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Research article

# Water use conflict between wetland and agriculture

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ABSTRACT

To analyze the water use conflict and its driving factors between wetland and agriculture at both regional and local scales, agricultural water consumption and wetland water storage changes in the Sanjiang Plain, the main grain-producing area in Heilongjiang Province of Amur River Basin, were investigated based on statistical data, field survey and GIS calculation. A specific case study in the Qixing River National Nature Reserve (QNNR) wetland-farmland system was completed using a water balance approach. Results showed that the proportion of agricultural water increased from 71.8% to 88.0% while that of ecological water only hovered around approximately 1% in Heilongjiang Province during 2004–2015. Due to wetland loss and degradation, the total surface water storage in the Sanjiang Plain wetlands decreased from $14.46 \times 10^9$ t in the 1980s to $4.70 \times 10^9$ t in 2010. Agricultural development in successive years, and the dramatic increased requirement for water in paddy fields, intensified the water use conflict between wetlands in the QNNR and surrounding farmlands. Groundwater extraction for irrigation was approximately twice as high as the total infiltration recharge from wetlands and farmlands. It is concluded that the degraded natural water resource endowments are struggle to sustainably support stable grain production as a mainstay of national food safety, which determined the competitive relationship between wetland and agriculture. To mitigate this conflict, adaptive wetland (e.g. water transfer at stagger time, precise water recharge, resourced meltwater) and agricultural techniques (e.g. water-saving irrigation and planting, soil water capacity increment, rainfed agriculture) and five key management solutions were recommended.

## 1. Introduction

Wetland ecosystems have irreplaceable and important functions in terms of protecting water resources, and both global and local water cycling rely heavily on wetlands. More than half of global natural wetlands have been lost due to anthropogenic activities since 1900, which has caused major negative impacts on hydrology in multiple scales (Stacke and Hagemann, 2012; Russi et al., 2013; WWAP, 2018). Agriculture, as the world's largest freshwater consumer that accounts for approximate 85% of global water consumption with most used for irrigation, will continue to increase its demand for water resources (Jury and Hjjr, 2007; Siebert et al., 2010; WWAP, 2012). Currently, most irrigated agriculture around the world is under the circumstance of full-utilization or overexploitation of water resources, and developing countries can only meet their food needs by expanding irrigated agriculture with improved water projects and wastewater treatment plants. However, these water projects solely or mainly serve agricultural irrigation and lack consideration of natural ecosystems such as wetlands, which has threatened many wetlands (Peck et al., 2004; Martinez-Santos et al., 2008; Verones et al., 2012). The ecological characteristics of the hydrologically related wetlands have been affected directly or indirectly, which leads to the degradation of some important ecosystem services that the wetlands provide or even wetland loss (Junk et al., 2013; Flávio et al., 2017). Therefore, it is particularly important to coordinate agricultural and ecological water uses.

China has been and still is struggling to produce enough food to feed its large population (Zong et al., 2013). The issue of food security drove the Chinese government to implement a policy of land reclamation. As a result of agricultural and industrial water transfers, the freshwater that should have entered wetlands had been dramatically reduced (An et al.,

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2007). The history and current status of wetland in the Sanjiang Plain of Northeast China, to a certain extent, represents the entire state of China. Driven by the Chinese government's comprehensive development strategy of agricultural modernization, urbanization and new industrialization, wetlands are increasingly threatened by the use of water in the entire basin (Wu et al., 2012). The Sanjiang Plain is the major grain-producing area of the Amur River Basin; meanwhile, it is the largest distribution area of freshwater palustrine wetlands in China. Currently, water scarcity has become an increasingly important constraint on wetland conservation and agricultural development in this area, which will further aggravate the competition for water resources between wetlands and agriculture. Therefore, more effective measures should be deployed to protect water resources as early as possible to maintain the important ecosystem functions of natural wetlands.

The objectives of this study were 1) to understand the conflict situation between wetland water use and agricultural water use in the Sanjiang Plain, 2) to calculate the water balance of the wetland-farmland system, 3) to find the natural and anthropogenic factors causing this conflict, and 4) to propose relevant suggestions based on the results.

## 2. Materials and methods

### 2.1. Study area description

The Sanjiang Plain, which is located in Heilongjiang Province of Northeast China, is an alluvial plain formed by the Amur River, Songhua River and Ussuri River, with a total land area of $1.09 \times 10^7$ ha (Yang et al., 2001). Since the 1950s, the area has undergone continuous high-intensity agricultural reclamation. The originally natural wetlands landscape has been completely transformed into China's important commodity grain base, which has made tremendous contributions to improve the national food production and provide human food and clothing. However, this contribution is at the expense of comprehensive wetland degradation and loss that was attributed to the unsustainable overexploitation of agricultural development (Zou et al., 2018). Historically, in this area, the depth of groundwater is relatively shallow and can supply river water each year. Since 1990, the groundwater depth has gradually increased due to the increasing scale and intensity of groundwater exploitation, resulting in annual recharge from surface water to groundwater (Gu, 2017).

