and soil moisture, the threshold friction velocity can be expressed as:

$$u_{*t}(d_s; \lambda, \theta) = u_{*t}(d_s) f_\lambda(\lambda) f_w(\theta), \tag{1}$$

Where u_{*t} $(d_s;\ \lambda,\ \theta)$ denotes the threshold friction velocity of sand particles with diameter d_s in the presence of vegetation and soil