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Estimation of water consumption for ecosystems based on Vegetation Interfaces Processes Model: A case study of the Aksu River Basin, Northwest China

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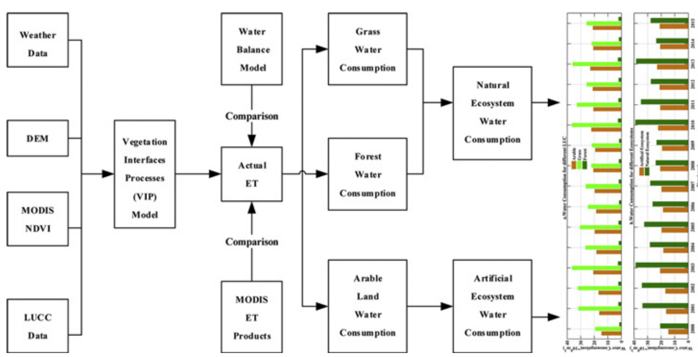
HIGHLIGHTS

- The estimation of actual ET in the Aksu River basin is rare.
- The eco-hydrological model and water balance model were applied.
- The significant increase was detected in water consumption of arable land or artificial ecosystem.
- The message is useful for water management and planning.

GRAPHICAL ABSTRACT



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ABSTRACT

Based on the Moderate Resolution Imaging Spectroradiometer (MODIS) - Normalized Difference Vegetation Index (NDVI), the Vegetation Interfaces Processes (VIP) model simulated the spatio-temporal patterns of actual evapotranspiration (ET) and the water consumption of different ecosystems in the Aksu River Basin, Northwest China between 2000 and 2015. The results revealed that: (1) the applicability of the VIP model was confirmed, with good agreement ($R^2 = 0.79$, $P < 0.05$) between the VIP-ET and water balance model (WB)-ET in the Aksu River Basin; (2)arable land showed the highest annual actual ET per unit pixel (362.4 mm/pixel), followed by forest (159.6 mm/pixel), and grass land (142.8 mm/pixel); (3) water consumption for arable, forest, and grass land were determined as 19.45×10^8, 1.94×10^8, and 28×10^8 m^3/a, respectively; and (4) there was a significant trend ($P < 0.05$) of increasing water consumption of 0.379×10^8 m^3/a in the artificial ecosystem, but there was no significant trend in the time series of the natural ecosystem. Overall, the study demonstrated that the VIP model is able to supply important information for water resource management at the catchment-scale.

1. Introduction

In the past 50 years, air temperature in the arid region of Northwest China has increased at a rate of 0.33–0.39 °C/decade (Zhang et al., 2010; Li et al., 2012; Li et al., 2013). With intensified warming, there has been increasing impact on water resources, especially on surface runoff

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supplies from glacier and snow melt water in arid-region rivers (Xu et al., 2011). Thus, it is important to understand hydrometeorological processes responses to variations in different climate factors (i.e., temperature, precipitation, and ET) to develop sustainable strategies for regional water resources assessment and management (Li et al., 2016b; Liu et al., 2011; Zhao et al., 2012; Zhao et al., 2015).

Terrestrial actual ET is an important factor in the study of water and energy budgets (Rosenberg, 1983; Kustas and Norman, 1996; Jung et al., 2010; Vinukollu et al., 2011; Mo et al., 2017), and is the major transporter of water and energy between the atmosphere, hydrosphere, and biosphere (Priestley and Taylor, 1972; Alton et al., 2009; Matin and Bourque, 2013). Additionally, the long term tendency of ET has been regarded as a significant indicator for assessing intensification of the regional water cycle (Mo et al., 2017). Thus, accurate estimation of actual ET at the watershed-scale is of benefit to environmental research and application, including drought and water resources management planning (Raupach, 2001), evaluation of net primary productivity and ecosystem carbon exchange (Eamus, 2003), studies of global and regional climate change (Kingston et al., 2009), and catchment water balance estimation (Cammalleri et al., 2010).

The Aksu River is the main tributary of the Tarim River, which is located in the arid Northwest of China and nearly half of its water originates as glacier and snow melt from the mountains (Li et al., 2016b). In recent years, hydrological processes in the Aksu River Basin have been severely affected by the influence of climate change on the more sensitive and vulnerable aspects of the physical system. For example, Jiang et al. (2005) reported that the rise in temperature has had a greater effect on runoff than precipitation in the Aksu River, and Xu et al. (2011) found that there was a close relationship between variations in annual runoff and regional climate change. However, there have been few studies of actual ET in the Aksu River Basin at the catchment-scale. Li (2013) and Jian et al. (2016) explored changes in actual ET in the Aksu River Basin based on the Advection-Aridity (AA) model, but this work was based solely on weather station data. Studies of ET at the catchment-scale and at high-spatial resolution are more appropriate for the assessment and management of watershed water resources (Liu et al., 2016).

