REVITALIZATION OF CANAL IRRIGATION IN CENTRAL ASIA

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Abstract
Since 2000, the Governments of Central Asian states have been taking several actions to improve water distribution and increase agricultural productivity on the irrigated lands in the Syrdarya River midstream, including Syrdarya province of Uzbekistan, Zafarabad district of Tajikistan and Makhtaral Irrigation Project (MIP) in Kazakhstan. Several projects were implemented in the MIP area using loans from WB, ADB and the state budget to rehabilitate canals, clean drainage and collector systems and install drainage wells. However, despite these actions the gains were not clear: yield of cotton, the main crop in the study area, remained low, being on average around 2 t/ha. The three periods were distinguished: (a) 2000-2003, theperiod before interventions; (b) 2004-2007, projects implementation period; and (c) 2008-2011, post-intervention period. The studies clearly showedthe areas with the vegetation improvement and continuous degradation. The results of the studies could be used by policy makers to specify further activities within improving water management plan in the MIP or similar areas. The evaluation of the impact of interventions was conducted with help of RS/GIS analyses. For this purpose long-term Landsat satellite images were used. Field studies were initiated at two sites: from July 2013 subsurface evaporation basin studies were initiated at Novbahor farm, Bayaut district and Licorice studies from September 2013 in Galaba farm, Bayaut district of Uzbekistan. Licorice demo site was also established in Nukus district of Karakalpakistan.

Key words: Syrdarya River, rehabilitate canals, drainage, Meteorological measurements, salinity soils, ground water.

Introduction

Agricultural sector is a backbone of the national economies in the Central Asian countries (CAC) and a source of income for ca. 60% of the population. Irrigation enables obtaining higher yields and is practiced in 7.9 million ha in CAC. However, mismanagement of the land and water resources causes extensive land degradation in the form of salinization and waterlogging, which in turn reduces land productivity and jeopardizes livelihoods of farmers and rural population involved in agricultural activities. Currently, ca. 30% of the irrigated areas in Central Asia are affected by salinization and waterlogging. In Uzbekistan, ca. 50% of the irrigated lands are subject to salinization to a different degree. After the breakdown of the Soviet Union, investments into the agricultural sector have reduced significantly, which induced further degradation.

The Aral Sea basin is dominated by two main rivers, the Amu Darya and Syr Darya that discharge into the Aral Sea. The potential annual inflow of these two rivers into the Sea amounts to 109 km^3, however in recent years the inflow has declined to a mere trickle because of large-scale irrigation withdrawals (Cai et al., 2003). In the 1960's the Aral Sea was the worlds fourth largest inland lake, by the early 1990's the sea had shrunk to approximately half its size and was three times more saline (Micklin, 1993). This has had a significant impact on the livelihoods of 35 million people who depended directly on the Aral Sea for goods and services.

Waterlogging of soil root zone occurs because of over-application of water by traditionally widely used furrow and basin irrigation methods and seepage losses from the earthen irrigation networks. In natural topographic depression areas and areas with slow lateral groundwater (GW) flow, the GW reaches critical levels and contributes to reappearance of salts in the soil root zone. To cope with salinization and waterlogging, extensive drainage networks have been constructed to maintain favorable soil moisture-salinity balances, while pre-season leaching of saline soils is applied to remove salts from the soil profile. This practice allowed keeping the agricultural productivity in optimal levels. In recent years, degradation of the drainage networks and progressive water insufficiency combined with uncertainty of the water supply related to the global climate change aggravated the situation with land degradation.

Revitalization of the drainage networks is expensive and in conditions of water insufficiency and uncertainty of climate change may be only partially effective. Moreover, economic difficulties during the post-Soviet period require inexpensive, but cost- and time-effective approaches that could be adopted by the farmers. One of such options may be to use the deep ponds in the vicinity of the irrigated fields, which will allow lowering shallow GW and at the same time productively utilize the drainage water. Moreover, such ponds may serve as additional source of income for farmers, where soil-enriching water plants like azolla, commercial and firewood trees and fish may be grown. Another option is to shift to advanced surface irrigation methods, which will enable uniform soil moisture distribution spatially and vertically while minimizing GW recharge.

