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RESEARCH ACTIVITIES TITLED DETERMINING OPTIMUM WATER AND NUTRIENTS LEACHING REQUIREMENTS FOR THE SALINE AREAS OF KHOREZM, UZBEKISTAN

CRP-DS Action site: Aral Sea basin (the Khorezm province, Uzbekistan).

Integrated Land and Water Productivity Improvement in Aral Sea Basin

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Data collection site:	the Khorezm province

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Rationale

Irrational water use and mismanagement are at the root of several environmental problems in the Aral Sea Basin, including secondary salinization. Pre-season leaching (February-March) is a common practice of farmers to manage soil salinity challenges. For example, farmers in the Khorezm region tend applying up to 600 mm of leaching volume to prevent accumulation of salts in the root-zone. However, excessive leaching volume causes the water tables to rise at 1-1.5 m depth which are dangerous depths. These shallow groundwater levels cause secondary soil salinization by capillary rise into the rooting-zone, which nullifies pre-season salt leaching efforts, entails yield losses and seriously threatens economic growth and development. (Grieve et al. 1986; Smets et al. 1997; Willis et al. 1997; Christen et al. 2001; Singh 2004; Murtaza et al. 2006).

Nitrogen (N) plays an important role in crops grown with irrigation. It is important to use an optimum amount of water and nitrogen for the best management of crop production and in the process avoid nitrogen leaching below the root zone (Gheysari et al., 2009; Wang et al., 2010). Hence, excessive irrigation/leaching amounts can reduce the effectiveness of fertilizer applications by leaching them below the root-zone and thereby causing reduction in crop yield. On other hand, reduced leaching amounts can cause secondary soil salinity in root-zone.

This study aims to determine the trade-offs between the amounts of water used for leaching salts to control soil salinity but minimizing nutrient leaching and enhance soil fertility, control water table and increase agricultural water productivity and efficiency.

Introduction

Irrigated agriculture is highly important for the national economy and population livelihoods of Central Asia. However, secondary soil salinization and waterlogging triggered by mismanagement of land and water resources jeopardize the sustainability of crop production. To cope with salinization, leaching of saline soils is regularly conducted throughout the region, which however did not result in the long term desalination of the fields. Moreover, this procedure inevitably involves additional financial costs and use of limited freshwater resources, while its effects on desalination and overall agricultural sustainability is questionable.

Conducted in non-vegetation season, the leaching practice consumes large amounts of water, and also affects shifting of nutrients in the soil root zone. The effects of pre-season leaching practices are not sufficiently studied in conditions of the province or other agricultural areas. To address this issue, this project aims at identifying and evaluating the efficiency and effectiveness of the leaching procedures against environmental and socio-economic impacts. The leaching assessment methodology is provided that describes the site selection based on environmental and management settings, as well as utilizes GIS tools and modeling (HYDRUS-1D).

The methodology consists of several steps. Firstly, the spatial information on the environmental and management factors that influence effectiveness and efficiency of leaching have been collected in the form of thematic GIS layers. Secondly, the areas with similar conditions were delineated into the uniform spatial units or sites. The sites with different characteristics were separately analyzed through modeling. At the same time, representative farms were chosen in the sites for conducting a socio-economic survey. Finally, the results of the modeling were calibrated and validated, as to draw conclusions about the effectiveness and efficiency of the leaching practices.

Study area

This study concentrates in the irrigated agricultural areas of the Khorezm province, Uzbekistan, located in the neighborhood of the Aral Sea (Figure 1). Khorezm is a lowland flat area with elevation varying between 112 and 138 m mean sea level (Kats, 1976). The province, with a total area of 680 thousand ha and arable area of about 270 thousand ha (40 % from total), is located in the lower reach of the Amudarya River in Northwest Uzbekistan (41°41′ N latitude, 39°40′ E longitude). It is the smallest administrative region in the country, which borders the southern edge of the ecologically degraded Aral Sea area and is one of the most problematic areas regarding salinity, irrigation water availability and overall crop performance (Martius et al., 2004).

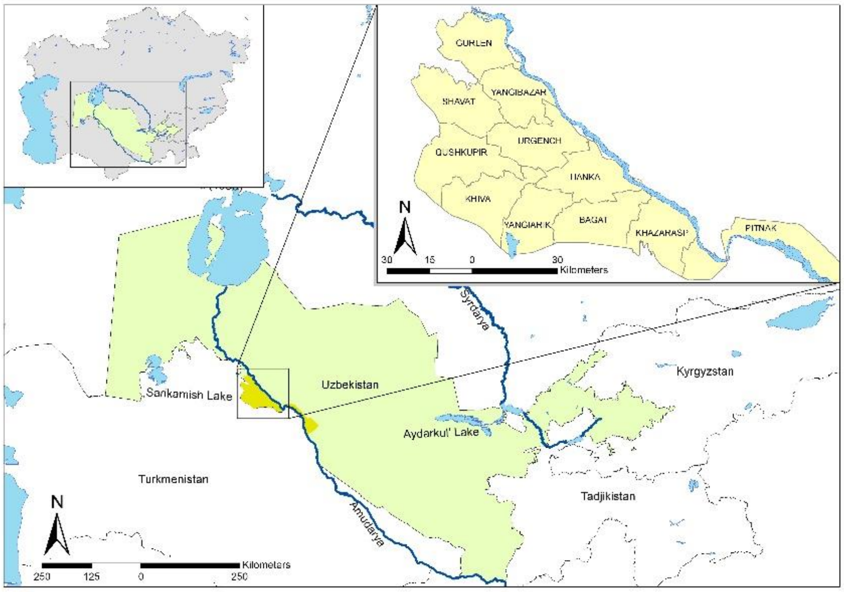


Figure 1. Irrigation and drainage infrastructure of the Khorezm province

Khorezm is surrounded by the Karakum and Kizilkum deserts, which determine the arid sharply continental climate as characterized by hot summers with temperatures rising to +45^{o}C and cold winters with temperatures falling as low as –28^{o}C (Glazirin et al., 1999). The long-term annual average reference evapotranspiration (ET_o) and precipitation for the last 25 years in the Khorezm province are 1,338 and 94 mm, respectively (Figure 2) and thus, agriculture is only possible with irrigation (Conrad et al. 2012).

The agro-ecological conditions render Khorezm suitable for the production of annual, warm-season crops. The main crops produced in the province are cotton (*Gossypium hirsutum L.*) (49 % of total cultivated land); winter wheat (*Triticum aestivum L.*, 21 %); forage crops (12 %); rice (*Oryza sativa L.*, 10 %); and fruits and vegetables (8 %). The irrigation period for all crops except for winter wheat lasts from April till September. Only wheat is irrigated 1 – 2 times before winter in September – October and then from March to June.

