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Controls on aeolian sediment dynamics by natural riparian vegetation in the Eastern Tarim Basin, NW China

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ABSTRACT

The Eastern Tarim basin suffers from sand and dust storms. Drifting sand is a big natural hazard for the road infrastructure and causes high costs for mitigation measures. Natural vegetation is considered having the capability to reduce sand drift and thereby to be an effective protection for the roads, an argument also frequently used for propagating restoration measures at the Tarim River. Nevertheless no quantitative estimation is available up to now even if the research on the interaction of ecology and geomorphology has gained more and more interest in recent years. This study uses the physical principles of drag partition to model the sediment retention by natural vegetation. For an investigation area of about 10 km^2 11,656 kg of sediment could be fixed by the plants, sediment which is not available for sand drift hazards on the road running through the area. Furthermore the spatially explicit approach of this study allows the creation of sediment retention maps which can be used for further environmental planning and scientific interpretations of biogeomorphological interactions between the natural riparian vegetation at the Tarim River and aeolian sediment dynamics.

1. Introduction

Sand- and dust storms are among the biggest environmental problems in the arid regions of Northwest China. One hotspot of aeolian activity is the Tarim Basin in Xinjiang (Shao and Dong, 2006; Wang and Jia, 2013). Beside effects on health and well-being of local people there is a strong impact on the road trafficability of the National Highway 218 running from Xinjiang to Inner China. Drifting sand causes high costs for road maintenance, e.g., through the construction of reed checkerboards or the cleaning of the road from sand accumulations (Han et al., 2003; Dong et al., 2004; Lei et al., 2008). The natural riparian vegetation along the Tarim River, the so-called Tugai forests, is considered to have the capabilities to reduce sand and dust storms (Thevs et al., 2008). Since 2000, there is the effort to restore the floodplain forests in the lower reaches of the Tarim degraded by water shortage caused by agricultural overexploitation of water resources (Halik et al., 2006; Cyffka et al., 2013; Aishan et al., 2015). One frequent argument for the restoration measures is the protection function of this natural vegetation against drifting sand. So consequently the capability of controlling aeolian sediment would be a powerful indicator for the evaluation of the restoration project.

In the international scientific community research on the interaction of ecological and geomorphological processes became increasing attention in the research field of bio- or ecogeomorphology (Viles, 1988; Viles et al., 2008; Corenblit et al., 2011). For the case of aeolian processes, Wolfe and Nickling (1993) describe the basic mechanisms of the plants' influence in their early work: first, vegetation covers the soil surface and shelters it from the wind. Second, it extracts momentum from the air and reduces the erosive forces of the wind on the surface. Third, it traps soil particles. Since 1993, a number of studies have been carried out about these basic relationships (see, e.g., Okin et al., 2006 and Ravi et al., 2011 for a review). Since the classical work of Bagnold (1941) on modelling aeolian sediment transport, big advances have been made in including vegetation in models. Early approaches focused on the vegetation coverage as influencing factor (Ash and Wasson, 1983; Wasson and Nanninga, 1986). Also in the light of wind erosion on agricultural areas, there is evidence of modelling the effect of plants on this process. Most common models for models in agriculture are the empirical Revised Wind Erosion Equation (Fryrear et al., 1998) and the process based Wind Erosion Prediction System (Hagen, 1991). Today, the application of drag partition schemes is standard in modelling the effect of vegetation on sediment mobilization. This physical principle accounts for the alteration of the momentum flux of the wind to the surface by vegetation and is independent from statistical relationships of

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vegetation cover and sediment mobilization or transport (Raupach et al., 1993; Gillies et al., 2002; Shao, 2008; Leenders et al., 2005, 2011; Walter et al., 2012).

Despite these developments in research on aeolian processes and its interactions with vegetation, there is to our knowledge no quantitative estimation of the influence of the Tugai forests at the lower reaches of the Tarim River on the sediment mobilization and transport by wind. The main objective of this study is now to apply a biogeomorphological approach to the lower reaches of the Tarim River and to give a quantitative estimation of the sediment fixation capability of natural vegetation based on a spatially explicit physical based model. With this work we contribute to a better understanding of the role of natural Tugai forests in fixing aeolian sediment and help to make predictions about the potential influence of vegetation changes.

2. Material and methods

2.1. Study area

The study area is located near the village of Arghan in the lower reaches of the Tarim River in Xinjiang, NW China (Fig. 1). Changing river courses in the past formed a wide alluvial plain separating the Taklamakan from the Kuruk Tagh desert. Soils in this sediment are only poorly developed and mainly composed of underlying loamy material with a cover of silty sand (Ginau et al., 2013). This alluvial area is also the habitat of the floodplain vegetation, the so-called Tugai forests.