The goal of the work is to contribute to socioeconomic and environmental sustainability of the irrigated agriculture in the Central Asia. The invetigation has four interrelated objectives:

1) The evaluate the impact of state interventions on salinity levels and productivity of the irrigated soils;
2) To continue testing Licorice for rehabilitation of salt affected abandoned soils;
3) To evaluate subsurface evaporation basin (SEB) as a tool for collection and productive utilization of irrigation losses.

Study area

The Mirzachul desert is a ca. 10,000 ha plain, located between northern latitudes 40 and 41^{o} in the territories of Uzbekistan (Syrdarya province) and southern Kazakhstan. The plain is confined by the Turkestan ridge in the south, western Tyen-Shan in the east and the system of Nuratamountains in the west and is open only in the north and northwest. It extends for more than 100 km away towards, and becomes part of, the Kizilkum desert. Mirzachul has elevation altitudes ranging 235-370 m ASL, and slopes from the Turkestan ridge towards the Kizilkum desert. The slope decreases very gradually, only 3-4 m in every 1 km in the southern direction and less than 2 m in the northern direction. The plain is located on three terraces of the Syrdarya River and mostly composed of loess loams and sandy loams,andprolluvial deposits in the south. Soils of the desert are extensively saline, with local solonchak spots in unused areas. The plain was developed for cultivation some 80-100 years ago. The Syrdarya River is the source of freshwater supplies for irrigation. Land salinization dictates relatively low agricultural productivity of the main crops cotton and wheat in the province. Salinization is mainly of sulphate type. Chloride salts tend to accumulate in deeper soil horizons. Sulfurous sodium and gypsum are the main salt constituents in the upper solonchak horizons.

Theclimateof the Mirzachul plain iscontinental, which is reflected in the high amplitude of temperature fluctuations during seasons, low air humidity and drastic changes of the seasons. The average temperature in July is 27.9^{0}C and in January –2.1^{0}C. The precipitation is ca. 240 – 300 mm, being maximum in winter and spring. Frost-free period is 205-230 days, and the sum of effective temperatures (above 10^{0}C) is 33680^{0}C. Evapotraspiration is 1600 mm yr^{-1}, annual average air humidity is 50 – 54%.

The research site is located in the Navbahor Water Consumers Association (WCA) of the Boyovut district, Syrdarya province. The WCA has an area of 7978 ha. Lithology of the area is characterized by stratified saline loam and clay soils.According to the official data, in 2003-2004 the low-saline area was 1003 ha (12.6 %), average saline 2744 ha (34.4 %) and heavy saline 2131 ha (26.7 %). Non-used land is 2100 ha. Average GW table is at 1.5-2.5 m below surface, rising up to 1-1.2 m during leaching and irrigation events. Infiltration from the fields and earthen beds of the irrigation networks are the main contributors of the GWrecharge. GW salinity is around 4 – 5 g l^{-1}, mainly of sulphate type. Magnitude of the GW salinity changes within the season: during the growth period salinity decreases due to intensive irrigations, at the end of the fall it increases. Lateral GW flow is extremely slow, which has an effect on the rise of GW table and its salinity. Land salinization affects productivity; out of 2100 ha of non-used land 1500 ha in the WCA are not used because of high salinity levels and waterlogging.

The research field selected for the in-depth study covers an area of 29 ha (Figure 7). The cropping pattern in this and neighboring fields is a cotton-wheatrotation. Water for irrigation to the field is supplied through the concrete flume in the southwest. A drain runs in the south-to-north direction in the east of the field.

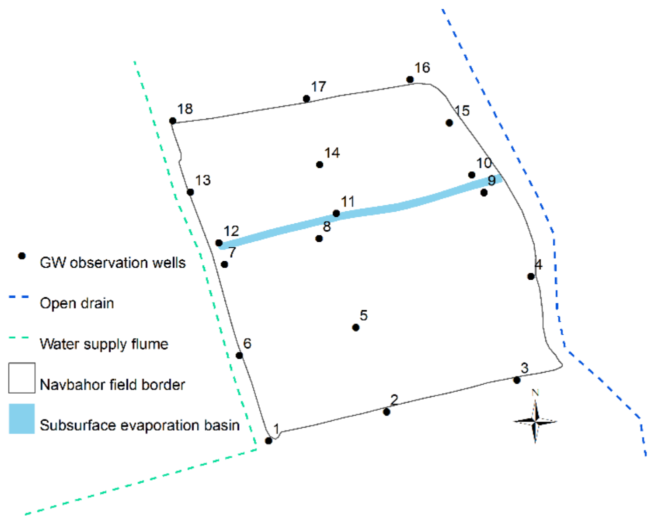


Figure 7.The scheme of the research site. Location of the groundwater wells (blue marks and black labels), the subsurface evaporation basin and the field drain is shown