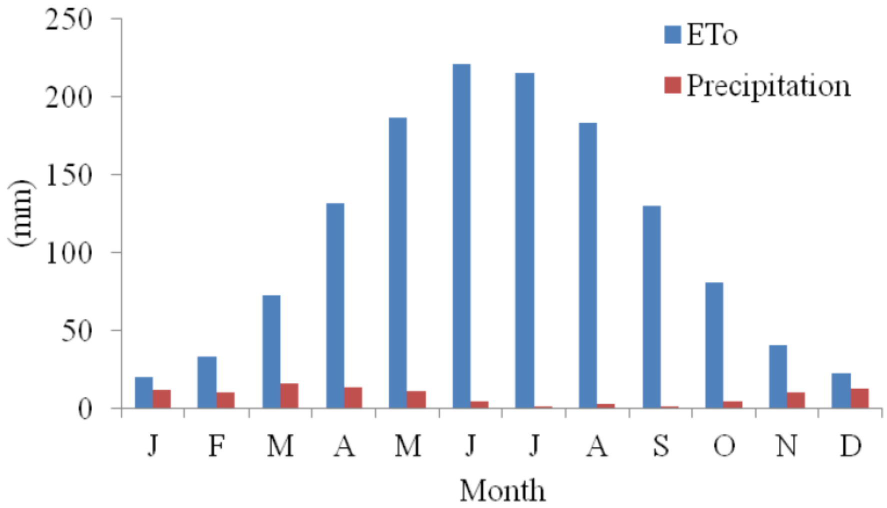


Figure 2. Average monthly reference evapotranspiration and precipitation (means from 1985-2007)

Irrigation and water use

The Amudarya River is the main water source in the Khorezm province. The long term average water intake from the river amounts to ca. 5 km^3 yr^{-1}, although there was a sharp decrease in water supply in dry years 2000 and 2001 (UPRADIK, 2006). Pre-season leaching consumes ca. 25 % of this total supply. The water flow in the Amudarya River increases from March onwards, reaches a maximum in June-July and sometimes August, and decreases until February.

The river water is distributed to the agricultural fields through an irrigation network consisting of *magistral* (conveyance), inter-farm (distribution) and on-farm (supply) canals. Canals conveying water through districts are defined as *magistral*. Inter-farms canals transport water from the *magistral* canals to the boundary of former collective farms and present Water Consumers Associations (WUAs). There, on-farm canals convey water from the inter-farm canals to the field level networks. Water is supplied by on-farm canals using gravity, and in some cases on-farm canal water is pumped into small ditches to facilitate water application to the fields located at more elevated points. The major branches of the irrigation and drainage system are presented in Figure 3.

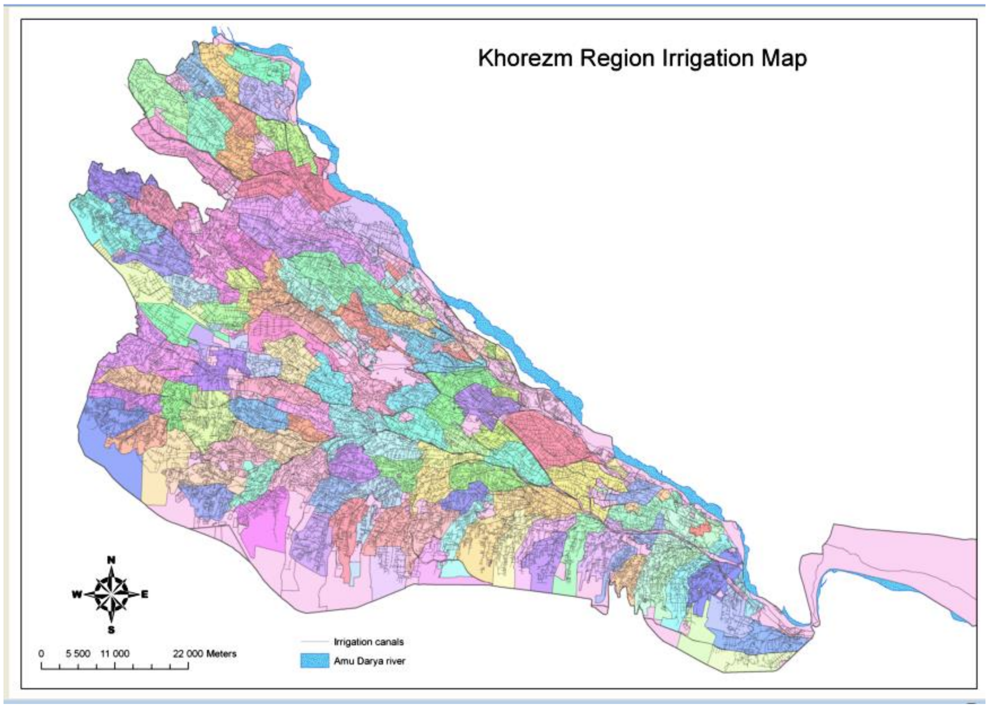


Figure 3. Irrigation and drainage network in Khorezm

Compared to the whole Aral Sea Basin, the Khorezm province, which makes only 3% of the total area, has a comparatively very dense irrigation network (Table 1). Yet, only 11% of these canals are lined (Vodproject, 1999), greatly reducing the amount of water that ultimately reaches agricultural fields. Mostly surface irrigation is practiced that includes 64% furrow, 31% strip and 5% basin irrigation (Abdullaev, 2002).

Table 1. Extension of irrigation and drainage network in the Aral Sea Basin and in Khorezm.

	Aral Sea Basin	Khorezm	(%)
Irrigated area	7.9 M ha	250000 ha	3
Canal length, km			
magistral & inter-farm irrigation	28000	1895	7
On-farm irrigation	168000	14338	9
Total	196000	16233	16
magistral & inter-farm drainage	30000	1305	4
On-farm drainage	107000	6374	6
Total	137000	7679	10

Source: 1:25000 GIS maps (ZEF/UNESCO GIS lab Urgench)

The drainage network is indispensable for controlling groundwater levels and salinity. The network in Khorezm is mainly open horizontal. Drainage water is conveyed via hierarchically constructed collectors from the irrigated fields into numerous small lakes and depressions outside of the irrigated area. The main repository is the Sarykamish Depression, which was formerly connected with the Aral Sea.

Flood and furrow irrigation is the main and most widespread irrigation technique used, which explains the high gross water use of about 20 thousand m^3 ha^{-1} of water (Figure 4) (UPRADIK, 2006).

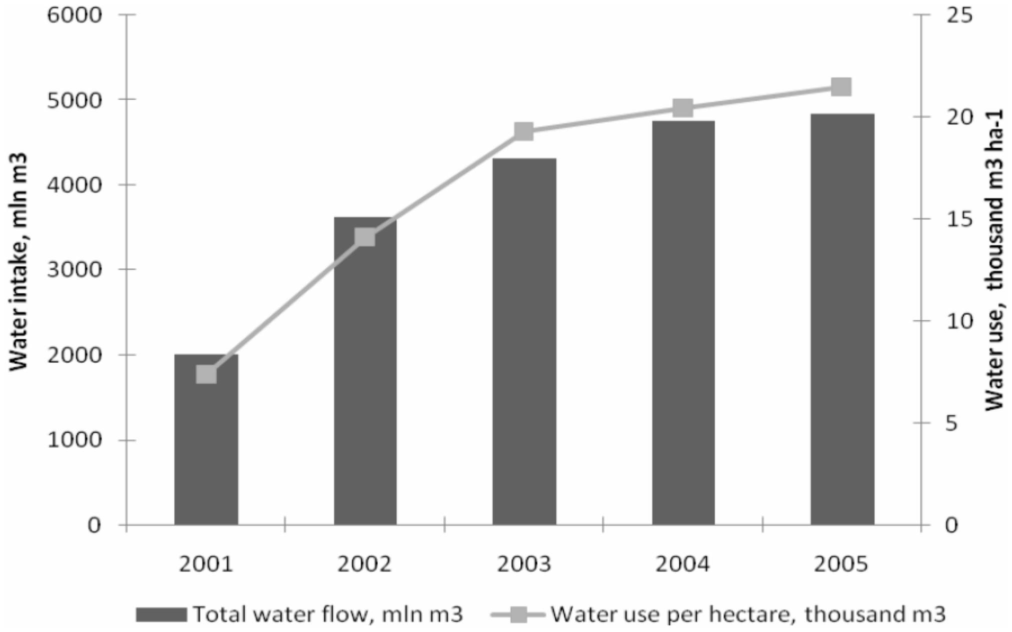


Figure 4. Water intake and water use per hectare in the province during the vegetation and leaching period. Source: UPRADIK, 2006

