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Morphological characteristics of interactions between deserts and rivers in northern China

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A B S T R A C T

Arid regions are affected by long-term interactions between various factors including water and wind. Recent research has concentrated on aeolian–fluvial interactions in dryland environments, including the important role of rivers in providing sand and spaces for deserts development, as well as the influences of aeolian activity upon river landforms. However, there is still a lack of comprehensive data at the large watershed scale to support such research. In this study, we analyzed statistically the morphological parameters related to twelve deserts and ten watersheds in dryland regions of northern China using remote sensing data, maps of desert and watershed distributions, and classification of aeolian landforms. Results indicate that, in view of the relationship between deserts and rivers, the geomorphic structures of drainage basins in northern China can be overall divided into five large drainage zones: northwestern drainage (ND), western drainage (WD), drainage of northern Qinghai-Tibet Plateau (PD), middle drainage (MD) and eastern drainage (ED). In the terms of percent area of desert in drainages, it can be sequenced as WD > MD > ND > ED > PD. For percent area of shifting dunes in deserts, WD > PD > MD > ED > ND. Considering the classification of aeolian dunes, transverse dune dominates in all drainages, and its proportion can be sorted as PD > ED > MD > WD > ND. There is a significant difference in their morphological parameters between interior and exterior watersheds. In exterior watersheds, desert area, shifting dune or transverse dune areas are not significantly associated with drainage area respectively, but interior watersheds have good correlations between them. And in three rivers of Tarim Basin, along with increasing distance from the river bank, the types of aeolian dune (complexity) increased step-wisely, implying that sand dune extends along the river terrace. Those data and preliminary findings confirm that the rivers are indispensable to the development and evolution of deserts, performing as channels ('arteries') and platforms ('skeletons') in providing sand sources and spaces.

1. Introduction

Arid landscapes are integrated products of spatial and temporal interactions both within and between different subcomponents of the geomorphological system (Tooth, 2008). Interactions between aeolian and fluvial systems occur widely on the surface of the Earth and play an important role in the development of arid landforms, spanning spatial and temporal scales that vary according to global, regional and local topography, climate, vegetation, hydrology and other factors (Langford, 1989; Lancaster, 1997; Kocurek, 1998; Bullard and McTainsh, 2003). A distinctive characteristic of dryland geomorphology by this interaction is that the rivers associate with adjacent aeolian dune fields (Nanson et al., 2002). Many sand seas or dune fields around the world are predominantly located within drainage basins with seasonally active rivers, streams and playas, such as Namib Desert – Kuiseb River Basin (Lancaster, 2002; Grodek et al., 2013), southwest Kalahari dune field – Auob, Nossop and Molopo Rivers (Bullard and Nash, 1998), Western Desert of Egypt – Nile River (El-Baz et al., 2000; Phillipps et al., 2012), Thar Desert – Luni River (Kale et al., 2000), Taklimakan Desert – Tarim River/Basin (Zhu et al., 1980; Sun et al., 2011), Simpson Desert – Lake Eyre Basin (Bullard and McTainsh, 2003), Algodones dune field – Colorado River (Sweet et al., 1988), Monte Desert – Colorado River (Argentina) (Abraham et al., 2009). Hence the formation and evolution of deserts have close relations with the rivers, while

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aeolian dunes influence channel processes and fluvial geomorphology (Tooth and Nanson, 2011).

Historically, fluvial and aeolian processes in dryland environments have been viewed as mutually exclusive. Over the last few decades, there has been a rising interest in the interactions between aeolian and fluvial processes from geomorphologists, sedimentologist and ecologists (Bullard and Livingstone, 2002; Field et al., 2009; Ravi et al., 2010; Belnap et al., 2011). More and more researchers have focused on the combination of desert and river landforms in arid zone, highlighting the important role of river in providing the plentiful sources, suitable space (and wind regime) for desert development (Bullard and McTainsh, 2003; Draut, 2012), and mutually controlling relationship of aeolian dune and river channel (Tooth and Nanson, 2011). Most of the above researches are limited to locally qualitative descriptions (Bullard and Nash, 1998), there have been fewer detailed data with a relatively large scale, such as dune fields in watersheds (Muhs et al., 2003; Bullard and McTainsh, 2003).

Dryland (arid, semi-arid and dry sub-humid zones) covers 3.15×10^6 km^2 in northern China (Ci and Wu, 1997), in which 12 main deserts (sandy desert, Gobi desert and sandy land) occupy 0.83×10^6 km^2, overlapping with various scale systems of endogenous and exogenous rivers (Table 1). In China, wind erosion and water erosion have been studied separately for a long time, relatively little is known about their interaction or consequent links to dryland environments (Shi et al., 2004; Song et al., 2006; Han et al., 2007). Here we integrate the data of remote sensing image and maps desert and drainage distributions in northern China, classification of aeolian landform. Using ArcGIS and SPSS tools, we investigated morphological parameters related to desert and drainage distributions of dryland in China, analyzed the characteristics and distributions of aeolian–fluvial interaction in arid and semi-arid zones, and explored spatial distribution patterns of aeolian dunes and rivers on watersheds scale.

