Agricultural Water Management 128 (2013) 55–64

Contents lists available at SciVerse ScienceDirect

Agricultural Water Management

journal homepage: www.elsevier.com/locate/agwat

Estimation of regional irrigation water requirement and water supply risk in the arid region of Northwestern China 1989–2010

Yanjun Shen[a,*], Shuo Li[a,b], Yaning Chen[c], Yongqing Qi[a], Shuowei Zhang[d]

[a] Key Laboratory for Agricultural Water Resources, Center for Agricultural Resources Research, Institute of Genetics and Developmental Biology, Chinese Academy of Sciences, Shijiazhuang 050021, China
[b] College of Resources and Environmental Sciences, Hebei Normal University, Shijiazhuang 050016, China
[c] State Key Laboratory of Desert and Oasis Ecology, Xinjiang Institute of Ecology and Geography, Chinese Academy of Sciences, Urumqi 830011, China
[d] Department of Geography, The State University of New York-Buffalo, Buffalo, USA

ARTICLE INFO

Article history:
Received 9 November 2012
Accepted 21 June 2013

Keywords:
Irrigation water requirement
Crop water requirement
Water resources
Penman–Monteith equation
Water supply risk
Arid region in Northwestern China (ARNWC)

ABSTRACT

Water use in agricultural sector shares more than 90% of the total water withdrawal in the arid region of Northwestern China (hereafter, ARNWC). Irrigation water demand is therefore essential to the water resources allocation to economy and natural ecosystems in the highly water deficit region. In this study, we analyzed the spatial and temporal variations of irrigation water demand as well as crop water requirement by combining the modified Penman–Monteith equation recommended by FAO and GIS technology. Crop and irrigation water requirements for 5 main crops, including wheat, corn, cotton, oilseed and sugar beet, from 1989 to 2010 were calculated and the spatio-temporal variations were analyzed. The results suggested that the demand of irrigation water in the ARNWC showed increasing trend during the past two decades, which mainly caused by fast increase in cotton cultivation areas, because irrigation water requirement for cotton was much larger than the other crops. The changes in cotton growing area significantly affected the spatial pattern of water demand. A total of 44.2 billion m^3 water was withdrawn for irrigation in year 2010. Larger amount of water was consumed for crops in Northern Xinjiang and Tarim River Basin than Qilian-Hexi region. Irrigation water requirement reaches its maximum in July and August. It is revealed that the critical period for water supply is during April and May through comparing the monthly irrigation water requirement with water availability, i.e. river discharge. Even though the annual water resources are much larger than the requirement, but for some basins, there is severe physical water shortage during the critical water use period in April and May. The water resource supply is expected to be facing more difficulties in future.

1. Introduction

Water is one of the essential resources in arid and semi-arid regions especially for agriculture. The arid region in Northwestern China (ARNWC) is one of the mostly water stressed regions in the world (Shen and Chen, 2010). This region is also an important food- and cotton-producing region in China, but the imbalance between water supply and demand is also very prominent in the region. Agricultural irrigation consumed most water resources in this region, and accounted for 91.8% of the total water consumption (Geng et al., 2006). The shortage of water resources has become a major limiting factor for the socio-economic development in the ARNWC. Even in places with relatively abundant water resources, it is not sufficient to meet the water demand of crop growth all the year round. With increasing acreage of crop growing, unreasonable crop planting structure, high irrigation quota, and low water use efficiency, the shortage of water resources is becoming increasingly serious. Therefore, quantifying agricultural irrigation water demand in the region, and analyzing the spatial and temporal characteristics of the irrigation water demand, are of importance to help improve the water management toward sustainable use.

Currently, there are several methods to calculate crop irrigation water requirement, including ground observation (based on crop planting structure and irrigation model), the crop model method, the remote sensing method, and the Penman–Monteith method recommended by the UN Food and Agriculture Organization (FAO). Ground observation can help calculating accurate water consumption estimation at farmland scale, but can hardly estimate the water requirement in a region. Remote sensing method always combines with ground meteorological observations and crop survey to estimate crop water demand (Ma et al., 2005; Mohamed et al., 2004). However, due to the error originated from the spatial and temporal resolutions of remote sensing data, there are still many technical issues need further, e.g. the interpolation method from

* Corresponding author. Tel.: +86 311 85825464; fax: +86 311 85815093.
E-mail address: yjshen@sjziam.ac.cn (Y. Shen).

0378-3774/$ – see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.agwat.2013.06.014