Land and water management structure

The land and water management reforms in Uzbekistan between 1998 and 2006 resulted in a shift of agricultural production from large-scale shirkats (joint stock enterprises with 2000 ha and more, which had originated from the former Soviet state farms) to small-scale farms of on average 15.6 ha managed by individual farmers (Djanibekov, 2006). To supply farmers with irrigation water, water users' associations (WUAs) have been established that operate on the scale of the former shirkats. The agricultural production, land and water resources are largely state-controlled; farmers have to meet production targets while receiving the inputs for free or at low cost. This more likely represents subsidization than taxation of the farmer, and adhering to it is often a risk-minimizing strategy (Muller, 2006; Rudenko and Lamers, 2006). The present state order for cotton covers 50% of the irrigated areas and for winter wheat about 30% (Djanibekov, 2006).

Before 2005, agricultural production in Khorezm was undertaken by *shirkats*, the large scale state farms, private farms and *dehqans*, the rural households. Since 2005-2006, however, in the framework of privatization in agriculture, the *shirkats* were abolished and more private farms were established in their place. Thus, the private farms have become the main agricultural producers throughout the province with about 196 thousand ha (OblStat, 2005) in their jurisdiction. Private farms grow cotton and wheat, the two state target crops. *Dehqans* possess and cultivate the remaining share of arable land; they are free from any state orders and produce the most fruits and vegetables in the province.

Soil quality classification (bonitet)

The potential of the land for crop cultivation has been assessed through the Soviet system of land fertility appraisal, so-called soil *bonitet* (Figure 5). This system ranks land quality of particular soils on a 100-point scale depending on parameters such as groundwater depth, salinity levels, soil organic matter (SOM) and gypsum content in the soil (Soil Science Institute 1989, FAO 2003). It allows determining production goals imposed by the state on the strategic crops cotton and wheat. Every score point equals a yield capacity of 0.04 t ha^{-1}, so that soils with a bonitet of 100 points are assumed to yield 4 t ha^{-1} cotton (FAO 2003). The official soil bonitet, however, often differs from the achievable harvest due to biases that influence the calculations for the yields that have to be handed to the government (Müller 2006b). According to the bonitet for the Khorezm province, some 1 5-20 % of the soils are classified as marginal, i.e., unsuitable for cropping (Abdullaev, 2002; Martius et al., 2004).

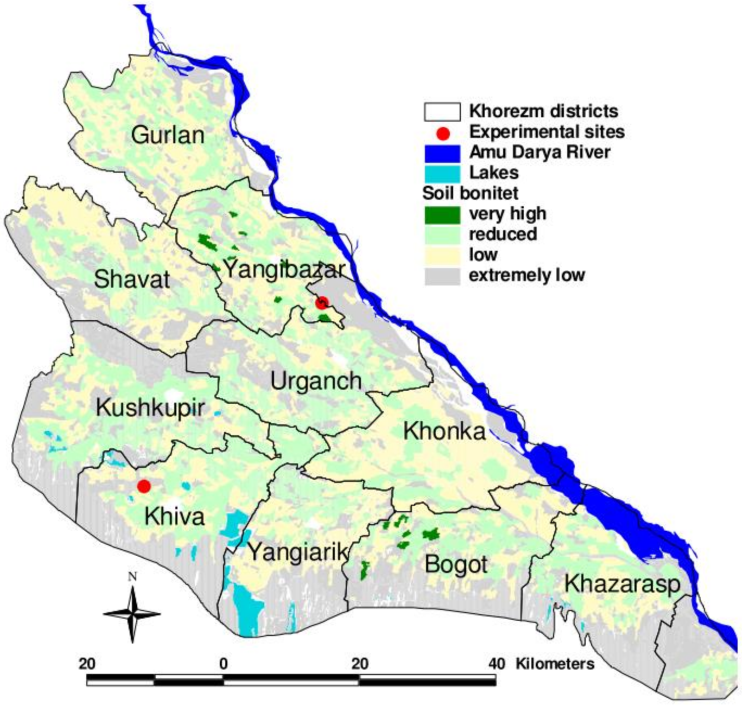


Figure 5. Soil quality appraisal system (bonitet) for agricultural crop cultivation.
(Source: Goskomzem - Soil and Agrochemistry Research Institute)

Hydromodule zoning for estimating irrigation volumes (norms)

Crop water demand is estimated by geographic location and is determined by the hydromodule zone of the area; this method was established during the Soviet period and is still used by water management organizations for planning water supply schedules. Climate, soil texture over the soil profile and groundwater level is taken into account for identifying crop water requirements in flood and furrow irrigation techniques. Since climate is considered homogenous throughout the Khorezm province, soil texture and groundwater levels are the main parameters determining crop water requirements in the existing nine different hydromodule zones.

Depending on soil texture, the hydromodule zone ranges between I and III in areas with groundwater levels deeper than three meters, hydromodule zones IV - VI belong to the areas where groundwater ranges between two and three meters. Hydromodule zones VII - IX belong to shallow groundwater tables, where groundwater is in the range of one to two meters. Because of the shallow groundwater tables, the last three hydromodule zones predominate in the Khorezm province (SAYUzNihi, 1992; Agroprom, 2005b, Table 2).

Table 2. Hydromodule zones

Hydromodule zone	Soil characteristics
VII	Thick sandy and sandy loamy layers
VIII	Light and medium loamy, heavy loamy with light texture in deeper layers
IX	Heavy loamy, clay compacted soil, heterogeneous soil layers

Source: Sayuznihi, 1992

The recommended water application norms for the hydromodule zone VII is lower compared to the others owing to the loamy soil texture, and higher for sandy loamy and clay soils (Table 3). These norms are supposed to be updated regularly, but the last update occurred 15 years ago (AgroProm, 2005b). Nevertheless, the water use norms are widely employed by WUAs and other water management organizations to plan water delivery to secondary water users.

Table 3. Water application norms in different hydromodule zones, m^3 ha^{-1}

Hydromodule zones	Cotton	Maize	Vegetables	Melons	Winter wheat	Other crops	Rice
VII	6400	6200	10500	4500	5600	5900	30000
VIII	4900	4600	8400	3500	4700	5200	35000
IX	5300	4900	9600	3800	5000	5700	40000

Source: AgroProm, 2005a

Relief, geomorphology, hydrogeology and soils

Formation of the soil lithological profile in Khorezm was chiefly influenced by the meandering Amudarya River, which carried and deposited sediments along its banks and in depressions (Nurmanov, 1966). According to Fayzullaev (1980), alluvial deposits along the meanders mostly consist of sand, while depressions are mainly filled with loam and clay. Subsequently, soils originating from these alluvial deposits are heterogeneously stratified and, within the area currently used for agriculture, dominated by clayey, loamy and sandy-loamy textures (Nurmanov, 1966).