Main species in the investigation area are *Populus euphratica* and *Tamarix* spp., herbaceous vegetation is absent due to the low groundwater level (Halik et al., 2006; Aishan et al., 2015). *P. euphratica* is a tree species belonging to the obligate phreatophytes, i.e., they depend on a permanent connection of the root system to the ground water. *Tamarix* respectively is a facultative phreatophyte being able to sustain a certain period disconnected from the ground water (Thomas, 2014). For rejuvenation, both species depend on bare river banks with a sufficient supply of soil moisture. Due to the extremely arid climate, these conditions only appear directly at the river channels (Thevs et al., 2008; Chen et al., 2010; Kuba et al., 2013). This leads to a specific stand structure of the Tugai forests. *Populus* is the dominating species with an overall stand density of 22.3 individuals/ha while *Tamarix* shows an overall density of 5.8 individuals/ha. Beside this, the plants show a characteristic pattern over the floodplain. Close to the river closer stands of the poplars dominate while in more distant areas with larger distance to the groundwater tamarisks become more dominant (see Fig. 2).

In the study area, the extreme aridity together with sufficiently strong northeasterly winds causes an extensive potential for aeolian sediment dynamics (Ginau et al., 2013). Due to the almost absent precipitation, Lancaster's dune mobility index, as an indicator for the climatic disposition to aeolian sediment dynamics, shows an extremely high value of 12,164, which underlines the importance of the floodplain vegetation's control on the aeolian sediment dynamics. Consequently, the topography shows aeolian landforms. East from the floodplain forest, transversal dunes dominate the landscape, while in the west nebkha dunes have developed associated with *Tamarix* spp. They are probably formed by eroded material of the floodplain. The advancing transversal dunes tend to cover degraded shrub vegetation in the windward side of the floodplain forest.

2.2. Model description

For modelling the control of natural riparian vegetation on aeolian sediment transport, we use a derivation of the Integrated Wind Erosion Modelling System (IWEMS) as described in Lu and Shao (2001) and Shao (2008). Sediment transport and on this basis also sediment fixation is modelled using the Owen Saltation equation with using a threshold friction velocity and a friction velocity (Owen, 1964; Shao, 2008; Webb and McGowan, 2009). Integrating the model in a GIS allows the integration of various data sources and the use of the output for further spatial analysis in research or environmental planning. Fig. 3 gives an overview of the input used for determining these two parametres in a natural environment.

2.2.1. Friction velocity

The friction velocity is the driver of sediment uptake and transport by wind and is defined as $u_* = \sqrt{\tau\rho_a}$, where τ is the drag created by wind and ρ_a is the density of the air (Shao, 2008). A commonly used approach for the derivation of u_* in aeolian geomorphology is the use of the log-linear wind profiles and the estimation of the roughness length z_0 (Shao, 2008; Wiggs, 2011). Eq. (1) gives the relationship between the windspeed, the roughness length and the friction velocity.

$$u_* = U(z)\frac{k}{\ln\left(\frac{z}{z_0+d}\right)} \tag{1}$$

$U(z)$ is the windspeed in height z, k is the Karman constant ($\sim$0.4) and d is a shifting parameter for the roughness length z_0 in case of bigger roughness elements and can be estimated with about 1/3 roughness element height (Shao, 2008; Wiggs, 2011). Vertical wind profiles on different surface types in the investigation area have been used to estimate the roughness length, d was estimated directly in the field.

While the original IWEMS uses an atmospheric model for the simulation of wind speeds, in this study an empirical approach is chosen. Fitting a statistical distribution function to the empirical wind data allows the operation with exceeding probabilities also used, e.g., in flood risk assessment (e.g., Merz, 2006). We choose a Weibull distribution for this purpose because it fits well to the often heavily skewed wind data (Sarkar et al., 2011).

2.2.2. Threshold friction velocity

The threshold friction velocity (u_{*t}) is an important parameter for modelling aeolian sediment movement. From this velocity onwards, sediment is mobilized and can be transported by the wind. Bagnold (1941) was among the first to develop an equation for u_{*t} as a function of the grain size d. For natural conditions, threshold friction velocity is not only dependent on the grain size, but also on the soil moisture in the topsoil, the presence of organic and inorganic soil crusts and the sheltering effect of vegetation (Ishizuka et al., 2008; Shao, 2008). Mathematically these influences are described as correction functions of u_{*t} for a certain grain size d (Shao, 2008):

$$u_{*t}(d,\theta,\lambda) = u_{*t}(d)f(\theta)f(\lambda) \tag{2}$$

where $u_{*t}(d)$ is the function of the threshold friction velocity for grain size d, $f(\theta)$ is the correction function for soil moisture and $f(\lambda)$ the correction function for vegetation. We use the scheme of Shao and Lu (2000) for the expression of the ideal threshold friction velocity given in Eq. (3).

$$u_{*t}(d) = \sqrt{a_1\left(\frac{\rho_p}{\rho_a}gd + \frac{a_2}{\rho_a d}\right)} \tag{3}$$

In this formula, ρ_a and ρ_p are the density of the air respectively the sediment, g is the gravity acceleration, d is the grain diameter and a_1 and a_2 are constants given with 0.0123 and 0.0003 (Shao and Lu, 2000).