Major milestones and activities

Activities at the research site. After the selection of the representative research site, the preparation activities included establishment of the field pond by widening and deepening the existing small field drain, installing GW monitoring wells and conducting sampling. Apart from actual field sampling, historical data collection will also be conducted.

Materials and data collection

Agricultural practice. The farmer makes all the decisions on the research field (cropping pattern, time and amounts of water, chemical applications, etc), no influence on these decisions from the researchers is imposed. In the fall 2013, winter wheat was sown in the southern part of the field, while only a small (1-ha) land parcel in the northern part was planted for private purposes. Taking into account such possible differences in management activities and natural settings the field was separated into the field #1 (southern part) and #2 (northern part), with the pond acting as the border between the field parts (cf. Figure7).

*Subsurface evaporation basin.*The basin of 465 m long and 10 m wide has been established in the middle of the field in September 2013 (Fig.8). The pond runs in the northwestern direction. It serves as an accumulator of the surplus surface water during irrigation events and also drains the field. A graduated metallic stick was installed in the middle of the pond to measure changes of water level in the pond. Measurements of the level and salinity of the pond water are conducted once in 3-5 days during, and 5-10 days outside, growth periods. The level measurements during the water application events are conducted more frequently.

Fig. 8. Subsurface evaporation basin at the research site (after deepening and widening the drainage ditch)

*Samplingof soil properties.*Two soil pits were dug to the depth of 210 cm (until GW table) in the field #1 and to 105 cm in the field #2 to describe the properties of the soil profile. The pits were established approximately in the middle of each field for the laboratory analyses of texture, bulk density, CECand other soil properties (see annexes 2-4).

Soil water retention characteristics are scheduled to be analyzed in the laboratory. The permeability of the soil at both fields will be determined using standard double ring infiltrometers with an outer ring of 40 cm and inner ring of 20 cm (Clothier, 2001). For a better soil water balance assessment, the soil-water pressure head will be measured with tensiometers. A soil-water retention (pF) curve, which describes the relationship between the volumetric soil water content θ (cm^3 cm^{-3}) and the soil matric potential h (cm) will be established in the laboratory.

Soil moisture. Repeated measurements of the soil moisture (gravimetric method) and salinity (EC) for the water and salt balance are scheduled to be analyzed in situ once in 5 days during growing period. At each field, the soil moisture will be taken at two locations within 300 mm depth increment to an actual GW tableat the measurement date. Additional soil moisture will be taken just before and after the water application events, to assess effects of irrigation on soil moisture distribution.To assess soil moisture, soil samples will be collected in tin cans to determine the gravimetrical soil moisture content.

Soil salinity. Soil salinity is measuredfor total dissolved solids (TDS) and electrical conductivity of the saturated extract (EC). To measure TDS, the salts remaining after the water has been evaporated are weighed and expressed in milligrams of total dissolved solids per liter of water. For measuring EC (in dS m^{-1}), locally produced portable electrical conductivity meter (EC-meter, Chernishov and Shirokova, 1999) was used. Few more soil samples will be collected for conversion of the EC into TDS.

Groundwater monitoring. Nine GW monitoring wells were installed in a staggered order in each field (18 wells overall) to a depth of 2.5 – 3.5 m for sampling GW table and salinity. The wells allow capturing GW flow within the research site during and beyond irrigation events. The wells are polyethylene pipes with diameter of 630 mm, perforated on the sides and closed from bottom (there is no pressure head) and top (to prevent vandalism). Measurements of the GW table and its electrical conductivity using EC-meter are conducted once in every 5 days during and 10 days outside growth periods.