According to the FAO classification, four soil types can be identified within Khorezm: mostly aridic and gleyic calcaric (sodic) Arenosols and calcaric Cambisols, while gleyic humus Fluvisols are commonly found along the Amudarya River (SAE, 2001). Organic matter in these soils ranges from 0.7 to 1.5 g 100 g^{-1}, while the cation exchange capacity varies between 5-10 cmol (+) kg^{-1}. Total nitrogen (N) and phosphorus (P) contents in Khorezm soil types are also low, usually ranging between

0.07-0.15 % and 0.10-0.18 %, respectively. Available potassium (K) content is classified as low or moderate (Fayzullaev, 1980). Consequently, the natural fertility of the soils in Khorezm is characterized as rather low, and cultivation of most agricultural crops requires high inputs of chemical fertilizers.

The relief of the Khorezm province is mostly flat with insignificant slopes. Slow lateral groundwater flow, averaging 19-26 mm yr^{-1} (Kats, 1976), as well as prevailing heavy soil textures and climate aridity restrict groundwater outflow and increase evaporative losses. These adverse natural drainage conditions, aggravated by excessive irrigation and poorly maintained drainage systems, often result in elevated groundwater levels. Moderate and highly saline soils are mostly concentrated in the Khazarasp (86%), Koshkupyr (77%), and Yangibazar (51%) districts. In the other districts, such soils are found on about 32% of the irrigated land (MMTU, 1997).

Typically, groundwater tables may rise up to 1.2-1.4 m during the growing period, March to August, and fall in October down to about 1.8 m. Despite the shallow levels of the groundwater levels in Khorezm, groundwater use for irrigation is limited due to the high energy expenses required for pumping in conditions of extremely slow lateral subsurface water movement (Katz, 1976). Another important reason restricting the utilization of groundwater is its salinity level, mostly inappropriate for crops.

During 1988-2001, the land area of Khorezm with groundwater levels shallower than 2.0 m averaged 84 %, while areas with elevated groundwater salinity of 3-10 g l^{-1} averaged about 10 % of the total irrigated area (MAWR, 2001). Such conditions require continuous operation of a well functioning artificial drainage system (Mukhammadiev, 1982). However, given the shallow groundwater table and increasing land salinization in Khorezm it can be concluded that the current draining and carrying function of the irrigation and drainage network is unsatisfactory (Ibrakhimov, 2005).

Leaching requirements and actual water applications

Leaching water, defined as water volume applied to the surface of the agricultural fields to generate a downward flow that washes away the accumulated salts during the vegetation season, is usually applied before the start of that season. Depending on the level of soil salinity and water availability, it is locally recommended to apply between 1500 and 6000 m^3 $ha\text{-}^{1}$ of water during one to three leaching events. The last leaching is usually applied between the last week of March and the second week of April. The purpose of the last leaching by farmers is concurrently to refill soil moisture to field capacity, and can thus be considered as a pre-sowing irrigation. However, there are no separate recommendations for the pre-sowing leaching.

In the Khorezm province, leaching is a consumer of ca. 25–30 % of the annual agricultural water consumption. According to Conrad (2006), vast amounts (around 1 km^3) of freshwater for leaching are annually supplied from the Tuyamuyun water reservoir, located at the south-eastern border of the Khorezm irrigation and drainage system, but despite all efforts, soil salinity has increased over the years (Nasonov, 2007). This low leaching efficiency in turn demands that still larger amounts of water are provided for leaching (Forkutsa et al., 2009). Soil salinisation in Khorezm is primarily a consequence of the shallow saline groundwater (Ikramov, 2001): regional average groundwater tables range around 1.0–1.2 m below the surface during most of the leaching and irrigation period (Ibrakhimov et al., 2007). It is postulated that the groundwater table becomes shallow due to substantial losses from the irrigation network, which is enhanced by the flat terrain and subsequent absence of any regional lateral groundwater flow (Kats, 1976).

Farmer's practices of cotton farming

Cotton farming is basically the same across the region, despite the size of the cotton growing private farms. Preparation of soil in the traditional farm practice in Khorezm includes leaching; levelling, including capital levelling on the average once in three years; ploughing, chiselling, and seed bed preparation. Cotton farming activities start as early as January with preparation of soil for the following vegetation season. Soil preparation activities constitute 10.3 % of the fixed state price for raw cotton paid to the farmers, including 2.2 % for leaching and 8.1 % for levelling, ploughing, chiseling. Each cotton farming activity has associated costs, be it machinery costs for mechanized activities, such as levelling, planting or labour costs for manual cotton farming activities, such as thinning, pesticide application; or input costs, such as seeds, fertilizers, fuel, pesticides.

Leaching accounts for about 40 % of the total irrigated water volume used in cotton growing (or ca. 4000 m^3 of total 8600 m^3 ha^{-1}). Most of the cotton grown in the country relies on irrigated agriculture where, depending on the availability of water, in June-August farmers irrigate 2 – 6 times per vegetation season. Irrigation costs in the given cotton value chain are taken into account in the form of pumping costs and costs of maintaining the irrigation and drainage channels, as well as Water Users Association (WUA) fees; these non-market values can be used as there is currently no price for water in Uzbekistan.

Planting activities take place in April-early May. Generally, sowing rates lie in the range of 30 to 90 kg of cottonseed per ha, with the average, most frequently applied rate of 70 kg ha^{-1} depending on the quality of cottonseed and weather conditions. Overall, planting accounts for 5.4 % of the fixed state price for raw cotton, including 4.3 % of cottonseed cost and 1.1 % of mechanized planting activities. Farmers get instructions on what cotton variety to plant and thus are supplied with the predetermined cottonseeds usually by the ginneries, which in part are responsible for preparing the cottonseed fund in the region. Most of the time cottonseed provided by the ginneries meets the requirements of farmers in terms of planting material, however, some farmers reported on shortage or poor quality of cottonseed and absence or irregular operation of alternative seed sources, such as commodity exchange or market place. Therefore, in case of additional need in cottonseed, farmers usually resort to the neighboring farmers growing cotton.

Fertilization in traditional cotton farming of Khorezm takes an important part with rather high application rates of various fertilizer types. Fertilizer application is mechanized and carried out 2-4 times in May – August. Fertilization together with cultivation contributes 24.4 % to the raw cotton value chain, where fertilizers cost share is 20.2 % and fertilizer application activity share is 4.2 percent. Fertilizers as used by Uzbek farmers seemed not to be of best or reasonable quality (Kienzler et al., 2007) compared to the international quality standards. Certain types of fertilizers were priced higher in Uzbekistan compared to the world market prices and also were hard to purchase.

Wheat farming

Cultivation of wheat in Khorezm, as well as other crops in general, is based on irrigated agriculture and usually on the conventional agricultural practices. In the Khorezm province, mainly winter wheat is grown in order to use agricultural lands after wheat harvest for other crops, which require short vegetation season (such like some vegetables or rice). Wheat farming basically can be broken into 10 categories of activities: soil leaching, soil preparation (levelling, chiselling), seeding, pesticide application, cultivation, fertilizer application, weeding, irrigation, harvesting and pre-treatment and transportation to the mills.

