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The dynamics of groundwater table and salinity over 17 years in Khorezm

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ABSTRACT

Salinization of irrigated agricultural land threatens ecological sustainability and livelihoods of people. Salinization is especially severe in the dry lowlands world-wide and in Central Asia where large amounts of salts accumulated in the soil profile, originating from shallow saline groundwater (GW). Analysis of the unique dataset of 2000 monitoring wells of GW table and salinity in lowland Khorezm region of Uzbekistan over the period of 1990 till 2006 showed shallow GW levels of 1.1–1.4 m (±0.48–0.66 m) at start of leaching periods and 0.9–1.4 (±0.43–0.63 m) in July during the annual growing seasons. While leaching efficiency is decreased, shallow GW in July is far above the optimum levels of 1.4–1.5 m. The effects of topography, soil texture, and irrigation and drainage networks were found to favor shallow GW forced by excessive water diversion. The drainage network, which is seen by many specialists as underdeveloped and its improvement necessary to arrest unacceptable GW levels, is being used under its full capacity. The solution to alleviate land degradation is not only an improved drainage, but better controlled and more flexible water management.

1. Introduction

Irrigated agriculture comprises only 15% of the total cultivated area worldwide, but contributes some 40% of gross agricultural output feeding the world population of 6.7 billion people (UN-Water, 2006). Irrigated areas are concentrated in the arid and semiarid zones of the world where three quarters of the world population reside, the majority of them being involved in agriculture. Because of the irrigation, it became possible to turn otherwise unused land into cropland of often high productivity. In the Central Asian countries (CAC), for example, 11.43 Mha of the total area of 392.4 Mha are used for irrigated agriculture (PFU, 2008), but up to 34% of GDP comes from agricultural activities in which ca. 32% of population is involved. However, irrigated lands are subject to land degradation from waterlogging and salinization, which leads to decreased soil fertility and reduced crop yields.

At present, 20% of all cultivated land is degraded to some extent, and this area increases annually by about 5–7 Mha (Tanji and Kielen, 2002). The sustainability of food production in irrigated agriculture will be increasingly dependent upon sound water management and maintenance of the present agricultural resource base and the environment (Rhoades et al., 1992). At the same time, there is an alarmingly growing number of reports of water scarcity, which is going to increase in the near future (UN-Water, 2006).

Especially susceptible to salinity are the lowland areas, where irrigation activities have resulted in quick rise of the GW tables, e.g., the areas like Punjab province in Pakistan. In Australia the clearing of trees had an adverse effect on underground water which became extremely shallow and brought up salts from deep horizons (Robertson, 1996). Many irrigated areas in the US, China, Egypt, Australia and Pakistan are salinity-affected due to shallow saline groundwater (GW). The land degradation problems are especially acute in Central Asia. In Khorezm region, Uzbekistan, situated at the lower Amudarya River in the Aral Sea Basin, soil salinization and waterlogging are also mainly caused by the shallow GW tables, which become so due to field-water over-applications and seepage from the irrigation networks (Ikramov, 2004). Upward GW movement contributes significantly to soil moisture and crop transpiration (Zhang et al., 2004), which is a desired effect under water scarcity (Forkutsa et al., 2009a,b), but this leads to rapid salt accumulation in the soil root zone that causes land degradation and crop yield reduction (Hillel, 2000).

The critical GW level at which soil moisture is enhanced while salt uplift and accumulation are minimized is difficult to achieve and maintain. Therefore, the effects of different GW levels on soil salinization and moisture enhancement were analyzed and ranges of optimal levels found and where necessary, the drainage networks have been improved to maintain these levels.

For example, for most of Khorezm, soil conditions, irrigation water salinity and climate allow shallower GW levels compared to

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those in other regions of Uzbekistan (e.g., in the Syr Darya, Ikramov, 2004). Rakhimbaev et al. (1992) concluded that in Khorezm soil salinization takes place when the GW with salinity of >3 g l^{-1} is 2.0 m and shallower, and that the GW should not rise above 1.5 m when salinity is <3 g l^{-1}. Based on lysimeter studies, Kiseliova and Jumaniyazov (1975) concluded that the GW levels of 1.4–1.5 m are the most favorable for conditions of silty and sandy loamy soils. At this range of GW levels the actual crop yield nearly reaches the maximum attainable (Dukhovny, 1996). Lowering the GW further will decrease soil moisture, and at 2.0–2.5 m the upward flow ceases (Rakhimbaev et al., 1992) with the positive effect of greatly reduced soil salinization. Kahlown et al. (2005) also found similar GW levels not to cause extensive soil salinization under similar climatic conditions in agricultural lowland areas in Pakistan and where GW can be effectively used by crops.

It is known, however, that these relatively high GW tables also fulfill a second purpose, namely that of providing irrigation water through sub-surface supply (Forkutsa et al., 2009a,b). Thus, when the GW tables are lowered further to reduce salinization, irrigation timing and amounts will need to be adjusted to meet the changed situation. Kurbanbaev (2006) claimed that freshwater applications need to be nearly doubled.

