Physics and Chemistry of the Earth 89–90 (2015) 3–9

Contents lists available at ScienceDirect

Physics and Chemistry of the Earth

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

An integrated analysis of agricultural water-use efficiency: A case study in the Heihe River Basin in Northwest China

Guofeng Wang [a], Jiancheng Chen [a, *], Feng Wu [b, c], Zhihui Li [b, c, d]

[a] School of Economics and Management, Beijing Forestry University, Beijing 100083, China
[b] Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing 100101, China
[c] Center for Chinese Agricultural Policy, Chinese Academy of Sciences, Beijing 100101, China
[d] University of Chinese Academy of Sciences, Beijing, 100049, China

ARTICLE INFO

Article history:
Received 1 September 2015
Received in revised form
28 September 2015
Accepted 1 October 2015
Available online 23 October 2015

Keywords:
Water-use efficiency
Data envelopment analysis
Malmquist total productivity factor index
Tobit model
Heihe River Basin

ABSTRACT

The water-use efficiency has direct impacts on the water consumption of agriculture production and is vital to water conservation at both local and regional extent. The agricultural water-use efficiency is a critical indicator that reflects the effective water allocation and water productivity improvement among different agricultural sectors. Taking the Heihe River Basin as the case study area, this study explores the changing trajectories of agricultural water use based on the input–output data of 2003–2012, and estimates the water-use efficiency with Data Envelopment Analysis, Malmquist Total Productivity Index and the decomposition of total factor productivity. Further, the influence of driving factors on the water-use efficiency is analyzed with the Tobit model. The research results indicate that the average agricultural water-use efficiency in different counties is all lower than 1 during 2003–2012, indicating that there is still improvement space in the agricultural water-use efficiency. In addition, there is obvious heterogeneity in the agricultural water-use efficiency among different counties, especially prior to 2009. The research results from the Tobit model indicate that agricultural investment and production, economic growth, industrial restructuring and agricultural plants structural adjustment have significant influence on the agricultural water-use efficiency. The research results can provide significant references for agricultural water-use management in the middle reaches of the Heihe River Basin and other similar regions in Northwest China.

1. Introduction

Water resource is one of the most basic and critical elements for the living and production of human beings. The stable supply and efficient use of water resources play an important role in guaranteeing the sustainable socioeconomic development (Deng and Zhao, 2014; Singh et al., 2013; Zhao et al., 2010). UN World Water Development Report reveals that 66 countries with 21% of the world population would turn from moderate water shortage to severe situation by 2050, indicating great differences occur in global water distribution with severe water disequilibrium, which brings great challenge to the regional water supply (The United Nations World Water Development Report, 2014). As a country with large population, China has been evaluated as one of the major countries with apparent unbalanced water supply and demand in the millennium ecosystem assessment report (Duraiappah et al., 2005). The global climate change leads to aggravated drying in specific areas (Duraiappah et al., 2005), threatening the water sustainability, which is vital for the global sustainable socioeconomic development. The utilization of water resource, especially agricultural water resource, plays an important role in the economic development (Deng et al., 2015; Jiang et al., 2014; Li et al., 2015a,b). Agricultural water consumption accounts for the largest proportion in China. According to the Statistics in Ministry of Water Resources of the People's Republic of China, 51.5% of the cropland production depends on irrigation in 2014 (Deng and Zhao, 2014). Therefore, it is important to improve the agricultural water-use efficiency for the agricultural and extended economic development.

China will face the biggest challenge in agricultural water supply by 2050 (Deng et al., 2014). The water demand in China of

* Corresponding author.
E-mail addresses: wanggf_simlab@163.com (G. Wang), Chenjc_bjfu@hotmail.com (J. Chen), lizh.12b@igsnrr.ac.cn (Z. Li).

http://dx.doi.org/10.1016/j.pce.2015.10.009
1474-7065/

cultivated land will be over 100 billion m^3 to secure the food demand of approximately 1.5 billion people with the water supply only increase slightly in the foreseeable future, meanwhile a huge amount of water resource should be budgeted for restoring the destroyed ecology (Shi et al., 2014) and for the industrial sectors and other sectors, which will greatly constrain the water supply to the agricultural sectors (Shi et al., 2014; Wang et al., 2010).

There have been extensive researches on water resources, including water protection, effective utilization of water resources (Huang et al., 2013) and evaluation of water security (Chen et al., 2013) etc., particularly, the water-use efficiency has always been the core issue in different countries (Abu-Allaban et al., 2015; Kahil et al., 2015). At the early stage of the world development, water resource was regarded as "free commodity", while with the boom of global economy, the conflicts between water demand and supply have become fiercer, how to improve the water-use efficiency is becoming a very urgent task (Sun et al., 2014; Zhang and Wang, 2015). In UK, to improve the residents' living environment, the government has made great efforts to improve the water-use efficiency (Ruiz-Canales and Ferrández-Villena, 2015; Zhao et al., 2010). Experts in USA pointed out that the water price could improve the level of the water-use efficiency (Ruiz-Canales and Ferrández-Villena, 2015). In China, the government had carried out some related acts and measures to improve the water-use efficiency. For example, "Water Law of People's Republic of China", which was carried out in 2002, has given out some corresponding management policies for improving the industrial, agricultural and living water-use efficiency in terms of water resources allocation and water saving, such as the reduce, reuse and recycle of water.