Average officially reported wheat yield in Khorezm in 2005 was about 4.3 t ha^{-1}, but the average wheat yield of the surveyed farmers was about 3.6 t ha^{-1}. The principal cost components include (1) planting activities – 22.8 and 11.4 % of the state procurement and market price for wheat, respectively; fertilizer application – 41.9 and 20.9 % and harvesting, which absorbs about 11 % of the state procurement price or 5.4 % of market price for wheat. In general, wheat farming practices from planting to harvesting are mechanized and require little manual labour, which accounted for 6.2 % in case of the state quota wheat or 3.1 % in case of wheat free from state order. Direct inputs other than manual labour are the main cost items.

Winter wheat can grow in moderately saline soil conditions if the irrigation water salinity level (EC_w) does not exceed 4.0 dS m^{-1} during germination (Ayers and Westcot 1985, FAO 2008). At salinity levels in the soil of 6.0 dS m^{-1}, yield decreases are still negligible; however, 50 % of the yield will be lost due to salinity at levels of 13.0 dS m^{-1} (Ayers and Westcot 1985)

The length of the vegetation period for winter wheat is 180-250 days (FAO 2008). It is commonly planted in September and harvested in June. The Krasnodarian winter wheat cultivar Kupava is the most common variety in the region at present and covers 43 % of the area (FAO 2001). It is mainly used as bread wheat. Average height is 90-100 cm.

For Soviet wheat, the FAO (2008) recommends "high yield with one full irrigation and one to four spring irrigations with soil water depletion in the top 1 m soil depth not exceeding 70 % of the total available water". The official Uzbek recommendations for irrigating winter wheat range from 250-450 mm for the growth season depending on the groundwater level (Mansurov et al. 2008). The FAO (2008), on the other hand, assumes water requirements of 450-600 mm for optimal yields depending on the environment.

Fruits and vegetables farming

As in the case with cotton and wheat, fruits and vegetables in Khorezm have to be grown on the leached soil, which takes place in February-March. In March-April the soil is prepared for the upcoming vegetation season: chiselled, ploughed and loosening (Table 4).

Soil mechanical preparation is followed by pesticide application (except for vegetables) in May and fertilization in the period of March-September, depending on the vegetable variety. In case of fruits and grapes the existing plants are taken care of and maintained – fruit trees and grape plant are punched (in late autumn) and lime-washed. Fruits and grapes depending on variety are harvested starting from June until October. However, early fruits, imported from the neighboring regions can be found in the markets in spring, and for some fruits (apples for example) all year round. In case of vegetable growing, which are mainly annual crops, planting takes place in April-May. Planting is followed by thinning sometime in June. Vegetables are harvested in August-October mainly. Vegetables from the green houses appear on sale much earlier, starting late spring, however early vegetables are usually imported from other parts of Uzbekistan. Vegetable fields and gardens are irrigated several times throughout the vegetation season from April to September.

Table 4 Farming activities for fruits, vegetables and grapes in Khorezm

	Farming Activity	Fruits	Date (month)	Vegetables	Date (month)	Grapes	Date (month)
1	Soil leaching	X	02 – 03	X	03	X	02 – 03
2	Soil preparation	X	03 – 04	X	04	X	03
3	Punching	X	10			X	11
4	Pesticide application	X	05			X	05 – 07
5	Whitewashing	X	02 – 03			X	02 – 03
6	Fertilizer application	X	03 – 05	X	05 – 06	X	06 – 09
7	Planting			X	04 – 05		
8	Thinning			X	06		
9	Irrigation	X	04 – 09	X	05 – 08	X	06 – 09
10	Harvesting	X	06 – 10	X	08 – 11	X	10

Fertilizer application

Available nitrogen in the soil ranges between 0.07 - 0.09%, and 1.01-1.34% humus on average is available in the soils, and is evidence of the very low natural fertility of Khorezm soils (MAWR, 1999). Sufficient supply of nitrogen (N) to crops is essential to improve quality and sustain yields. In the irrigated areas of Uzbekistan, however, the efficiency of N- fertilizer use in cotton and wheat production is low, as N is frequently lost to the environment via denitrification or leaching (Ibragimov 2007, Scheer et al. 2008c). Due to heavy input subsidies during Soviet times, excessive use of fertilizers was common (Wegren 1989, Herrfahrdt 2004), and state and cooperative farms had little incentives to use fertilizers efficiently, pay attention to losses to the environment, or consider the cost-effectiveness of input management. Similarly, most fertility research before independence aimed at maximizing production rather than at promoting sustainable fertilizer use or improving the quality of cotton fiber or wheat flour.

Following the land reforms, Uzbek farmers remedy soil N deficiencies by applying the N fertilizers they can afford, which often differs from the N-fertilizer amounts recommended by Uzbek research institutions (WARMAP and EC-IFAS 1998, Djanibekov 2005). The constant mismatch between the N applied and removal of N with the harvested products will, however, eventually affect crop yield and quality due to the decline in soil fertility. In fact, declining cotton yields in Uzbekistan have already been reported (e.g., Herrfahrdt 2004), although the reasons for this trend are not fully understood. Given the on-going economic and agronomic changes in crop production in Uzbekistan, the N-fertilizer recommendations for irrigated cotton and wheat production need to be updated to meet the expectations of producers, minimize losses to the environment and improve or sustainably maintain soil fertility.

Environmental and management factors influencing leaching efficiency

Several environmental and management factors influencing leaching process include: soil texture, fertility and salinity, hydrogeology (groundwater table and salinity), climatic parameters to estimate evapotranspiration, cropping patterns. These factors are briefly described below:

Soil texture. Soil texture and its spatial and vertical heterogeneity may greatly influence soil hydraulic properties such as water permeability and conductivity, water holding capacity and air entry pressure value (Wösten et al. 2001) thus influencing the distribution of moisture and solutes in the soil profile. It is a major factor influencing groundwater recharge and capillary rise (Scanlon et al. 2006). Accumulation of salts within the root zone is highly influenced by both the evaporation demand and the height of capillary water rise, which in turn are controlled by soil texture and layers of differently textured soils, and groundwater depth and salinity (Li et al, 2013). Salt transport to the soil surface is mainly attributed to convection due to upward water movement in response to evapotranspiration, diffusion due to a salinity gradient with depth, and restricted drainage flow caused by the flow barrier effect (Kessler et al. 2010). Improved understanding of the effects of soil texture on evaporation, salt migration, and water and salt distribution in the presence of a water table will help address soil water dynamics and hence, crop water needs. Therefore, it is of great importance for agricultural, environmental, and geo-engineering applications such as land reclamation and estimation of crop water demand. Figure 6 shows the soil texture in Khorezm