The case study area is located in the middle reaches of the Qixing River, including the Qixing River National Nature Reserve (QNNR) and its neighbouring Friendship Farm and 597 Farm. It is located in the hinterland of the Sanjiang Plain in the eastern part of Heilongjiang Province (Fig. 1). Natural wetlands that were once widely distributed in the Qixing River sub-basin 60 years ago, have now become patches embedded in agricultural landscapes due to long-term agricultural development. The Qixing River is a tributary of the Naoli River, and the Naoli River is a tributary of the Ussuri River. The length of the Qixing River is 241 km, and the width is 6–30 m with the maximum less than 50 m. The drainage area of the Qixing River is $1.08 \times 10^6$ ha (Li et al., 2003). It originates in the Qixinglazi Mountains and flows eastward through the Sanhuanpao Flood Detention Zone (SFDZ) and enters the Naoli River. As a Ramsar Site (No. 1977, January 9, 2011), the QNNR covers a part of the Qixing River and represents the primitive, typical and complete reed mash landscape. The geographical coordinates are 46°39′45″–46°48′24″ N, 132°00′22″–132°24′46″ E, and the average elevation is 80 m. The total area of the QNNR is $2.00 \times 10^4$ ha. The temperate humid monsoon climate of the QNNR is subjected to an average annual temperature of 2.3 °C–3.4 °C; moreover, precipitation is 400–600 mm, and evaporation is approximately 3.84 mm. The main soil types include mars soil, among others. There are 264 vertebrate animals (e.g. *Grus japonensis*) in the wetlands, as well as 264 higher plants species (e.g. *Phragmites australis*) (Li et al., 2003; Ramsar Convention on Wetlands, 2014). The groundwater depth is 3–10 m. The main recharge of groundwater is atmospheric precipitation, and the main discharges are artificial extractions, which have been widely exploited and utilized (Ramsar Convention on Wetlands, 2014; Gu, 2017).

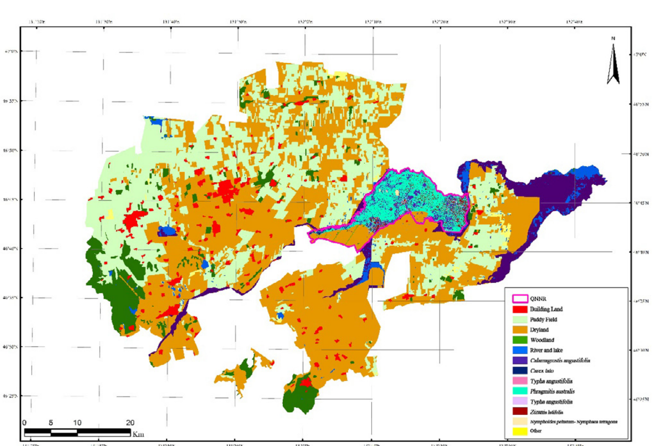

**Fig. 1.** Land use and cover of Qixing River Wetlands (QNNR) and the surrounding farms.

In recent years, the remaining natural wetlands in the Qixing River sub-basin are surrounded by nearby farmlands. Farmlands have been converted from drylands to paddy fields and have caused severe water scarcity (Zhou et al., 2015). The water use conflict between the wetlands and farmlands is becoming serious.

### 2.2. Regional agricultural water use and wetland storage changes

The data used in this study were collected from the National Bureau of Statistics of China (2017) and other published papers in Chinese. The correlation and regression analyses for the inter-annual variation in agricultural and ecological water uses in Heilongjiang Province were performed using IBM SPSS Statistics for Windows, version 21.0 (IBM-SPSS Inc., USA). All curve fittings were created using Origin Pro 8.0 (OriginLab Corp., USA).

The surface, soil and total water storages of the Sanjiang Plain wetlands in the 1970s and 2010 were calculated according to the field survey of the soil moisture and average surface water depth of typical wetland plant communities based on the distribution of wetlands in the Sanjiang Plain that were interpreted using remote sensing and geographical information system methods (Zou et al., 2018).

### 2.3. Wetland and farmland water requirement assessment framework

In both wetlands and their surrounding farmland, the water requirement can be divided into five parts: the actual evapotranspiration of vegetation after deducting precipitation, underground water storage changes, surface water storage changes, soil water storage changes and plant water changes. The actual evapotranspiration of vegetation can be measured by direct observation of the evapotranspiration under different regimes of water conditions; however, evapotranspiration can also be indirectly calculated by multiplying the potential evapotranspiration by the canopy cover/crop coefficients or by multiplying the open water evaporation by leaf area index-adjusted ratios (Drexler et al., 2004; Sun and Song, 2008; Xu et al., 2011). Considering the interannual variation and its smaller proportion in the total water storage, plant water storage is generally negligible. For the wetlands with large spatio-temporal dynamics, the surface water storage also needs to consider that wetland has different ecological characteristics in abundant, dry and flat water years, and there is a critical threshold of ecological water requirements for wetlands (Yang et al., 2008).