Agricultural Water Management 201 (2018) 99–106

Contents lists available at ScienceDirect

Agricultural Water Management

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

Understanding surface water–groundwater interactions for managing large irrigation schemes in the multi-country Fergana valley, Central Asia

Mirzakhayot Ibrakhimov[a], Usman Khalid Awan[b,*], Biju George[b], Umar Waqas Liaqat[c]

[a] Khorezm Rural Advisory Support Service (KRASS), Urgench, Uzbekistan
[b] International Center for Agricultural Research in the Dry Areas (ICARDA), Cairo, Egypt
[c] Environment and Remote Sensing Laboratory, Department of Water Resources, Graduate School of Water Resources, Sungkyunkwan University, Suwon, 440-746, Republic of Korea

ARTICLE INFO

Keywords:
Groundwater recharge
Net groundwater recharge
Water balance
Crop water requirements

ABSTRACT

Traditionally, surface water supplies are the sole sources to satisfy crop water requirements in large irrigation schemes such as those in the Fergana Valley, Central Asia. Recent studies indicate that 23–30% of these requirements are met from shallow groundwater, but this is not usually quantified. To manage favorable groundwater levels – i.e., without increasing soil salinity and nutrient leaching and reducing crop yields – information on, and quantification of, groundwater recharge and discharge rates at large spatial and temporal scales, as well as understanding their mechanisms of interaction, is indispensable. With the aim to quantify groundwater recharge, discharge and their interaction, a conceptual water balance model at a scale of a Water Consumers' Association was established on a monthly basis for a 10-year period. Average groundwater recharge was estimated as 780 ± 75.7 mm, representing 62% of surface water supplies. The highest average annual recharge (930 mm) driven by excessive precipitation and water supply was in 2010 and the lowest (667–726 mm) was in years of lower water availability: 2006–2008 and 2012. The net groundwater recharge was 82.4 ± 79 mm, and determined the groundwater level fluctuations. The highest positive net groundwater recharge rate (247 mm) and the shallowest groundwater level (123 cm) also occurred in 2010. The negative net recharge in 2006 (–11 mm), 2008 (–41 mm) and 2012 (–5 mm) indicated deeper groundwater levels during these periods. The groundwater recharge values were excessively high even for this large irrigation scheme. To save limited freshwater resources, groundwater discharge should be reduced, with one option being to reduce excessive drainage outflow.

1. Introduction

Groundwater is a critically important global water resource and it is intensively extracted at the rate of 982 $km^3\,yr^{-1}$ (Margat and van der Gun, 2013), of which around 60% is used for agriculture and the rest for domestic and industrial uses (Vrba and van der Gun, 2004). Around 38% of the irrigated areas worldwide have facilities for direct use of groundwater (Siebert et al., 2010). In other areas, capillary rise from shallow groundwater contributes around 20–25% to total crop water requirements (Awan et al., 2014; Ayars et al., 2006; Kahlown et al., 2005; Kazmi et al., 2012). Shallow groundwater within a few centimeters of the surface is, however, also a source of waterlogging and secondary soil salinization (Awan et al., 2011a; Kahlown et al., 2005). In many regions (e.g., North Africa, Arabian Peninsula and South Asia), groundwater is intensively extracted at rates that have resulted in declines in groundwater levels (Awan and Ismaeel, 2015; George et al., 2011; Venot et al., 2010). In the other areas, the contribution from shallow groundwater to crop water requirements is not accounted for (Awan et al., 2017), leading to freshwater over-supply and eventual waterlogging. Hence, appropriate groundwater management is a prerequisite for sustainable management of surface and groundwater resources in large irrigation schemes.

Water from the Amudarya and Syrdarya Rivers is a main source of irrigation in Central Asian countries, and drainage and groundwater serve as a safety net during severe droughts (FAO, 2001). In Central Asia, such as in the Fergana Valley (Karimov et al., 2014) and Khorezm (Awan et al., 2017) Provinces of Uzbekistan, groundwater serves as a storage of water that infiltrates due to excessive water applications in agricultural fields and seepage from earthen irrigation networks. The groundwater level reaches 1–3 m below the land surface during intensive irrigation and thus contributes to soil moisture enhancement through capillary rise. Due to uncertainty concerning timely surface

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* Corresponding author.
E-mail address: u.k.awan@cgiar.org (U.K. Awan).

https://doi.org/10.1016/j.agwat.2018.01.016
Received 26 September 2016; Received in revised form 11 December 2017; Accepted 15 January 2018