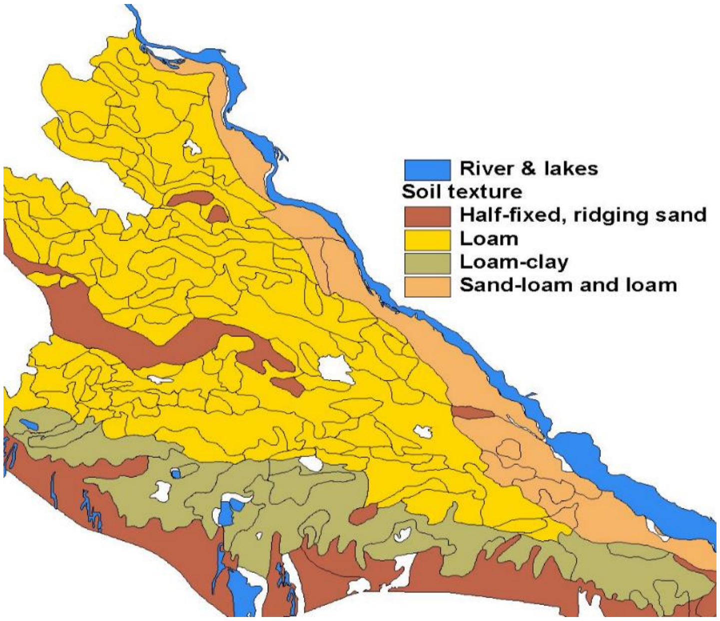


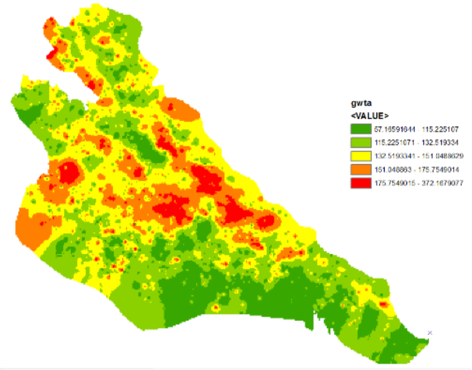
Figure 6. Soil texture in Khorezm

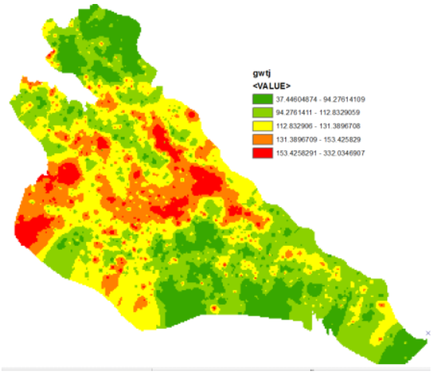
Groundwater depth and salinity. Evaporation process is the driving force that moves water and salts upward and extends the impact of groundwater within the root zone. During this process, the soil near the water table becomes saturated and with rising groundwater tables, the capillary front, dependent on soil texture, will rise close to the soil surface (Lehmann et al, 2008, Shokri and Salvucci, 2011). Evaporation capillary front is a term describing the textural influence on soil water and salt dynamics, and may vary widely in soils with different texture and hence, hydraulic properties (Shokri and Salvucci, 2011).

In areas with shallow groundwater tables, soil moisture contribution into the root zone of agricultural crops from groundwater can be significant and continuous (Chen and Hu, 2004). Finer-textured soils have higher capillary rise and hence, evaporation rates; consequently, with increasing distance from surface, the soil water content will gradually decrease at the upper limit of the capillary rise (Hillel, 2000). Consequently, the distribution of soil solutes in the profile is also affected because they usually transport with soil water. Frequently, such contribution of groundwater to soil moisture supply is neglected (Chen and Hu, 2004) or accounted for only statically, without spatio-temporal variations (XX).

The groundwater depth under which no significant evaporation could be detected is related to the properties of the capillary pressure-desaturation curve, and the accurate measurement of the soil hydraulic properties is important for determining the maximum evaporation rate (Wilson 1990). In sandy soils with an average particle size of 0.53 mm, the evaporation of less than 10% of an open water surface occurred under groundwater depth of ca. 60 cm ((Hellwig 1973). Two main factors affecting evaporation process within the soil profile are climate and soil properties, determining the retention curve (Wilson 1990). Close hydraulic connections between unsaturated and saturated soil horizons were observed with soil texture variations from clay to sand for groundwater levels within 0.5 m of the soil surface; nearly all evapotranspiration occurred from groundwater (Shah et al. 2007). Kahloun et al (2005) analyzed the effect of groundwater on crop yields in a 10-year lysimeter study and concluded that the contribution of groundwater in meeting the crop water requirements varied with the water-table depth, with the value of 1.5 – 2 m to be the most optimum in terms of crop water demand.

With a shallow water table, the groundwater may reach the soil surface through upward capillary water flow, which would maintain effective hydraulic connection in the soil profile above the water table. In this situation, groundwater can reach and be evaporated at the soil surface at a relatively high rate, which can bring salts up from deeper soil horizons (Nulsen 1981; Rasheed et al. 1989; Jalili et al. 2011). Once there is intense upward water flow, the risk of salinization at the soil surface will increase, even if the salt content in groundwater is low and there is no saline layer in the profile. Figures 7 and 8 show average groundwater table and salinity in the province.





