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Effects of the shallow water table on water use of winter wheat and ecosystem health: Implications for unlocking the potential of groundwater in the Fergana Valley (Central Asia)

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ABSTRACT

This paper analyzes the effect of the shallow water table on water use of the winter wheat (*Triticum aestivum L.*) that has replaced alfalfa (*Medicago sativa*) on the irrigated lands of the Fergana Valley, upstream of the Syrdarya River, in Central Asia. The effect of the shallow water table is investigated using HYDRUS-1D. Numerical simulations show that the contribution of the groundwater to evapotranspiration increases with a rising water table and decreases with increasing irrigation applications. Under irrigation conditions, an increase in the groundwater evapotranspiration is associated mainly with an increase in evaporation loss, causing a buildup of salinity in the crop root zone. Evaporation losses from fields planted with winter wheat after the harvest amount up to 45–47% of total evaporation thus affecting soil salinity and ecosystem health. Promoting the use of groundwater for irrigation in order to lower the groundwater table is suggested to achieve water savings from the change in the cropping pattern. Unlocking the potential of groundwater for irrigation in the Fergana Valley can also contribute toward managing soil salinity and improving the health and resilience of water, land and ecosystems of water, land and ecosystems (WLE).

1. Introduction

The basin water management, including the infrastructure and institutions, that was established in the Aral Sea Basin from 1960 to the mid-1980s, initially prioritized the water use for irrigation of cotton. From 1980 to 2010, the population of Central Asia doubled, increasing the demand for food production. Facing this food security challenge in new geo-political and socioeconomic environment after the forming of new independent states in the region after 1990, the states of Central Asia reoriented the focus of agricultural policy on food independency and prioritized food security. This was achieved in the region by the end of the 1990s by shifting from the cotton (6 years)/alfalfa (3 years) crop rotation to the cotton (2 years)/winter wheat (2 years) sequence. Since the irrigation season of alfalfa extends from March through September while winter wheat requires irrigation in October and then from March through May, the change of the cropping pattern from alfalfa to winter wheat results in the reduction of the summer irrigation. This released some of the water resources for the needs of the downstream water users. However, the water saving effect of this shift requires a certain clarification. As long as irrigation in Central Asia is entirely based on surface water, it is often associated with shallow groundwater tables. Water losses from irrigated fields and irrigation canals are the main source of groundwater recharge in the irrigated areas of Central Asia, amounting up to 70% of groundwater recharge in some regions, such as the Fergana valley (Borisov, 1990). Groundwater recharge from irrigation, coupled with poor natural and artificial drainage, leads to widespread shallow water table. On average, about 30% of the irrigated land has the water table less than 2 m below the soil surface. The water saving effect of the change in the cropping pattern becomes illusory for conditions with a shallow water table when intensive upward fluxes from the water table to the topsoil cause topsoil salinization, requiring more water for leaching.

The quantification of upward fluxes from a shallow groundwater table is a significant topic that has been extensively researched

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(Ganiev, 1979; Zhang et al., 1999; Soppe and Ayars, 2003; Kahlown et al., 2005; Babajimopoulos et al., 2007; Yang et al., 2007; Huo et al., 2011). In the Fergana Valley, Ganiev (1979) studied over a period of four years the capillary rise from a shallow water table in lysimeter experiments under fallow and natural conditions, and cropped with cotton or alfalfa. He found in loamy soils under cotton an increase in the capillary rise by 170, 280, and 330 mm for groundwater depths of 2.5, 2 and 1.5 m below the soil surface, respectively, compared to conditions with the water table below 3 m. In sandy loam soils, the capillary rise increased by 146 and 287 mm, and in sandy soils by 80 and 168 mm for groundwater depths of 2 and 1.5 m, respectively, as compared to conditions with the water table at a depth of 2.5 m or deeper. Zhang et al. (1999) reported that the ratio of the upward flux to alfalfa evapotranspiration (*ET*) varied between 25% and 65% for a non-saline soil with a groundwater table at a depth of 0.6–1 m. Soppe and Ayars (2003) maintained a groundwater table at a depth of 1.5 m in weighing lysimeters and found that groundwater contributed up to 40% of daily water used by the safflower crop. On a seasonal basis, 25% of the total crop water use originated from the groundwater. In the upper Indus basin near Lahore Pakistan, Kahlown et al. (2005) investigated the effect of shallow groundwater tables on the crop water use via 18 large-size drainage-type concrete lysimeters. They found that when a groundwater table was kept at a depth of 0.5 m, the entire water use of wheat was supplied by groundwater. Sunflower required only about 20% of its total water need from irrigation. However, in the same region, maize and sorghum were found to be sensitive to waterlogging, and crop yields were reduced with a rise of the groundwater table. Yang et al. (2007) quantified water fluxes in large weighing lysimeters, with a fluctuating groundwater table between 1.6 and 2.4 m during the wheat growth period and 0.7 and 2.3 m during the maize growth period, and found that, in a rotation system of wheat and maize, the cumulative capillary upward flux and the deep percolation were 89.6 and 55.9 mm, respectively. Liu and Luo (2011) conducted a lysimeter experiment to quantify the effects of shallow water tables on the water use and yield of winter wheat under rainfed conditions. The results showed that, under rainfed conditions, the seasonal contribution of groundwater met more than 65% of potential evapotranspiration of winter wheat when the water table depth was within 40–150 cm. Huo et al. (2011) studied the effect of the groundwater level and irrigation amounts on the water use of wheat in a lysimeter experiment at the Hongmen experimental station located in the Henan Province, China. Capillary rise supplied 29% of the water use of wheat during the time period from ripening to harvest when the groundwater table was 1.5 m deep, and was reduced when the depth of the groundwater table decreased. Water productivity of the wheat biomass increases and the yield decreases when groundwater levels decrease and the amount of irrigation water is reduced. Past studies indicated complex effects of the shallow water table on crop evapotranspiration.

