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Efficiency of water use and its implications for a water-food nexus in the Aral Sea Basin

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ABSTRACT

The excessive water use in Central Asian countries has caused an environmental disaster in the Aral Sea. In this regard, they need to improve the efficiency of the use of shared water resources to overcome their environmental and economic difficulties. Accordingly, the twin objectives of this study were firstly to analyse the challenges for the use of water resources in the Aral Sea Basin and secondly to estimate the agricultural water use efficiency according to the crop types and irrigation methods. The results showed that the economic efficiency of water use in Central Asian countries was lower than that of other Asian countries. Finally, this study illustrated that the selection of crop types and irrigation methods can improve the quantitative and economic efficiency of water use. However, a clear preliminary outline of interactions is necessary to avoid failure of coordination and collaboration for a regional win-win approach. In such an outline, this study will deliver valuable information on water efficiency in the Aral Sea basin.

1. Introduction

The Aral Sea disaster is the result of water mismanagement and inefficient irrigation systems in the Aral Sea Basin, where water resources are shared by the five key riparian countries in Central Asia: Uzbekistan, Turkmenistan, Tajikistan, Kazakhstan, and Kyrgyzstan (Peachey, 2004; Micklin, 2006). After the collapse of the Soviet Union, water security issues grew regarding the basin as the five riparian governments each tried to utilize freshwater resources only for their own national development (Lioubimtseva and Henebry, 2009; Abbink et al., 2010; Chatalova et al., 2017). Over the 40 years since, they have done little to reduce the environmental consequences of water development, including the decline in the depth of the Aral Sea by 26 m (Micklin, 2010). Consequently, the Aral Sea has been depleted, losing more than half of its surface area and roughly three-quarters of its volume compared to the levels measured in the 1960 s.

The water resource system in the Aral Sea Basin is one of the most complicated networks in the world because of the imbalance of shared water resources available to countries in Central Asia. The geopolitical issues among these countries make water governance in the basin difficult. Each has their own water policy to promote food security, energy generation, and economic growth (Wegerich 2004; Bazilian et al., 2011). These national water policies are, however, mostly focused on obtaining more water from the Aral Sea Basin's limited water supply. Such excessive competition for water has often led to water conflicts among the countries (Karaev, 2005). Recently, more attention has been paid to regional cooperation by these countries in determining the allocation of transboundary water resources (Schiff and Winters, 2002; McKinney, 2004; Schluter et al., 2005; Sadegh et al., 2010; Libert and Lipponen, 2012; Dinar et al., 2015). Yet, these countries still have not reached a compromise, and appear to be stuck in an impasse because of different views on water governance at the national and regional levels (Allouche, 2007).

The main economic activity in Aral Sea Basin is agriculture (Kienzler et al., 2012). Climatic and hydrological conditions of the countries in Central Asia are, however, unfavourable for farming because the region is arid. Despite this, agricultural production has focused on crops with high water demands, such as cotton and wheat (Pereira et al., 2009). Furthermore, crop irrigation using the traditional method of furrow irrigation has been shown to decrease the efficiency of water use and crop yield (Ward and Pulido-Velazquez, 2008). Consequently, agricultural water use has become a significant threat to water security and economic growth in the region. To resolve these problems, new and innovative methods have been suggested in the literature (Gordon et al., 2010; Molden et al., 2010; Chaudhry and Barbier, 2013). Water-intensive crops remain the main source of income in many parts of the region, thereby depleting the available water resources needed for continued economic growth.

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As previously mentioned, Central Asian countries will have to clear many hurdles to see sustained economic growth, including substantial environmental and economic pressures (Bichsel, 2009; Collins, 2009; Pomfret, 2014). To resolve this issue, they need to pursue growth potential, while minimizing long-term risk to the ecosystem. For example, the concept of Green Growth or Green Economy is one of several workable suggestions to overcome the complex problems facing the Aral Sea Basin because it aligns well with the activities the region has pursued (Pearce et al., 1989; Hoffmann, 2011; Mathews, 2012; Resnick et al., 2012; Antonelli et al., 2013; Young and Esau, 2013). In addition, such concepts may be an appropriate approach as a solution for issues that arise from the water–energy–food nexus (Waughray, 2011; UNESCAP, 2013; Allouche et al., 2014; Granit et al. 2013). In this regard, the concept of water-energy-food nexus has been studied in many countries (Jobbins et al., 2015; Portney et al., 2017; Yang and Wi, 2018). However, water–energy–food in a transboundary river basin can be weakened by excessive water competition at the regional scale. Therefore, more effort and time are needed to move gradually towards achieving water–energy–food nexus in the Aral Sea Basin.

This study focused on the water use efficiency for water-food nexus in the Aral Sea Basin. In this regard, the objectives of this study are as follows: 1) to analyse the challenges facing water resources in terms of the climate and economy; and 2) to calculate changes in agricultural water use if wheat land was converted to cotton land or vice versa, and if furrow irrigation or subsurface drip irrigation was used. To achieve these objectives, the authors investigated the water status of the five Central Asian countries (Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, and Uzbekistan) in the Aral Sea Basin at the regional level.

2. Materials and methods

2.1. Overview of Aral Sea Basin

The Aral Sea Basin includes portions of Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, Uzbekistan, Afghanistan, Iran, and China. However, the five Central Asian countries were the main focus of this study because most water resources in the Aral Sea Basin are consumed by these five countries.

