Estimation of groundwater contribution to crop water use in Kulavat irrigation command area in Khorezm, Uzbekistan

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Due to arid climate of Uzbekistan, water scarcity threatens the sustainable development of irrigated agriculture. In future, accounting all non-conventional water resources to mitigate water scarcity and to increase in-situ crop water use become main topic for most researches. In this context, groundwater evaporation (Egw) can be considered as one of the sources to meet crop-water use where the water table is shallow and groundwater salinity is low. In this study, soil texture, groundwater table depth and salinity maps are developed in geographical information system based on analyzing long-term archive data. These data then employed to estimate and map Egw through a semi-empirical approach. The results suggest that surface irrigation may be reduced considering Egw contribution ranging from 205-240 mm (e.g. light soils) to 305-360 mm (e.g. medium to heavy soils). The approach can be recommended to adjust the soil water balance in the root zone and optimize irrigation schedule.

Key words: groundwater evaporation, groundwater table, Khorezm, soil texture

INTRODUCTION

Irrigation water, consuming 90% of total available water resources, is a key driver of agricultural production in Uzbekistan. However, water scarcity, due to changing improper climate, has become an increasingly acute problem that threatens the sustainable development of irrigated agriculture in the country. Moreover, recent drought events in 2001, 2008 and 2011 caused tremendous damage to agriculture, economy, human wellbeing and health in the lowlands of the Amudarya River. Agricultural damage from drought in 2001 cost about 45 and 22.5 billion UzSum, where 36 and 13% of irrigated lands were not cultivated and 22 and 8% of croplands were dried up in Karakalpakstan and Khorezm, respectively (Gaipnazarov and Deivy, 2006). Considering the amount of water in the Amudarya River is predicted to reduce further due to affecting the climate change (Dukhovny and de Schutter, 2011), modifying the irrigation scheduling is needed to incorporate in-situ crop water use from shallow groundwater and correspondingly reduce irrigation water application and drainage water volumes to be disposed. Therefore, investigating the potential of groundwater evaporation contribution to crop-water use may be helpful in reducing water demand from the river.

Upward water flux from groundwater depend on several factors such as groundwater table (GWT) depth, soil hydraulic properties, crop growth stage, weather and irrigation, among others. Hence, there are several methods existing to estimate water upward movement from groundwater based on these factors. Although, direct measurement of groundwater evaporation is possible through lysimetric studies (Engulatov et al., 1964; Kats, 1976), modeling approaches (e.g., UPFLOW, Raes and Deproost, 2003; HYDRUS, Simunek et al., 1998, etc.), empirical approaches (e.g., empirical/semi-empirical equations with power or exponential functions; Laktaev, 1978; Dukhovny, 1984, etc.) and simple approach (e.g., graphical procedure; Doorenbos and Pruitt, 1977) are also available. However, these approaches are expensive and
METHODOLOGY

Study area

The study site is located in left bank plain of the Amudarya River within “Kulavat” irrigation command area (ICA) of Khorezm, Uzbekistan (Figure 1a and b). It lies between latitude 41°26’ to 41°37’ N and longitude 60°10’ to 60°53’ E. The site covering an area of approximately 42,000 hectares falls within the northern climatic zone (FAO, 2003). According to Köppen-Geiger climate classification map, the site is classified as arid and cold desert climate (BWk; Kottke et al., 2006). With scars and uneven distribution of mean annual precipitation of 94 mm year⁻¹ (Ibrakhimov et al., 2012) and high evaporation rate of 1400-1600 mm year⁻¹ (Kienzler et al., 2011), water from the Amudarya River is main source in practicing irrigated agriculture. Soil in the study site is formed under the influence of water from the meandering Amudarya River (Kats, 1976). Total length of irrigation and collector-drainage network in the study area are 1614 and 1025 km, respectively (Figure 1c) where specific length of in-farm irrigation (63 m/ha) and drainage (32 m/ha) network are denser compared to average values (51 and 25 m/ha, respectively) in the Khorezm province (Djanibekov, 2008; CAWATER info, 2016).

Soil texture and mapping

The soil of the study site consists of rock debris (alluvial deposits), which are fine layered and very deep (FAO,
2003). Soil texture map of the study area at 1:25,000-scale is acquired from Scientific Research Institute of Soil Science and Agrochemistry (SRISSA). The map containing texture information up to 2-3 m is scanned, digitized and geo-referenced in Khorezm Rural Advisory Support Service (KRASS) using georeferencing extension in ArcMap™ 9.2. In this study soil texture at 0-2 m is average weighted in order to create one layer soil texture map.

