Journal of Hydrology 539 (2016) 648–661

Contents lists available at ScienceDirect

Journal of Hydrology

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

Managing the water–energy–food nexus: Gains and losses from new water development in Amu Darya River Basin

Shokhrukh-Mirzo Jalilov [a,*], Marko Keskinen [a], Olli Varis [a], Saud Amer [b], Frank A. Ward [c]

[a] Water & Development Research Group, Aalto University, Finland
[b] US Geological Survey, United States
[c] Department of Agricultural Economics and Agricultural Business, New Mexico State University, United States

ARTICLE INFO

Article history:
Received 22 May 2015
Received in revised form 7 May 2016
Accepted 31 May 2016
Available online 6 June 2016
This manuscript was handled by Geoff Syme, Editor-in-Chief, with the assistance of Bellie Sivakumar, Associate Editor

Keywords:
Hydro-economic model
Water–energy–food nexus
Rogun
Nurek
Amu Darya
Central Asia

SUMMARY

According to the UN, the population of Central Asia will increase from its current approximately 65 million people to a well over 90 million by the end of this century. Taking this increasing population into consideration, it is impossible to project development strategies without considering three key factors in meeting the demands of a growing population: water, food and energy. Societies will have to choose, for instance, between using land and fertilizer for food production or for bio-based or renewable energy production, and between using fresh water for energy production or for irrigating crops. Thus water, food and energy are inextricably linked and must be considered together as a system. Recently, tensions among the Central Asian countries over the use of water for energy and energy production have increased with the building of Rogun Dam on the Vakhsh River, a tributary of the Amu Darya River. The dam will provide upstream Tajikistan with hydropower, while downstream countries fear it could negatively impact their irrigated agriculture. Despite recent peer reviewed literature on water resources management in Amu Darya Basin, none to date have addressed the interconnection and mutual impacts within water–energy–food systems in face of constructing the Rogun Dam. We examine two potential operation modes of the dam: *Energy Mode* (ensuring Tajikistan's hydropower needs) and *Irrigation Mode* (ensuring water for agriculture downstream). Results show that the *Energy Mode* could ensure more than double Tajikistan's energy capacity, but would reduce water availability during the growing season, resulting in an average 37% decline in agricultural benefits in downstream countries. The *Irrigation Mode* could bring a surplus in agricultural benefits to Tajikistan and Uzbekistan in addition an increasing energy benefits in Tajikistan by two fold. However, energy production in the *Irrigation Mode* would be non-optimally distributed over the seasons resulting in the most of hydropower being produced during the growing season. Neither operation mode provides optimal benefits for all the countries, emphasizing how difficult it is to actually reach a win–win scenario across the water–energy–food security nexus in transboundary river basins.

1. Introduction

1.1. Water–energy–food nexus

Food, water and energy are essential for human existence and well-being. Sustainable access to and management of these resources is a foundation for long-term economic growth and development. Challenged by the importance of efficient and balanced use of these scarce resources, several recent academic works have paid increasing attention to the concept of a water, energy and food security nexus. This concept calls for an integrated and systematic approach to address water, energy, and food security at several levels and in numerous settings (Rasul, 2014; WEF, 2011; Hoff, 2011; Hellegers et al., 2008). Understanding and identifying the linkages among these key resources and improving their use efficiency could mean a major win–win outcomes for well-being worldwide (GWSP, 2014).

The nexus approach recognizes the interlinkages between water, energy, and food production. It looks for ways to conceptualize and, if possible, quantify these linkages into a single framework to assess and manage their use that shows full respect for their connections (Hermann et al., 2012; Hussey and Pittock, 2012; Sharma and Bazaz, 2012; Bazilian et al., 2011; Scott et al., 2011; Hellegers et al., 2008). While there is an increasing amount of research trying to consider these three resources together

* Corresponding author. Tel.: +358 46 6171001.
E-mail address: sjalilov@gmail.com (S.-M. Jalilov).

http://dx.doi.org/10.1016/j.jhydrol.2016.05.071
0022-1694/

Fig. 1. Map of Central Asia with the site of Rogun Dam. Data source on rivers: World Data Bank II (1980) Global river network. CIA, U.S. government. Data source on national boundaries: USGS (2001) Administrative boundaries, Global GIS Database (Reston, VA: US Geological Survey). Data source on the location of Rogun Dam: The Economist (2013).