The Fergana Valley, this study focuses on, has 900,000 ha of irrigated land and it thus represents an example of large-scale irrigated agriculture in Asia (Fig. 1a). The valley has significant potential for the production of food crops. For instance, the valley receives net radiation with the capacity to evaporate over 1120 mm/yr of water. Irrigated crops grown in the valley have the potential to utilize 70–80% of the available energy if the crop growth is not constrained by a water deficit or other factors. However, actual evapotranspiration is even lower and varies in the range of 611–722 mm/yr, of which only about 70% is transpired by crops (Karimov et al., 2012). The reduction of the area under fodder crops by replacing alfalfa with the winter wheat/fallow system reduced the crop water use in these areas on average by 30%. A risk of increasing soil salinity under shallow groundwater conditions in the Fergana Valley from a low saline to highly saline level may further reduce the crop water use and yields of cotton and wheat by about 25%. While productively utilizing only 38–45% of the available energy (due to many reasons such as a low fraction of the area covered by crops, short duration of the cropping season, or conventional furrow irrigation practices) farmers of the Fergana Valley produce over 850,000 Mg of cotton, 1300,000 Mg of wheat, and 1000,000 Mg of vegetables and other agricultural commodities. Current production volumes could be increased almost twofold if thermal, soil, and water resources are used in the most productive way. In order to achieve this, it is important to move into a cyclic process of reallocating water from a use that produces low or no benefits to one that generates higher benefits (Molden, 1997; Molden and Sakthivadivel, 1999) and thus achieves more welfare per drop of water (Molden et al., 2010). The change in the cropping pattern is one of the measures available to policymakers to meet the demand for scarce water, to increase food production through better exploitation of energy and land resources, and to tactically adapt to climate change (Hanjra and Qureshi, 2010).

Since 1992 the cotton/alfalfa crop rotation, which dominated in the Fergana Valley, has been replaced by the cotton/wheat sequence. Additionally, the cotton growing area was reduced by 82,000 ha by allocating 34,000 ha to vegetables and 48,000 ha to winter wheat. This approach was attractive for policy makers as a

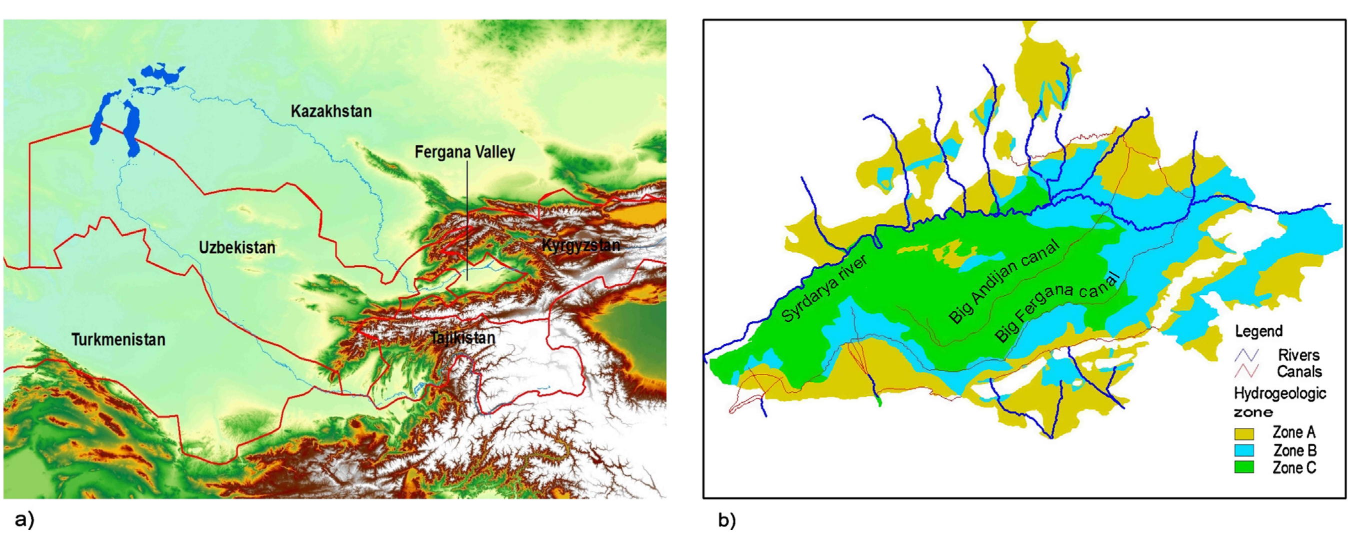

Fig. 1. (a) Central Asia and (b) hydrogeological zones of the Fergana Valley.