### Groundwater monitoring wells and GWT depth and salinity mapping

Long-term observations (1990-2004) at a 10-daily basis on GWT and seasonal (April, July, October) basis on GW salinity are obtained from the Khorezm Melioration Expedition (ME) of the Ministry of Agriculture and Water Resources Management (MAWR). The depth of GW is measured by field-staff from the ME using a tapeline with a man-made cylinder (kolpushka) that flaps when it reaches the water surface in the well. The GW salinity of samples are analyzed according to the procedure detailed in standard methods 2520 B by using the hand-held conductivity meter ("IKS – Express T" device; Chernishev, 2007). In total 219 monitoring wells are exist within the Kulavat command area. Although, one observation well has to serve about 100 ha land area according to acting norm (VNIIGiM, 1978), in fact one well serves about 130 ha that may influences on proper assessment of land reclamation condition. Nevertheless, due to availability of data for long-term period, archive data from the MEis used in this study. Spatial distribution of average long-term vegetation period (April-September) GWT and GW salinity are mapped through inverse distance weighting (IDW) method in ArcMap™ environment. Being a deterministic method, in IDW, surfaces are created from measured well data that based on the extent of similarity and value for any unmeasured location (in-between wells) are predicted using the measured values surrounding the prediction location.

### Groundwater contribution

Capillary rise in this study is defined as the volume of water leaving a static water table due to soil evaporation and plant transpiration (ET0) within corresponding soil texture boundary. Hence soil in the study site is correspond to semi-hydromorphic reclamation regime (Dukhovny et al., 1979); following equation proposed by Averyanov (1978) is used in order to estimate evaporation from GWT:

$$E_{gw} = ET_0 \left(1 - \frac{h}{H_{cr}}\right)^n$$  

Where, $E_{gw}$: seasonal groundwater contribution to aeration zone due to soil evaporation and crop transpiration (mm); $ET_0$: potential evapotranspiration during the season considered (mm); $h$: average GWT for the vegetation period (m); $H_{cr}$: critical GWT from which aeration zone GW contribution starts (m); $n$: index that depend on soil capillarity condition (-).

Daily average climate parameters from 1970-2007 are collected from “Urgench” weather station (Table 1). Air temperatures (mean, minimum and maximum), mean relative humidity and wind speed at 2 m height above soil surface are used to estimate $ET_0$ (e.g., “ET0 Calculator”, Raes, 2009) that based on FAO Penman-Monteith method (Allen et al., 1998).

Parameters such as $H_{cr}$ and “n” for Eq. (1) are obtained from (Laktaev, 1978) that are given for light textured soil classes (Table 2).

### RESULTS AND DISCUSSIONS

#### Soil texture

Soil in the site according to USDA soil texture classification is dominated by medium loams (41%) which together with light loams and sands constitute 89% of all soils in the study area (Figure 2). This soil is also dominated in irrigated land of Khorezm province (86%, Akramkhanov et al., 2012).

#### Groundwater table depth and salinity

About 50% of lands in the study area arecovered by shallow GWT depth (0-1.5 m) during the vegetation period (Figure 3a) which is higher than the critical threshold of 1.5 m defined for the Khorezm Region (Khamzina et al., 2008). Such shallow GWT depth may pose a risk for secondary soil salinization in one hand and increase considerably groundwater contribution to ET on other hand (Forkutsa, 2010).

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**Table 1. Climate parameters of “Urgench” weather station, Khorezm (Uzhydromet, 2008)**

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Annual mean</th>
<th>Annual sd1</th>
<th>Annual cv2</th>
<th>Growing period mean</th>
<th>Growing period sd</th>
<th>Growing period cv</th>
<th>Non-growing period mean</th>
<th>Non-growing period sd</th>
<th>Non-growing period cv</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air temperature (°C)</td>
<td>13.1</td>
<td>0.7</td>
<td>5</td>
<td>23.0</td>
<td>0.7</td>
<td>5</td>
<td>3.1</td>
<td>1.4</td>
<td>10</td>
</tr>
<tr>
<td>Relative humidity (%)</td>
<td>58.3</td>
<td>3.3</td>
<td>6</td>
<td>46.4</td>
<td>4.1</td>
<td>7</td>
<td>70.3</td>
<td>3.5</td>
<td>6</td>
</tr>
<tr>
<td>Wind speed (m/s)</td>
<td>3.6</td>
<td>0.2</td>
<td>7</td>
<td>3.6</td>
<td>0.3</td>
<td>8</td>
<td>3.6</td>
<td>0.3</td>
<td>7</td>
</tr>
<tr>
<td>Precipitation (mm)</td>
<td>94.7</td>
<td>34.5</td>
<td>4</td>
<td>33.3</td>
<td>23.3</td>
<td>7</td>
<td>61.3</td>
<td>24.9</td>
<td>4</td>
</tr>
</tbody>
</table>

