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Water allocation and water consumption of irrigated agriculture and natural vegetation in the Aksu-Tarim river basin, Xinjiang, China

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ABSTRACT

A significant part of the world's largest river basins are located in areas of arid and semi-arid climate, such as the Amu Darya, Jordan, Murray-Darling, Yellow River, and Aksu-Tarim river basin. These river basins are experiencing water scarcity resulting in conflicts between upstream and downstream, conflicts between water users, and degradation of the natural ecosystems. Therefore, in many river basins, including the Aksu-Tarim river basin, water quota systems have been established, in order to allocate water under scarcity. The Aksu-Tarim river basin (NW China) has developed into one of the most important cotton production areas worldwide. In this paper, we aim at assessing the water consumption through irrigated agriculture, mainly cotton, and natural vegetation in the Aksu-Tarim river basin against the background of this water quota system. Firstly, we map the evapotranspiration (ET_a) as water consumption of irrigated agriculture and natural vegetation in the Aksu-Tarim river basin. Secondly, we calculate water balances and relate them to the water quota system. We employed the remote sensing method Simplified Surface Energy Balance Index (S-SEBI), in order to map ET_a based on MODIS satellite images for the growing seasons 2009, 2010, and 2011. Thereby, the MODIS products 8-day land surface temperature (MOD11A2), 16-day albedo (MCD43A3), and 16-day NDVI (MOD13A1) were used. The ET_a of cotton ranges from 884 to 1198 mm. The ET_a of the natural vegetation of a total coverage ranges from 715 in 2009 to 960 mm in 2011, clearly following the annual runoff of the Aksu and Tarim River. The water balance of the Aksu-Tarim river basin is −3.25 to −3.73 km^3, 0.1–0.53 km^3, and −3.55 to −4.12 km^3 in 2009, 2010, and 2011, respectively. The water quotas along the Aksu River and the upper reaches of the Tarim are exceeded by water consumption, while the quotas along the middle and lower reaches are not met. Considerable amounts of groundwater, including fossil groundwater, are exploited for irrigation along the Aksu and Tarim River, which must be regarded as exploitation of a non-renewable resource.

1. Introduction

A significant part of the world's largest river basins are located in areas of arid and semi-arid climate, such as the Amu Darya, Jordan, Murray-Darling, Yellow River, and Tarim river basin (Central Asia Atlas, 2012; GLOWA Jordan, 2008; Glantz, 2010; ICWC, 1992; Murray Darling Basin Commission, 2006; Song et al., 2000; Tang and Deng, 2010; Zhu et al., 2003). These river basins are experiencing water scarcity resulting in conflicts between upstream and downstream regions, conflicts between water users, and degradation of the natural ecosystems. In these areas, agriculture, mostly irrigated agriculture, is the largest consumer of water (Howell, 2001). Given the background of increasing populations, increasing demand for agricultural products, and thus increasing water demands, water distribution in river basins between upstream and downstream as well as between water users plays and will play an important role for societies within such river basins (FAO, 2012). In many river basins, water quota systems have been established in order to allocate distinct amounts of water to different users and different sections of a river as reviewed by Molle (2009). In Central Asia, quota systems have been introduced between countries for the Amu Darya and Syr

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Darya, which are the two tributaries of the Aral Sea (ICWC, 1992), on provincial level for the Heihe River, China (Chen et al., 2006), and for the Tarim River according to tributaries and river sections (Tang and Deng, 2010).

The Tarim Basin, which includes the Tarim and its tributaries, located in Xinjiang, Northwest China (Fig. 1), harbors 54% (352,200 ha) of the world's riparian *Populus euphratica* Oliv. forests (http://whc.unesco.org/en/tentativelists/5532/). Those forests form a mosaic of riparian forests, wetlands, shrub vegetation, and small stands of herbaceous vegetation (Thevs et al., 2008; Zhang et al., 2005) and provide habitat for wildlife (http://whc.unesco.org/en/tentativelists/5532/). The *P. euphratica* forests are the only forests in the Tarim Basin. Those forests and the wetlands are the most productive ecosystems of the drylands in the Tarim Basin (Thevs et al., 2007, 2012). Furthermore, the Tarim Basin has become the world's most important cotton production region with a total annual cotton lint production of 2.1 million t, i.e. 8.85% of the world production in 2010 (Xinjiang Statistics Bureau, 2011; http://faostat.fao.org/). In 2011, the share of the cotton lint production in Xinjiang of the worldwide production climbed to 11% (USDA, 2013; http://faostat.fao.org/). Half of the cotton in the Tarim Basin is produced along the Aksu and Tarim River (Feike et al., 2014; Xinjiang Statistics Bureau, 2011). Therefore, it is relevant to show how the water quota system under intensive and increasing agriculture works.