2. Regional setting

2.1. Ten drainages and twelve deserts

From *Geographic Atlas of China* (Wang and Zuo, 2010), northern China has twenty-two first-grade drainages, including thirteen peripheral and nine interior ones. Taking the watersheds and its relevant deserts or sandy lands as an elementary study area, we find out the relationship between rivers and deserts (sandy lands) in northern China. Here each watershed with an area of more than 4×10^4 km^2 and deserts over 2000 km^2 was chosen. Based on this criteria, excluding three interior regions (Wuyurhe, Baichen and Ili River) and nine exterior drainages (Suifenhe River, Tumen jiang River, Yalu jiang River, etc.), the study area of this paper covers six interior regions, Junger Basin, Tarim Basin, Qaidam Basin, Hexi Corridor–Alashan Region, Inner Mongolia Region, Ordos Region and four exterior drainages, Ertix River, Yellow River, Liaohe River, Heilongjiang River. Twelve deserts (sandy lands) inlay those drainages, including Taklimakan Desert, Gurbantunggut Desert, Kumtag Desert, Qaidam Basin Desert, Badan Jaran Desert, Tengger Desert, Ulan Buh Desert, Hobq Desert, Mu Us Sandy Land, Otindag Sandy Land, Horqin Sandy Land, Hulun Buir Sandy Land (Wu, 2009) (Fig. 1).

We divided the sand seas of northern China into 5 major zones according to location, topography and climate as: (1) Northwestern Deserts, located in the south of the Altai Mountains and the north of the Tianshan Mountains, including Gurbantunggut Desert; (2) Western Deserts, located in the north of Kunlun Mountains and Altun Mountains and the south of the Tianshan Mountains, including Taklimakan Desert and Kumtag Desert; (3) deserts in the northern margin of the Tibetan Plateau, i.e. Qaidam Basin Desert; (4) Middle Deserts, located in the north of the Qilian Mountains, the east of Mazong Mountains, the west of Langshan Mountains and Helan Mountains, including Badain Jaran Desert and Tengger Desert; (5) Eastern Deserts, located in the south of the Mongolian border, through the western part of Yin Mountains, Helan Mountains and the east line of Wushaoling, the west of the Taihang Mountains, including Ulan Buh Desert, Hobq Desert, Mu Us Sandy Land, Otindag Sandy Land, Horqin Sandy Land and Hulun Buir Sandy Land. Correspondingly, based on the geographic location and the combination with deserts, the watersheds were divided into five major drainage zones as northwestern drainages (ND), Ertix River and Junger Basin interior region; western drainage (WD), Tarim Basin; drainage of northern Qinghai-Tibet Plateau (PD), mainly Qaidam Basin; the middle drainages (MD), Hexi Corridor–Alashan and Inner Mongolia interior regions; eastern drainages (ED), Ordos interior region and Yellow River, Liaohe River, Heilongjiang River exterior drainages.

Table 1
Main deserts and its relevant rivers in China (Zhu et al., 1980; Wu, 2009).

Deserts/sandy lands[a]	Area (km^2)[b]	Main rivers/lakes	Age of desert formation[c]
Gurbantunggut Desert	51,130	Manas River, Ebinur Lake	Q1
Taklimakan Desert	365,000	Tarim River, Hotan River, Qarqan River, etc.	N2–Q1
Kumtag Desert	21,970	Shule River, Lop Nor	Q2
Qaidam Basin Desert	14,940	Qaidam River, Golmud River, Leningrad River, etc	Q2
Qinghai Lake Basin Desert	1300	Qinghai Lake, Buh River, etc	Q4
Gonghe Basin Desert	5900	Yellow River	Q3
Badain Jaran Desert	50,510	Hei River, Shiyang River, Paleolake(?)	Q1(N2?)
Tengger Desert	42,320	Shiyang River, Yellow River, Paleolake(?)	Q2(?)
Ulan Buh Desert	10,750	Yellow River	Q4?
Hobq Desert	17,310	Yellow River, Ten Hundi	Q3–Q4
Mu Us Sandy Land	38,940	Wuding River, Kuye River, etc	Q2–Q3
Otindag Sandy Land	29,220	Shandian River (Luan River), Dalai Nur	Q3
Horqin Sandy Land	50,440	Xar Moron River (Xiliao River)	Q3–Q4
Hulun Buir Sandy Land	6410	Hailar River, Orxon River	Q4
Songnen Sandy Land	6010	Songhua River, Nenjiang River	Q4

[a] In Chinese literature, the deserts (sand seas or dune fields) are conventionally termed as two kinds, one is desert (sandy desert and Gobi desert, Shamo in Chinese), another is sandy land (Shadi in Chinese), mainly according to climatic region (location) and dune mobility (vegetation) with a rough boundary of Helan Mountains (Zhu et al., 1980). The former Shamo is concentrated in arid and supper-arid regions, mostly as shifting dunes; and the latter Shadi, in semi-arid and sub-humid regions, as fixed and semi-fixed dunes.
[b] The desert areas here has slight deviation comparing with our statistics by remote sensing data in Table 3.
[c] Mainly from Sun and Liu (2006), Yang (2006) and Guo and Wang (2013a,b).