*Water application measurements.*Water supply for leaching and irrigation into the research site will be measured using Cipoletti weirs. There are four inlets in the concrete flume, from which the irrigation water is applied into the field. In future, installation of two Parshall flumes in the irrigation canal at the entrance to the site and exit (to measure outflowing water) is envisaged. During irrigation events, the salinity of the water will be measured with the EC-meter.

Site size and micro-topography. The sizes of both fields were determined with help of a mobile A-GPS device, which provides an additional accuracy of location determination. All corners of both fields and several points on the sides were taken and analyzed in ArcGIS software. Prior to analysis, the coordinate system of the GPS points was converted from WGS 1984 into the Pulkovo 1942 geographic coordinate system.

A geodetic survey to identify field micro-topography and slope, heights of the monitoring wells and drain depth was conducted with help of laser emitter and telescopic graduated signal receiver. Knowledge of the field topography allows assessing actual GW flow, locally elevated and depression areas and thus, describes possible salinization patterns. Ca. 218 elevation points and GPS locations were collected. Spline interpolation method was used for interpolation between the point data.

Meteorological measurements. Meteorological data are necessary to estimate the evapotranspiration and the effective part of rainfall. Daily measurement of the evapotranspiration and rainfall will be performed in the research siteusing Class-A pan with manual daily measurements. For this purpose, a pan with proper dimensions will be made locally. A rain gauge will also be installed and measured daily. At the moment, the historical and present-day data from local meteorological station will be obtained.

Phenologicalmeasurements.Phenologicalmeasurements are carried out once a week in the first field (the field #2 is not sown in 2013, except for a 1-ha parcel). In each field, the wheat is monitored to determine theplantheight(bymeasuringstick),rootingdepth(dugandmeasured),plantdensityand other properties.Phenological measurements will be used to estimate a crop coefficient for calculation of the ET.

RESULTS AND DISCUSSION

Site size and micro-topography. The dimensions of the field #1 are 380 m wide, 485 m long and the area is 18.4 ha. The field #2 is 460 x 230 m, and the area is 10.6 ha.

A geodetic survey(Fig.9) showed very high elevation in the southwestern corner of the field #1. The difference between the elevation of this part of the field and the area around the pond is 216 cm. On the contrary, the second field has relatively smoother, yet still high, elevation; the difference between the highest and lowest points constitutes64 cm. Both fields have a depression at the center of the evaporation basin.