To cope with salinization, Khorezmian farmers practice pre-season leaching, a common practice to ameliorate saline soils (Qadir et al., 2000). A network of 9000 km of drainage channels has been constructed in the region to discharge the saline waters out of the irrigated areas. Leaching in Khorezm consumes some 25–30% of the overall annual agricultural freshwater consumption of 4.5–5 km^3 (data from www.cawater-info.uz), but this is still the practice accepted from Soviet times in spite of the insufficiency of water resources reported for Uzbekistan (Olimjanov and Mamarasulov, 2006) and the doubtful effects of the leaching under shallow GW levels (Forkutsa et al., 2009b). However, all that leaching has shown to reduce salinization ineffectively, and salt load increases are reported over the years (Nasonov, 2007), with more than 50% of them being considered as moderately-to-highly saline during the 1980s (Ibrakhimov et al., 2007).

Khorezm is a flat region; susceptibility to quick GW table rise and subsequent soil salinization due to natural conditions of the region is counterbalanced by the drainage network and irrigation activities. During pre-season (end of February–March) leaching and growing (May–August) period, respectively the deepest possible and the above-mentioned acceptable GW levels are preferable. Analyses of the changing management structure (*shirkats* until 2003–2005 and private farmers since then) can also shed light on the effects of management activities on GW levels to control soil salinization. The emphasis of this paper is on (i) analyzing the annual and seasonal dynamics of the GW table and salinity in the Khorezm region as a result of natural and human-induced influences, (ii) identifying the factors of shallow GW tables in Khorezm and assessing their influence, and (iii) suggesting management interventions that contribute to the alleviation of the salinization of the scarce land and water resources in the region. Analyses are based on a GW data set from a grid of water gauging stations covering the entire Khorezm region, for the period of 1990–2006, and data on topography, texture and distance to irrigation/drainage canals.

2. Materials and methods

2.1. Study area and agricultural practices

Khorezm (Fig. 1) in the northwest of Uzbekistan (40°27–41°06′N, 58°31′–61°24′E) is a flat region with elevation points between 112 and 138 m a.s.l. (Kats, 1976). About 270,000 ha (40%) of the total area can be irrigated (Vodproject, 1999). The region, surrounded by the Karakum and Kyzylkum deserts, has an arid continental climate. The Amudarya River in the northeastern border of the region is the main source of water for irrigation. Due largely to the geographically downstream location, the salinity of the river water is generally higher compared to that in the upstream regions.

Due mainly to flatness and the hydrogeological situation, lateral GW flows generally do not exceed 19–26 cm $year^{-1}$; and thus,

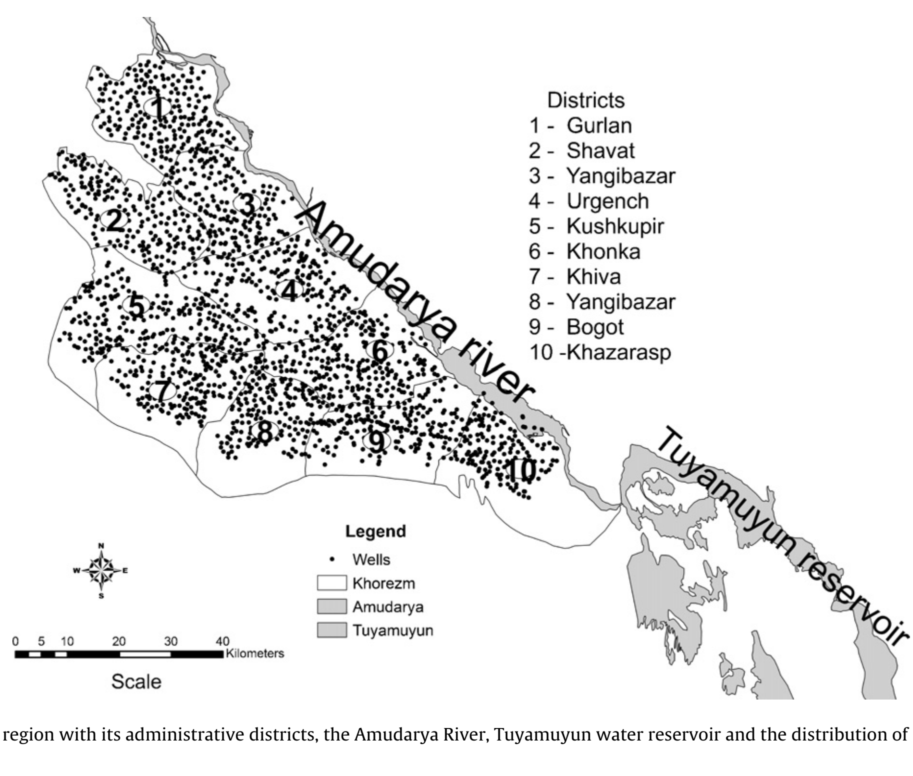

Fig. 1. Khorezm region with its administrative districts, the Amudarya River, Tuyamuyun water reservoir and the distribution of monitoring wells.