1 Standard deviation from mean; 2 Coefficient of variation (%)
Table 2. Parameters “n” and “Hcr” for various soil textures used in Eq. (1)(Laktaev, 1978)

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Sandy loam</th>
<th>Light loam</th>
<th>Medium loam</th>
<th>Heavy loam</th>
<th>Clay</th>
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<tbody>
<tr>
<td>Hcr</td>
<td>2</td>
<td>2.5</td>
<td>3</td>
<td>3.5</td>
<td>4</td>
</tr>
<tr>
<td>n</td>
<td>1.5</td>
<td>1.6</td>
<td>1.75</td>
<td>1.9</td>
<td>2</td>
</tr>
</tbody>
</table>

Figure 2: Soil texture map and area by classes (in %)

2006). The latter, however, in long-term perspective may result soil salinization in the irrigated areas, if significant salt exists in the groundwater. Fortunately, 98.7% of total land area in study site has GW salinity ≤ 3 g/l during the vegetation period (Figure 3b).

Groundwater contribution (Egw) to ETo

Calculated total ETo for the vegetation period during 1970-2007 is varied from 1090 to 1340 mm with average value being 1220 mm for that period. The mean value is higher than total water supply in Khorezm province (970 mm) during the period (Yakubov and Gaipnazarov, 2005). Predicted Egw (Figure 4), ranging from 119 (sandy soil in non-irrigated areas) and 205 (sandy loam) to 360 mm (heavy loam soil) under GWT depth of 1.3-1.4 m (long-term vegetation period GWT isaveraged within each soil texture class boundary) is within the range of values reported by Forkutsa (2006). In her study, the Egw is ranged from 115 mm (for sand) and 229 mm (for sandy loam) in Khorezm that has similar environmental condition. Using the same approach, Laktaev (1978) estimated Egw for the northern climatic zone that ranged from 65 mm (sandy loam) to 190 mm (heavy loam) under GWT of 1-2 m. Such low values of Egw in his study can be explained by consideration of reduced irrigation norm (500 mm) used instead ETo. Findings of Babajimopoulos et al. (2007) of 283.8 mm Egw for loamy and heavy loamy soils are also corresponding to the current results. However, their results represent point scale information, and their application is limited to experimental studies.

Based on the results, groundwater evaporation contributed 19-30 and 21-37% of the evapotranspiration (ETo) and water supply during the growing period in irrigated lands. These values are within the range of Yakubov and Gaipnazarov (2005) estimated Egw for Khorezm condition (e.g., 32-44%) as well as Hutmacher et al. (1996) for Fresno County, California condition (e.g., 30-42%).

Conclusions

The GIS software, with available soil and hydrological data (e.g., GWT and salinity) successfully employed to estimate the evaporation rates from shallow groundwater table during the vegetation period. The results suggest that surface irrigation may be reduced as shallow groundwater (< 1.5 m, 50% from total land area) with low salinity (< 3 g/l, 99%) contribute Egw from 205-240 mm (light soils) to 305-360 mm (medium to heavy soil) to the root zone. The presented simulations indicate that classical approach proposed by Averyanov (1978) is able to assess the correct order of magnitude of groundwater contribution (Egw) under various GWT depths and in different soil types that exist in study area. The results can be used to adjust the soil water balance in the root zone and optimize irrigation schedule for similar environmental conditions (weather, soil, hydrology etc.). Further, the method can be applied for
Figure 3: Average GW table depth (a) and salinity (b) during vegetation period (averaged for 1990-2004)

Figure 4: Groundwater evaporation map during the vegetation period (averaged from 1990-2004)
all irrigated lands in Uzbekistan owing availability of regular data on GWT depth and salinity (e.g., ME), soil texture (e.g., SRISSA) and climate (e.g., Uzhydromet).

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Conflict of interests

The authors declare that they have no conflicting interests.

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