(Rasul, 2014; Ringler et al., 2013; Gulati et al., 2013), there are few analyses done quantitatively with respect to their linkages with different policy and planning options (Bazilian et al., 2011).

The water–energy–food security nexus is particularly challenging in transboundary river basins. In such settings, each riparian country tends to maximize its own water, energy and food security. Yet, for the same reason the nexus approach is particularly relevant for transboundary settings, as it can reveal potential win–win and lose–lose situations that the actions of different countries can create for the entire region around the basin. The political character of water is also strong in transboundary basins, as the national interests of each riparian country define the outcomes of basin-wide decision-making process related to water resources development (Jägerskog et al., 2013; Earle et al., 2010).

A few previous studies stress the existence of a tight connection between the complex challenges of water, energy and food. Lee et al. (2011) presented an optimal scenario of integrated basin management in the presence of a dam. Using an example of Lake Aswan, located between Egypt and Sudan, the study showed that a move from the baseline status-quo condition to the socially optimal level will increase total basin-wide net present value by more than $500 billion (Lee et al., 2011). In addition, the study also analyzed other scenarios of cooperation. Wyrwoll (2011) demonstrated the case of the Xayaburi Project which consists of 11 mainstream dams on the Mekong River; while the project could be the "battery of Asia" (Wyrwoll, 2011) it would also have a devastating effect on food security in the region. A comprehensive study of large hydropower projects all over the world by Ansar et al. (2014) makes an interesting conclusion that ". . .in most countries large hydropower dams will be too costly in absolute terms and take too long to build to deliver a positive risk-adjusted return unless suitable risk management measures outlined" (Ansar et al., 2014, p. 43). Therefore, decision-makers in developing countries should explore other energy alternatives with shorter building period (Ansar et al., 2014). The most recent study by Chen et al. (2016) based on a firsthand analysis of global data on dams and socio-economic conditions, identifies the close relationship between dams and socio-economic development. They conclude that "whether dam construction should continue is no longer a question, as the need, especially in the developing countries and the LDCs, is obvious" (Chen et al., 2016, p. 27).

1.2. Amu Darya River Basin and Rogun Dam

This study investigates linkages between water, energy production and food security in the transboundary Amu Darya River Basin (ADRB). The focus is on the planned Rogun Hydropower Plant (RHP) on the second largest Amu Darya tributary i.e. Vakhsh River (Fig. 1).

The Amu Darya River is the largest river in Central Asia in terms of its length (2540 km) (Wegerich, 2008) as well as its average annual flow of 65 km^3 (Spoor and Krutov, 2003). The Basin area contains a land area of about 309,000 km^2 (Wegerich, 2008) and it is home to approximately 55 million (CIA, 2011). The mainstream is supplied by two main tributaries, the Vakhsh and Pyandj Rivers, and it inflows to the Aral Sea. The discharge regime of the Vakhsh River varies by season, with the lowest flows during winter and maximums in summer (Savchenkov et al., 1989). This phenomenon is mainly explained by melting snow and glaciers into the Vakhsh River (Konovalov, 2009).

The Amu Darya River is shared by five riparian countries – Afghanistan, Kyrgyzstan,[1] Tajikistan, Turkmenistan, and Uzbekistan. On its route from the headwaters to the Aral Sea, the river also serves as a border between Afghanistan and Tajikistan as well as between Afghanistan and Uzbekistan. There have long been heated debates among the riparian countries over the development of the Amu Darya River Basin (ADRB). Currently the debate evolves particularly around the planned Rogun Dam and around Tajikistan's right to hydropower production as well as Uzbekistan's concerns about possible negative impacts on its irrigated agriculture. There are currently few signs of willingness among the riparian countries to

[1] Kyrgyzstan supplies 2% of the total flow in the basin (SIC ICWC, 2010) and according to the "Agreement on Cooperation in Joint Management, Use and Protection of Interstate Sources of Water Resources" signed in February 1992 entitled to use only 0.6% of annual flow. Therefore, this country has not been considered in the study.