The VIP model used in this paper, which was established by Mo and Liu (2001) and improved by Mo et al. (2011) and Mo et al. (2015), estimates ET at the pixel-scale based on remote sensing imagery. The VIP model incorporates multi-modules, which can simulate the exchanges of energy, water, and carbon between terrestrial ecosystems and the atmosphere (Mo et al., 2014). Furthermore, the model has been applied to many regions and basins in China, including the Lushi Basin (Mo et al., 2004), Xitiao River catchment (Mo and Meng, 2011), Northest China (Mo et al., 2014), and North China (Mo et al., 2017). The research objectives of this study were: (1) to explore the accuracy of VIP-ET in the Aksu River Basin; (2) to quantitatively assess the actual ET for different kinds of land use in the Aksu River Basin; (3) to estimate the water consumption of multi-ecosystems in the Aksu River Basin.

2. Study area

Aksu River Basin (40.28–42.45°N and 75.58–80.98°E) is located in the northern Tarim River Basin, along the southern slopes of the Tienshan Mountains, Northwest China (Li et al., 2016b) (Fig. 1). The Aksu River is the largest in terms of runoff in the Tarim River Basin and covers an area of 5.14 × 10^4 km^2 (Wang et al., 2010), including a floodplain area of 1.4 × 10^4 km^2 (Xu et al., 2011; Huang et al., 2015). The climate of the basin is influenced by the blocking effect of terrain and its long distance from the ocean, with low average annual precipitation (64 mm), high average annual potential ET (1890 mm), and large average annual temperature range (9.2–11.5 °C) (Xu et al., 2011). Aksu River Basin runoff is mainly derived from the Tienshan Mountains and is influenced by the complex climatic conditions and hydrological environment (Xu et al., 2011).

Crop growth in the Aksu region is highly dependent on irrigation water which is directly diverted from the river or stored in reservoirs (Huang et al., 2015). The largest irrigation district of Tarim River Basin incorporates the downstream reaches of the Aksu River Basin and accounts for the highest water cost in the basin (Han et al., 2015). Polluted river water is rerouted for irrigation and vegetable production in the lower reaches, causing vegetation degradation and salinization of cultivated lands (Ji et al., 2000; Guo et al., 2003). There is a clear conflict between water supply and demand in the Aksu River Basin.

3. Materials and method

Meteorological data, land use cover change (LUCC) data, digital elevation model (DEM) data, and MODIS-NDVI were used to drive the VIP model in this study. Meanwhile, the hydrometeorological data were applied to construct the WB model. Then, the MODIS-ET and WB-ET were obtained to verify the results of the VIP model simulation.

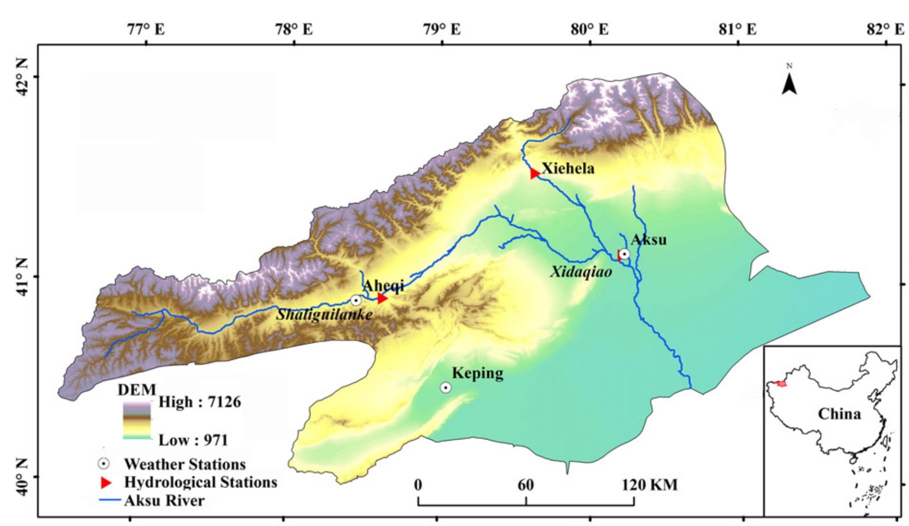

Fig. 1. The study area. (The left up figure is the main condition of the study area, while the right down is the location of the study area in China.)