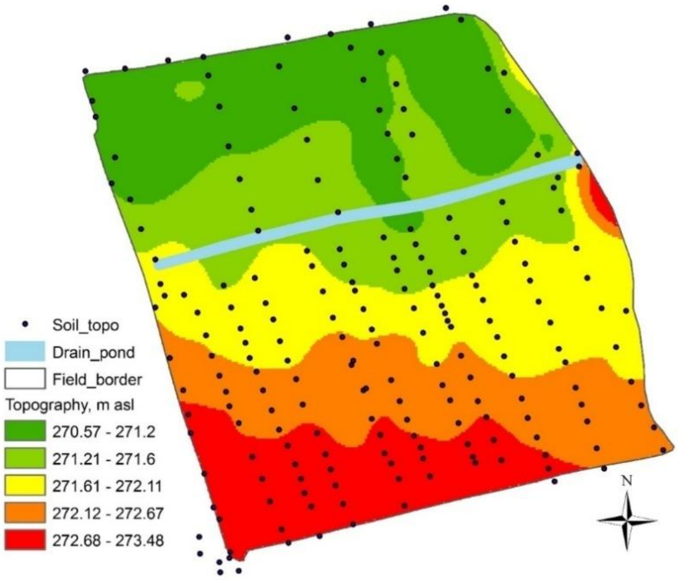


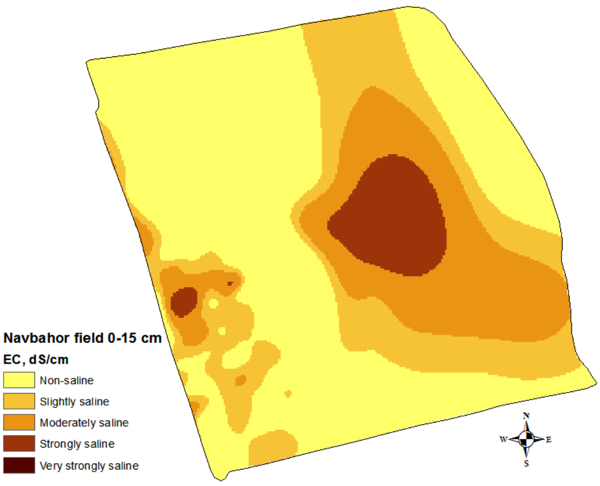
Figure 9. Field micro-topography

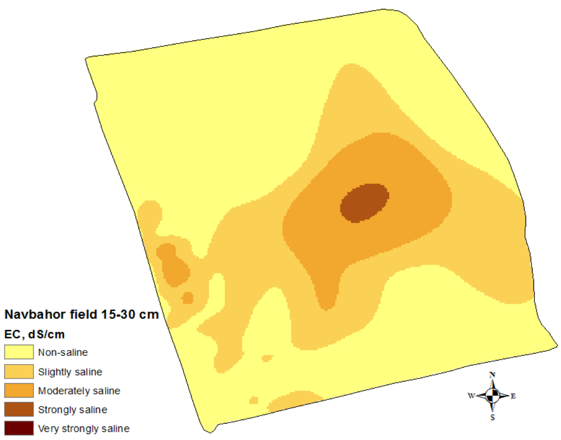
Soil physical properties. The soil texture of both fields is virtually homogeneous (annex 3). According to Kachinsky's classification (Handbook on soil science, 1980), the soil is light loamy, changing to medium loamy from the depth of 120 cm until GW table. For comparison of methods, the FAO classification is also provided, according to which the soil in the field #1 is loamy and sandy loamy from top until 120 cm, then changing to silty loamy. The soil of the field #2 is loamy and sandy loamy. The bulk density estimated to the depths 0-30 cm and 30-60 cm is 1.1-1.2 g cm^{-3} in the field #1 and 1.4 g cm^{-3} in the field #2. Assuming a particle density of 2.66 g cm^{-3} (loamy soils), soil porosity was estimated to be 0.55–0.58 cm^3 cm^{-3} in the field #1 and 0.47 cm^3 cm^{-3}in the field #2.

Soil chemical properties. Bicarbonate content of soils (HCO_3) in both fields was similar and homogeneous throughout the profile, ranging 0.15 – 0.22 %. Soil *pH* is in the range of 7.2-7.59 and is characterized as chemically neutral, favorable for crop development. The distribution of the SO_4, *CA* and *Mg* ions also appeared to be homogeneous throughout the soil profile except for the pit #1, where at depths 120-210 cm the amounts of these ions were much lower. The ions SO_4 ranged between 0.71 – 0.926 % with lowest values 4.79 – 5.96 %, *Ca* 0.23 – 0.308 %, *Mg* 0.010 – 0.036 %.

The amounts of *Cl* ion are somewhat higher in the field #1 compared to that in the field #2 and slightly increase with depth. The assessment of the chloride to sulphate ratio indicating the type of salinity showed that salinization of the soil in both fields is of sulphate type (Kaurichev, 1989). According to the FAO classification, the fields are slightly saline (EC ranges 1.01 – 2.86 dS m^{-1}) (Abrol et al, 1988).The soil organic matter in the 30 cm layer (0.84 – 0.86 % in the field #1 and 0.76 – 0.95 % in the field #2) is classified as moderate (Krasnouhova et al. 1988). The soil humus in the deeper horizons is expectedly classified as poor to very poor. Plant-available phosphorus (P_2O_5) is higher at the topsoil (4.7-5 mg kg^{-1}) and lower in the deeper horizons (2.5-3.5 mg kg^{-1}in both fields), classified by Musaev (2001) as very poor. The contents of potassium (K_2O) was 204.7 – 322.7 mg kg^{-1} in the field #1 and 156.5 – 204.7 mg kg^{-1} in the field #2, classified as low to moderate.

Soil salinity. The soil salinity was measured in 78 locations in 15 cm depth increments. The resulting maps for each measured depth were produced by interpolating with the Spline interpolation method (Fig. 5). The soil salinity maps for each depth increment are shown in the Fig.10.