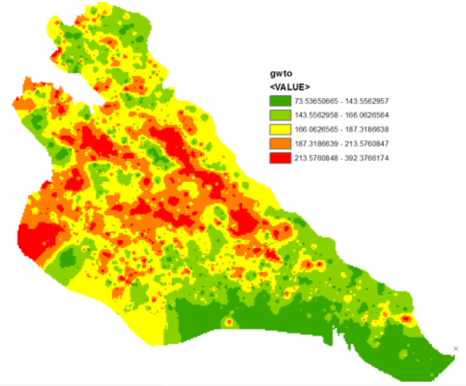


Figure 7. Average groundwater table in the Khorezm province

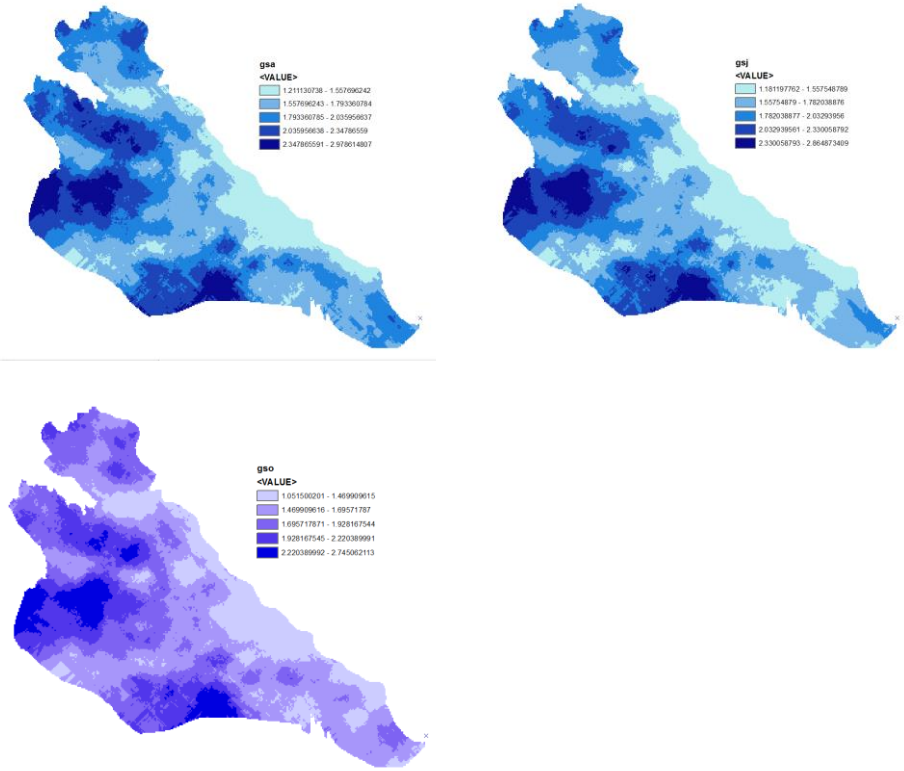


Figure 8. Average groundwater salinity in the Khorezm province

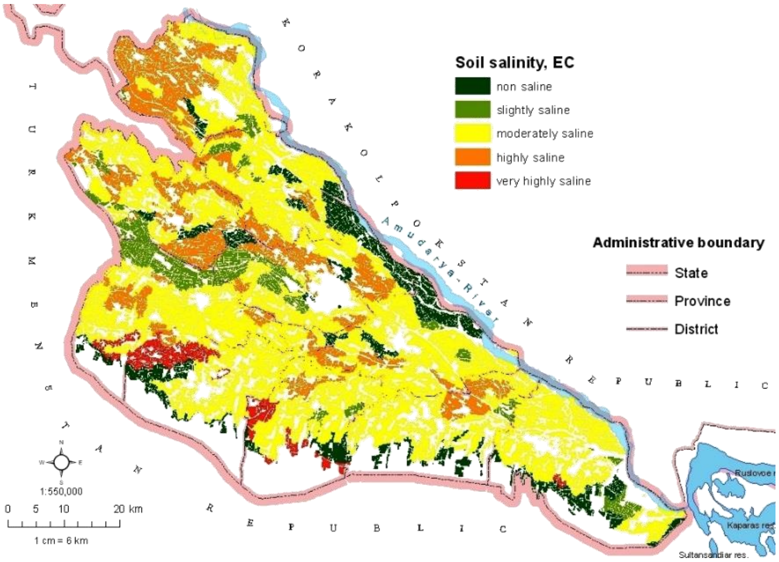


Figure 9. Soil salinity in the Khorezm province

Source: ZEF/UNESCO GIS lab Urgench

Delineation of the agricultural areas into different Irrigation Response Units (IRU)

The effects of leaching can be assumed similar in the environmental settings sharing uniform properties, e.g., in soils with the same texture and structure, similar groundwater tables and salinity, cropping patterns, etc. Consequently, the areas with the different environmental and management conditions require individual modeling efforts. Therefore, the total agricultural area of the Khorezm province was segregated into the units with similar properties. For this, the following environmental and management factors were processed into the GIS environment: soil texture, soil bonitet, groundwater table and salinity (Figure 10). Cropping patterns are not freely available, but work is going on to estimate them utilizing freely available satellite images and ground truthing.

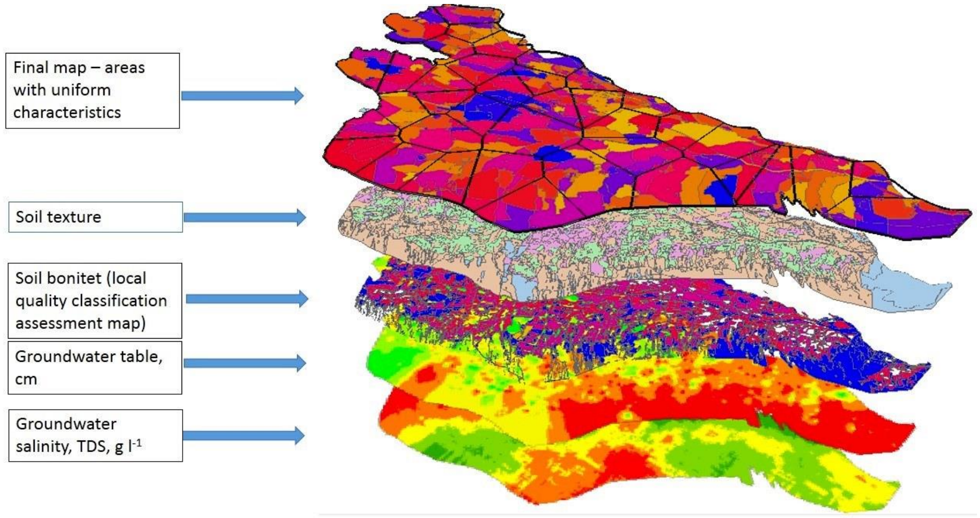


Figure 10. Procedure to segregate the total agricultural area of the Khorezm province into the Irrigation Response Units using environmental and management factors.
Source of the maps: ZEF/UNESCO GIS lab Urgench

Modeling in the HYDRUS-1D environment

HYDRUS-1D is a software package for simulating water, heat and solute movement in one-dimensional variably saturated media. The model computer program numerically solves the Richards' equation for saturated–unsaturated water flow, dual-porosity type flow and dual-permeability type flow, while advection- and dispersion-type equations are used for heat and solute transport.

Richards' equation is a fundamental equation used in the HYDRUS-1D model for calculating the water flow. HYDRUS-1D provides the codes for different sub-models and equations to calculate the unknown in the Richards' equation. The one-dimensional Richards' equation simulates water movement in variably saturated media assuming that the air phase plays an insignificant role in the liquid flow process and that water flow due to thermal gradients can be neglected (Simunek et al. 2005). It is described as follows:

$$\frac{\partial\theta}{\partial t} = \frac{\partial}{\partial x}\left[K\left(\frac{\partial h}{\partial x} + \cos\alpha\right)\right] - S \quad \text{Eq. 1}$$

where h is water pressure head, cm, θ is volumetric water content (cm cm^{-1}), t is time, days, x is spatial coordinate, cm (positive upward), S is sink term, $\text{cm}^3\ \text{cm}^{-3}\ \text{day}^{-1}$, α is angle between flow direction and the vertical axis ($\alpha = 0°$ for vertical flow, 90° for horizontal flow) and K is unsaturated hydraulic conductivity function, cm day^{-1}.

For the influence of soil water and solute stress on transpiration (root water uptake), Hydrus requires potential evaporation (top boundary) and transpiration (sink term in the Richards equation) as separate inputs in time steps which can be either per day, hour, or minute. Daily time steps were used. The top boundary conditions are additionally defined by irrigation and precipitation. Here in correspondence with field conditions, ‘‘ponding’’, i.e., water building up on the soil surface, was allowed to take place. The bottom boundary conditions were governed by shallow groundwater, and thus measured groundwater table depths were used to describe the bottom boundary of the soil profile. Groundwater depths were linearly interpolated to obtain daily model inputs.

Dual approach to estimate crop evapotranspiration

The evaporation and the potential transpiration rates were determined by the dual crop coefficient approach based on the FAO-56 Penman–Monteith equation (Allen et al. 1998). In this approach, the effects of crop transpiration and soil evaporation are determined separately. Two coefficients, i.e., the basal crop coefficient (K_{cb}) to describe plant transpiration and the soil water evaporation coefficient (K_e) to describe evaporation from the soil surface were determined using the Excel spreadsheet of Allen et al. (1998).