The Aral Sea Basin is morphologically divided into two zones, a plain in the central and western parts of the basin and mountains in the east (Dukhovny and Sokolov, 2003) (Fig.1). The plain zone has two main deserts: the Kara Kum desert in the western and southwestern parts of the basin and the Kyzyl Kum desert in the northern part of the basin. The mountainous areas includes two main mountain ranges: the Tien Shan and Pamir. Hydrologically, these two mountain ranges are a very important source of water in the Aral Sea Basin because the two main transboundary rivers (the Syr Darya and the Amu Darya) are fed by runoff from melting snows and glaciers (Bernauer and Siegfried, 2012; Hagg et al., 2013; Sorg et al., 2014).

The area of Aral Sea Basin is approximately 154.8 Mha (million hectares) in total and consists of lands controlled by Kazakhstan (34.4 Mha), Kyrgyzstan (12.5 Mha), Tajikistan (14.3 Mha), Turkmenistan (48.8 Mha), and Uzbekistan (44.8 Mha). The basin, therefore, makes up approximately 39% of the total 400 Mha area of the five countries (CAWATERinfo, 2015). The population in the Aral Sea Basin was 46 million in 2006 and includes many diverse cultures. The population in the basin has grown by 31 million people in less than 50 years (Sokolov, 2009). The basin has a continental, arid and semi-arid climate, with precipitation concentrated during the spring and winter seasons. Precipitation exhibits a spatial difference according to the morphological characteristics of the basin. For example, yearly precipitation ranges from 80 to 150 mm on the plains and from 600 to 800 mm in the mountains (CAWATERinfo, 2015). The amount of precipitation may not be enough to ensure that the rivers flow into the basin perennially. During the dry season, river flow is maintained by snow and glacier meltwater from mountainous regions rather than from precipitation (Granit et al., 2010).

The sources of water for the Central Asian countries are the Syr Darya and the Amu Darya rivers (Glantz, 1999; Ntegeka et al., 2014). Each river basin has a separate network of hydraulic structures to control or reserve water resources (Fang et al., 2005; Allouche, 2007). The regional operation of each network is very complicated because these hydraulic structures are constructed and operated under the guidance of the national water policy of each country (Vinogradov and Langford, 2001; Micklin, 2007; Scheer et al., 2008). The Syr Darya River and its tributaries flow along and within the borders of four countries: Kirghizstan, Kazakhstan, Tajikistan, and Uzbekistan. The Syr Darya is the main source of irrigation water to Kazakhstan, Tajikistan, and Uzbekistan (Immerzeel et al., 2010; Kaser et al., 2010). The Syr Darya has a bearing capacity of 37.2 billion m^3 and is 3019 km long, making it the longest river in the basin. The Amu Darya River and its major tributaries flow along and within the borders of three countries: Tajikistan, Turkmenistan, and Uzbekistan. The Amu Darya provides water for hydropower generation and irrigation in those countries (Mergili et al., 2013). It has an average annual flow of 79.3 billion m^3, making it the largest river in terms of water capacity in the Aral Sea Basin, and measures 2540 km in length from the headwaters of its tributary, the Pyandzh, to the Aral Sea (CAWATERinfo, 2015).

Since the Soviet era (1918–1991), the increasing demand for water within these transboundary rivers has made it difficult to assign water allocations among the countries. Furthermore, agricultural irrigation water in Central Asia has significantly contributed to economic production, accounting for more than 15% of the total GDP, except in Kazakhstan (9.9%) (Kienzler et al., 2012).

In these situations, unclear water allocation regulations incite competition among the countries to secure more water (Bichsel, 2009; Libert and Lipponen, 2012). As a result, excessive water consumption has led to a remarkable decrease in the surface area of and volume of the Aral Sea over the last 50 years. Compared to 1960, the surface area and volume decreased to 12.5% and 7.7%, respectively, in 2009 (Micklin, 2010). In the Aral Sea basin, inefficient irrigation systems and mismanagement of irrigation water allocations have also resulted in elevated water and soil salinity levels, widespread environmental degradation, and diminished agricultural productivity (Niyazov et al., 2012; Lioubimtseva, 2014). Furthermore, in an effort to obtain sufficient water resources, these Central Asian countries have pursued independent water policies, resulting in conflicts.

2.2. Status of water and land resources in the Aral Sea Basin

Available water resources in the Aral Sea Basin include surface water, groundwater, and return water from residential areas and agricultural activities. The average annual river flow in the basin is 116.48 km^3/yr with contributions from the Amu Darya (79.28 km^3/yr) and Syr Darya basins (37.20 km^3/yr) (Table 1). Among the Central Asian countries, Tajikistan and Kazakhstan have the most and the least river flow in the basin, respectively. Specifically, the average annual river flow is highest in Tajikistan for the Amu Darya basin and Kyrgyzstan for the Syr Darya basin. Both Tajikistan and Kyrgyzstan are located in upstream reaches of each basin and are more mountainous, with more rain than the other countries. Agricultural lands, including irrigated lands, measure 9.86 Mha, making up 5.8% of total area of the basin (Table 2). Uzbekistan has more agricultural land (5.48 Mha) than the other four countries combined. As a whole, these countries have created an imbalance between water use and natural water generation because agricultural water supply mostly depends on irrigation (with a large contribution to river flow and a very low amount of agricultural area, Kyrgyzstan is a notable exception). Land used for cotton and wheat production, the main crops in the basin, measure 2.66 Mha and 2.92 Mha, respectively. High water consumption is required to produce these two crops. However, immediate replacement of these water