The research on the agricultural water-use efficiency started in the middle of 20th century (Wang et al., 2001). Departments within UN specially established research institutions for water resource issues (Chen et al., 2015a; Kaminski et al., 2015; Yin et al., 2015). There have also been many scholars attempting to find out ways to improve the agricultural water-use efficiency. For example, Li et al. (2015a,b) reveals that water-use efficiency were uneven in the 31 provinces of China, with the irrigation efficiency in Hunan and Jiangsu Province (irrigation land) reaching only 60% during 2005–2012. In addition, the average water-use efficiency was 30% in Northwest China in 2006, where only 3% of the water was effectively used and the rest water was wasted (Zhang et al., 2014). While, the water-use efficiency has improved significantly in some regions of Northwest China. For example, Minqin County, a typical agricultural area of Northwest China, has experienced three stages to achieve the comprehensive agricultural water use, during 2000–2003, the water-use efficiency proliferated from 22% to 42%; during 2004–2008, while the water-use efficiency increased with 6% annually; and from 2009 to 2012 the efficiency finally reached 76%.

China is suffering from severe water shortage, and the distribution of water resources are of high heterogeneous in space and time, which further aggravates the imbalance between water supply and demand (Hubacek et al., 2009;Wang, 2010). The contradiction between water supply and demand is more serious in the arid and semi-arid regions in Northwest China (e.g., Shaanxi, Qinghai, Gansu, Ningxia and Xinjiang), where water shortage has become the key constraint factor of economic development (Du et al., 2013; Liao and Dong, 2011). As a less developed and ecological fragile region, Northwest China has to face the contradictions between eco-environment protection and economic development (Li et al., 2013). The water use amount and water exploitation rate in Northwest China have increased rapidly with the booming of China's economy during the past decades. For example, the water exploitation rate has reached 50% in Gansu Province and 70% in Xinjiang Province in 2009, which is much higher than the global average level (Zhao and Lian, 2015). Besides, the agriculture, which is the supporting industry of Northwest China, plays a key role in influencing the water use amount and water-use efficiency. Previous research shows that the water-use efficiency was low in most provinces in Northwest China, thus analyzing the influencing mechanism of agricultural water-use efficiency is vital to deal with the contradiction in the allocation of water resources among agriculture, industry and ecology in Northwest China.

There are various influencing factors of the water-use efficiency among different agricultural sectors. From a macro perspective, the industrial structure has strong impacts on agricultural water use, and the proportions of three main industries determine the allocation of water resources (Valta et al., 2015). In particular, the irrigation water-use efficiency is significantly affected by the demand for import–export business and the endowment of water resources (Dupoue et al., 2015), the proportion of canal water use, water price and the technology of water-saving irrigation (Binet et al., 2014) and institution for water utilization (Li et al., 2015a,b). From the perspective of individual households, there are also a series of factors contributing to the differences in water-use efficiency among regions, e.g., the age, agricultural labor force, irrigation area, ratio of agricultural income in the total income, level of awareness of water resource shortage, cost of water use, irrigation water source, and the implementation of water saving technology (Fischer et al., 2014). For example, previous research in Northwest and Southwest China suggested that the effects of influencing factors (e.g., irrigation area, length of the canal, water price and investment in irrigation) were different in the two regions due to the difference in the level of water shortage (Wang, 2010). In general, the regional water-use efficiency was determined by the coupling effect of nature and society. In the past, researches are mostly focused on the physical and engineering dimensions while with less studies at the socio-economic dimension. The investigation into the regional agricultural water-use efficiency is instructive for the understanding of the mutual feedback between agricultural water use and eco-environment. In this research, we are attempting to uncover the varying pattern of the regional agricultural water-use efficiency in the context of rapid industrialization, urbanization and climate change, and to propose the regulating factor for the improvement of regional agricultural water-use efficiency.

Previous researches on water resources in the Heihe River Basin mainly concentrated on the local water bearing capacity, water use strategies for water resources sustainability (Deng and Zhao, 2014; Nian et al., 2014; Wang et al., 2015; Wu et al., 2014b), which have pointed out that the eco-footprint of agriculture was much higher than that of other sectors (Wu et al., 2014c; Zhang et al., 2012). In this study, the Data Envelopment Analysis (DEA) and Malmquist Total Factor Productivity Index were first used to calculate the agricultural water-use efficiency and total factor productivity (TFP) growth rate in the agricultural production area of the Heihe River Basin from 2003 to 2012. Then the Tobit model was used to analyze the driving factors of the agricultural water-use efficiency. The results of this study can provide important references for the sustainable use of water resources and improvement of the agricultural water-use efficiency in the Heihe River Basin and other similar regions.

2. Study area

The Heihe river originates from Qilian Mountain in the northeast of Qinghai-Tibet Plateau, and goes through Qinghai, Gansu and Inner Mongolia (Nian et al., 2014; Wang et al., 2015). Endowed with the continental dry climate, it is characterized with low rainfall, strong evaporation, and serious water resource deficiency (Wu