The potential evaporation (E_p) and transpiration (T_p) rates then were determined by multiplying the reference evapotranspiration (ET_o) with the corresponding coefficients. Reference evapotranspiration was estimated by using the climatic parameters. The climatic parameters, such as relative humidity, minimum and maximum air temperature, wind speed and solar radiation were used to calculate the reference evapotranspiration (ET_o).

$$E_p = K_{cb} \text{ x } ET_0 \qquad \text{Eq. 2}$$

Where K_{cb} is a basal crop coefficient.

$$T_p = K_{cb} \text{ x } ET_0 \qquad \text{Eq. 3}$$

where K_e is soil water evaporation coefficient. The final crop-specific evapotranspiration (ET_c) equation is as follows:

$$ET_c = (K_{cb} + K_e) \text{ x } ET_0 \qquad \text{Eq. 4}$$

For the lower boundary condition, the averaged groundwater levels for each HRU collected on a 5- to 10-day basis were linearly interpolated to obtain daily model inputs. The groundwater levels are classified as shallow, medium and deep. The detail of this classification is explained in Awan et al. (2013).

The transformation of ETa into the evaporation and transpiration is shown in Figure 11.

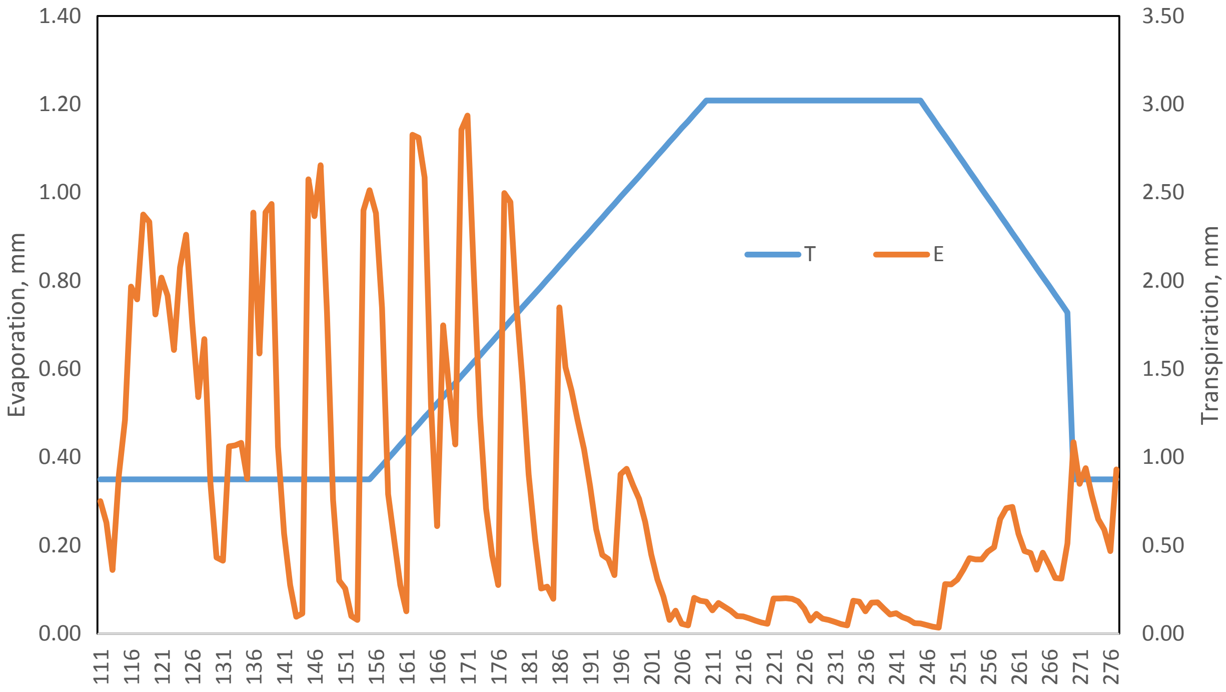


Figure 11. Evaporation and transpiration of cotton fields in the Khorezm province

Average annual groundwater table has a typical pattern shown in Figure 12.

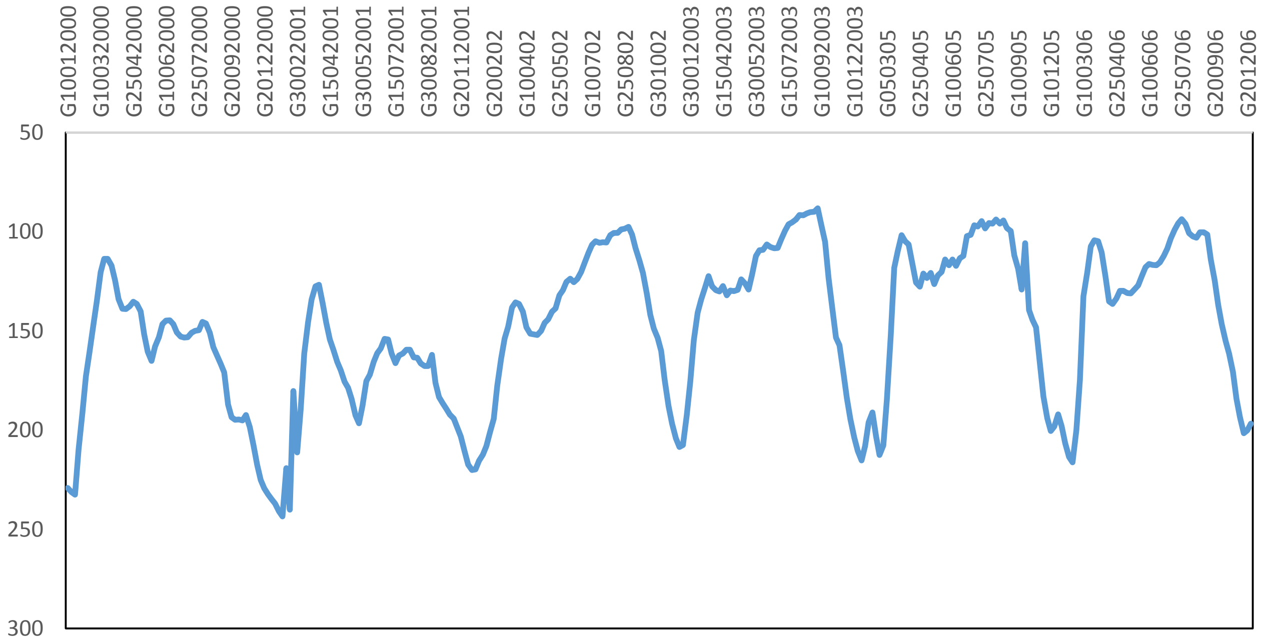


Figure 12. Long term average monthly groundwater table during the period from 2000 till 2006

Next steps

1. Identify farmers irrigation and leaching practices for major crops e.g., cotton, wheat, barley, maize and vegetables
2. Identify water ample, water scarce and average water available years and their probability for Khorezm. This information will be collected from the water supply data to Khorezm during last ten years
3. Collection of required data for whole Khorezm for the parameters which will influence the water and nitrates leaching e.g., soil texture, soil salinity, groundwater level, groundwater salinity, crop pattern, climate parameters, soil fertility)
4. Creating a matrix based on the data collected in 3 for entire Khorezm region(GIS mapping and matrix development)
5. Use of HYDRUS-1D model for simulating soil moisture, soil salinity and soil fertility at different depths and eventually optimized water and nutrients leaching
6. Sensitivity analysis for each parameters effecting the profitability of agriculture
7. Develop guidelines documents and software for calculating optimum water leaching and nutrients amounts for Khorezm basin. Organize a workshop in sharing the results with the local stakeholders.