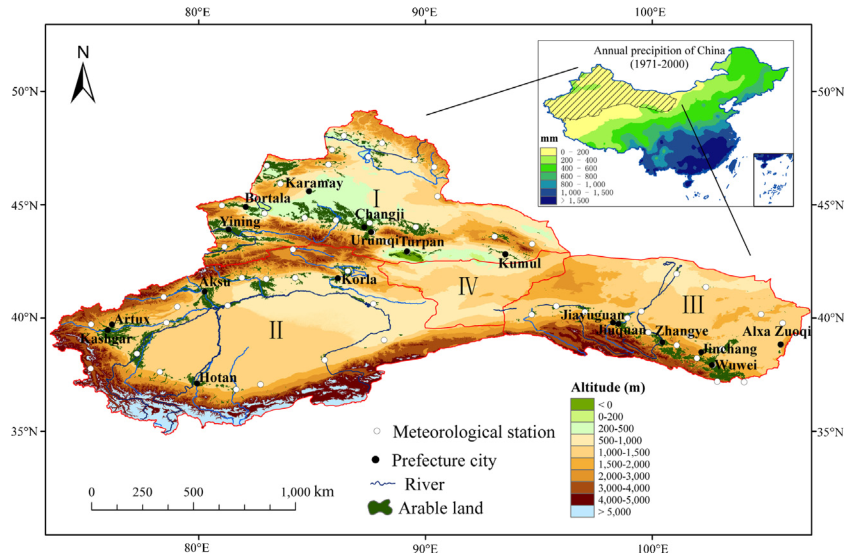

Fig. 1. Geomorphologic setting and zoning of the ARNWC. The embedded figure shows the distribution of annual precipitation, precipitation in the study area is generally less than 200 mm/yr.

instantaneous satellite image to daily or seasonal water consumption. The Penman–Monteith method has a simple equation and better physical basis, and been widely used in the estimation of crop water requirement. Liu et al. (2005) calculated water requirements of major crops in North China using the Penman–Monteith method. Xiao et al. (2006) calculated and analyzed the spatio-temporal characteristics of water demand of corn in China. Er-Raki et al. (2007) studied water demand of wheat in Morocco using the Penman–Monteith equation combined with land surface remote sensing data. Du et al. (2006) studied the response of irrigation to cotton production and physiology in the oasis in Northwestern China. Although the above studies looked at the water requirement of unit area crop, they did not consider the impact of rainfall on crop irrigation water demand, and could not quantify the total water demand at a regional scale, especially, in the ARNWC.

In this paper, based on Penman–Monteith method and combined ground observation data of crop growing acreage, we calculated and analyzed the temporal and spatial variations of agricultural irrigation water demand in the ARNWC. The objectives of this study are: (1) to give a whole picture of spatial and temporal changes of irrigation water demand and the water availability and (2) to provide quantitative information for spatial irrigation water demand as well as the water demand structure for different crops in the hyper arid region of China. We hope these results can help improve the water resources management in this highly water deficit region.

2. The ARNWC

The ARNWC is located in the central part of Eurasian continent, including all of Xinjiang, Hexi Corridor in Gansu and the west of the Helan Mountain of Inner Mongolia; its geographical location is between longitude 73–125° E and latitude 35–50° N (Luo and Yang, 2003); the total area is approximately 2.02 million square kilometers, accounting for more than one fifth of China's total terrestrial area. The Kunlun–Altun–Qilian Mountains are the south boundary of the area (Fig. 1), which combined with the Qinghai-Tibet Plateau, blocks the vapor from Indian Ocean. Altai Mountain is the northern boundary, blocking the vapor from the Arctic Ocean. Tianshan Mountains lie in the middle of the region and form the landscapes of alpine, inland basins, gobi desert and widespread sandy desert. This inland region is controlled by continental climate, with little rainfall throughout the year and strong evaporative potential. The average annual precipitation is only 130 mm, with uneven spatial and temporal distributions. The highest rainfall occurs at the eastern end of the Tianshan Mountains in the Ili River Valley, which could amount up to 800 mm/yr or above; annual precipitation is generally less than 50 mm in the oasis areas, where most agricultural activities exist. However, the potential evaporation in this arid region can be as large as 3200 mm/yr, 8–10 times the annual rainfall (Shen and Chen, 2010; Chen et al., 2012). The hyper arid region is thus one of the most arid regions in the world (Shen and Chen, 2010).

Abundant radiation and heat resources in this region make it an ideal place for thermophilous and photophilous crops growth, so it becomes an important high-quality and also high-yield cotton production zone (Xu et al., 2011). Other crops like wheat and corn are also widely cultivated in this region. The arable land is mainly distributed in oases embedded at the edge of the deserts, relying on surface water and groundwater for irrigation. At the end of 2010, the total area of farmland was 4.9 million hectares, effective irrigation reached 4.682 million hectares, and the total crop growing area amounted to 5.55 million ha. Cotton growing area was 1.5 million ha, and its acreage and production accounted for 31% and 42.7% of the country's total, respectively. According to Bureau of Xinjiang Water Resources (2011), the annual withdrawal for irrigation reached to 48.83 billion m^3, accounting for 91.3% of the total water consumption in Xinjiang in 2010.

The irrigated area in northwestern arid regions increased from 2.7 million hectares in 1989 to about 4.4 million hectares (Fig. 2) in 2010, and the fastest increase goes to cotton growing land. In the irrigated farmland, wheat and corn growing acreage was about 2 million hectares, with little change in the total over the past 20 years. Beet and oilseed acreage was approximately 0.4–0.5 million hectares, which slightly declined in recent years. The cotton growing area showed the most fast increase, from only 0.4 million hectares in 1989, mainly distributed in Tarim River Basin, to 1.5 million hectares by 2008. In 2010, the cotton growing area slightly declined to 1.3 million hectares, still accounting for ~1/3 of the total cropping areas.