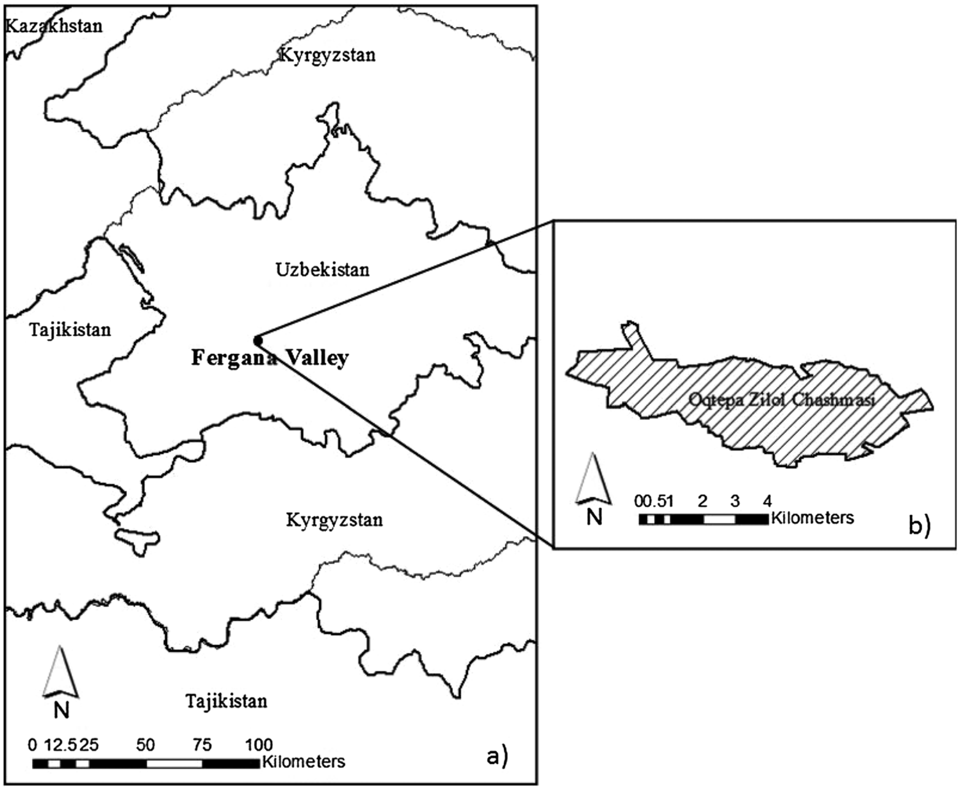

Fig. 1. Geographic location of the Fergana Valley (a) and the Oktepa Zilol Chashmasi Water Consumers' Association (b).

water supplies, farmers rely on shallow groundwater of low salinity by blocking field drains. At the same time, the ratio between drainage discharge and irrigation water supplies from agricultural fields in Uzbekistan is extremely high. For example, Awan et al. (2011b) reported that in Khorezm Province, 55% of the surface water supply is drained out from the agricultural system – much above the target value of 10% for large irrigation schemes (Bastiaanssen and Bos, 1999). This drainage discharge during cropping seasons in the Central Asian lowlands is unsustainably excessive.

Simulation scenarios of future climate change using Global Circulation Models showed that the surface water supplies in Central Asia will be reduced (Immerzeel et al., 2012) due to reduced thickness of glaciers. This may lead to conflicts concerning water sharing due to the transboundary nature of the flow of the main Central Asian rivers, and the intensified competition for water among various sectors such as domestic water use, agriculture, industry and the environment. Therefore, changes in surface water supply will impact recharge and thus discharge rates. In turn, under maintained high drainage discharge rates, lower groundwater levels will contribute less to crop water requirements, forcing farmers to utilize more surface water for irrigation (Tischbein et al., 2013). It is thus a prerequisite to better understand the interaction between the surface and groundwater resources to develop a groundwater management policy that will not only consider the recharge into, but also the discharge from, the groundwater reservoir.

Various methods of estimating groundwater recharge and discharge have been developed. The groundwater recharge methods vary from the small-field scale to large irrigation schemes and from simple water balance estimations (Scanlon et al., 2002) to complex recharge models (Awan et al., 2013; Beekman et al., 1999; Lerner et al., 1990; Massuel et al., 2013; Sylvain et al., 2014). It is necessary to choose a groundwater recharge estimation method based on appropriate spatial and temporal scales, and to account for the range and reliability of the method (Scanlon et al., 2002). In the current study, the traditional root zone water balance method based on the concept of estimating the incoming and outgoing components and changes within the soil profile was chosen for its simplicity and ease of capturing real field conditions. This method in combination with groundwater modeling has been used in the irrigated areas of the Indus Basin to simulate groundwater flow and so predict changes in groundwater levels in response to intervention scenarios in irrigation practices (Sarwar and Eggers, 2006). Maréchal et al. (2006) used the water balance method to estimate specific yield and groundwater recharge in an unconfined aquifer with significant seasonal fluctuations in the water table. They noted that the method has the advantage of estimating these parameters at the scale of interest without the need for extensive data and measurements. Yin et al. (2011) applied three methods to estimate groundwater recharge, including the water balance method, and concluded that each method had inherent uncertainty. The water balance method is easy to apply, inexpensive and produces low estimation errors. Implementing it requires data that are easy to collect: discharge can be estimated by measuring field-level drainage discharge or groundwater abstraction from tube wells. Estimating upward flux is another way of measuring groundwater discharge. The groundwater abstraction can also be estimated using remote sensing techniques (Awan et al., 2016).

The objectives of this work were to quantify groundwater recharge, discharge and net groundwater recharge (recharge minus discharge) at a Water Consumers' Association (WCA) level. The irrigated areas of the Fergana Valley in Uzbekistan were chosen for this study, and analyses were conducted on a monthly basis for the period 2004–2011. Policymakers in the region can use this knowledge to manage the surface and groundwater resources in a sustainable way under changing climate situations.

2. Materials and methods

The study area for this research is a typical environmental setting in Fergana Valley with low precipitation and, hence, frequent irrigation applications, shallow groundwater levels and massive irrigation and drainage networks. The activities included obtaining datasets of irrigation water supplies and drainage discharge, climate and cropping patterns to construct a water balance model. Components of the water balance such as actual crop-specific evapotranspiration, net