The Tarim Basin covers an area of 1.02 million km^2, and is home to a population of 9.02 million people (Tan and Zhou, 2007). The area of irrigated land has increased all over the Tarim Basin, from 706,000 ha in 1949, over 1,330,000 ha in 1980 and 1,412,000 ha in 1990 (Xia, 1998), in 2010 to 1,600,000 ha (Xinjiang Statistics Bureau, 2011). Due to the arid climate with an annual precipitation of 30–70 mm (Liu, 1997; Tang and Deng, 2010), all agriculture depends on irrigation with river water being the most important source for water. However, during the past five decades there has been a slight increase of runoff from the headwaters into the Aksu River, but due to land reclamation along the Aksu, the inflow from the Aksu into the Tarim at Aral shows a decreasing trend (Tang and Deng, 2010; Xu et al., 2005, 2010).

Population growth and agricultural development, partly driven by resettlement of people from other Chinese provinces to Xinjiang, resulted in degradation of the natural ecosystems and desiccation of the two terminal lakes of the Tarim river basin, Lop Nor and Taitema, by beginning of the 1970s (Feng et al., 2005; Hao et al., 2009; Song et al., 2000; Zhang, 2006; Zhang et al., 2003). In order to balance the water use between economic development (mainly irrigated agriculture) and environmental flow along the Tarim, the Xinjiang Government developed a water distribution program and water quota system, which will be introduced in section 3 (Peng et al., 2014; Song et al., 2000; Tang and Deng, 2010; Zhang, 2006). The aim of this paper is to assess the water consumption through

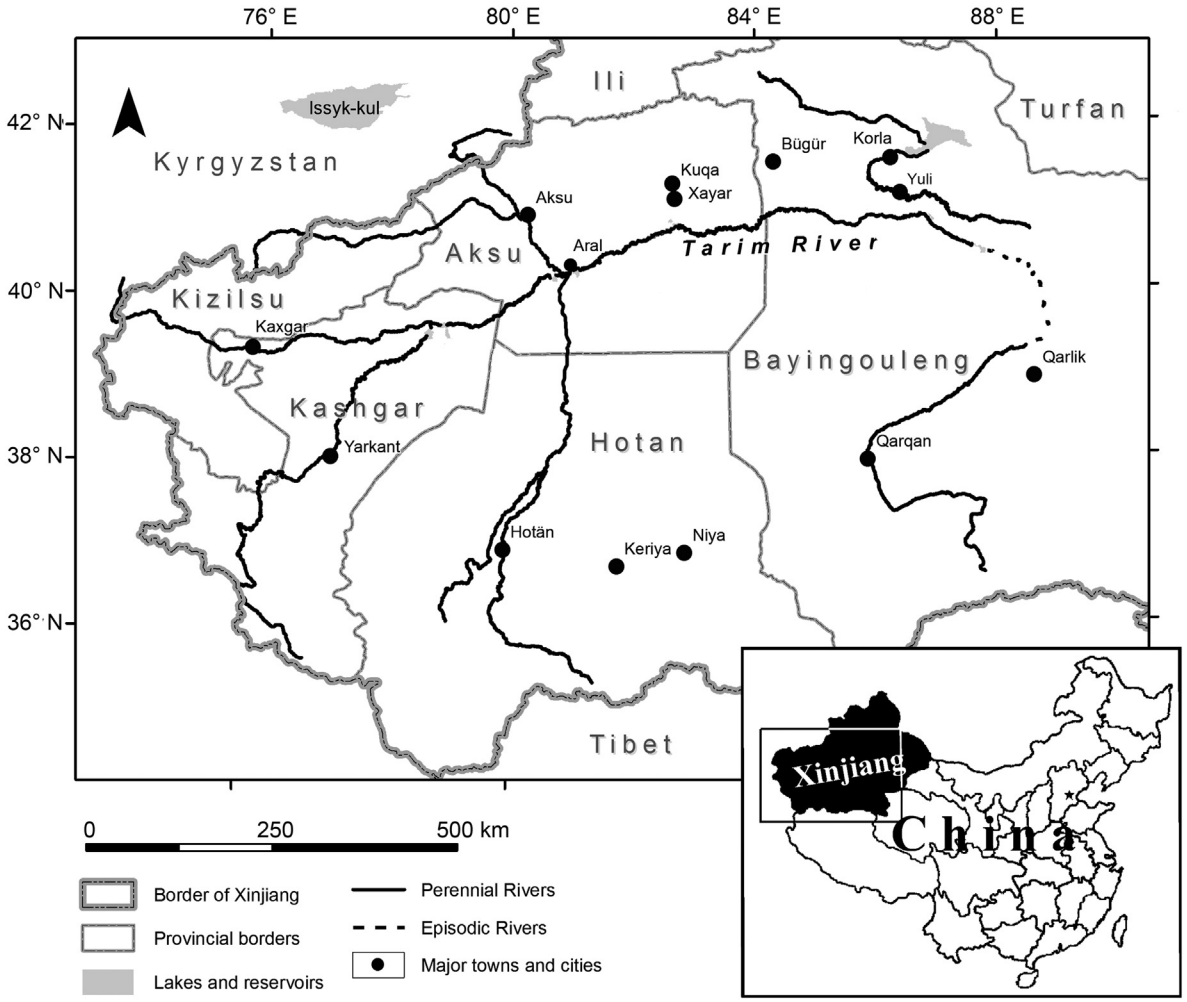

Fig. 1. Map of the Tarim Basin with its administrative units.