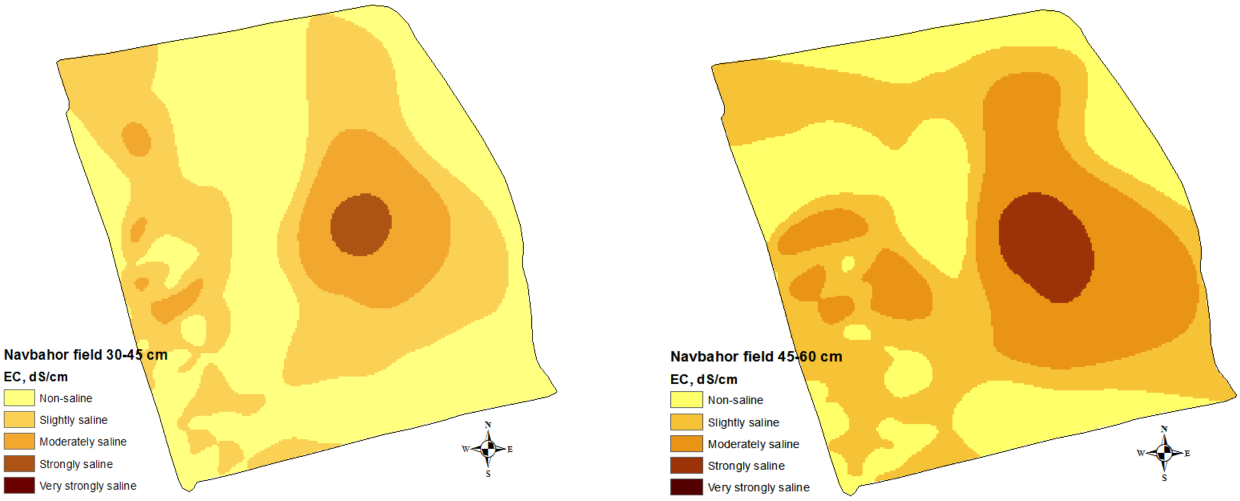


Fig. 10.Soil salinity (19.11.2013) at 15 cm depth increment in the research site in Navbakhor Water Users Association.

Water measurements. There was only one irrigation event into the field #1 during the period 15-20.10.2013. The estimation showed that 1200 m^3 ha^{-1} of water was applied during this event. There will be no further irrigation events in 2013.

Groundwater table and salinity. In general, the average GW table over the entire area is 168 ±56 cm. However, taking into account the extremely high elevation of the southern part of the field #1 the wells № 1-3 were excluded from the estimations. The "actual" average GW table is in the range of 154-157 cm (±46, Figure 11). There was a negligible GW table rise during the irrigation event.

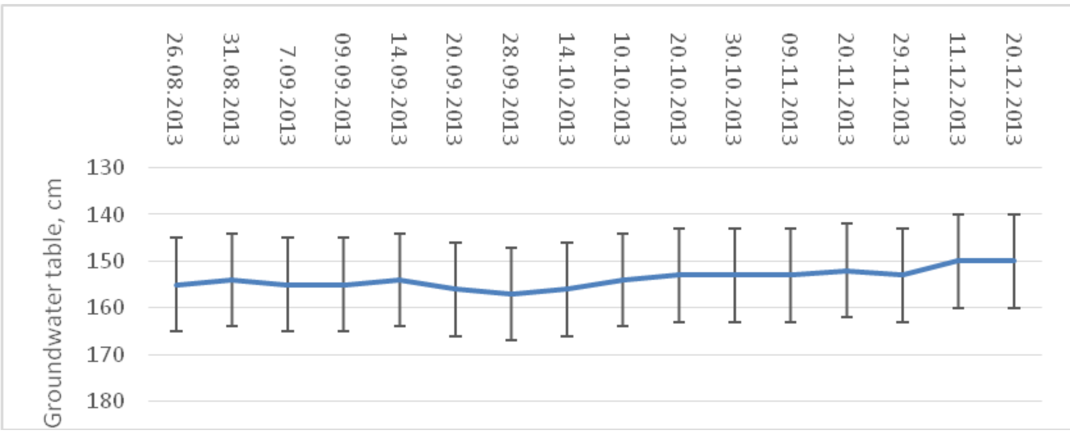


Fig. 11. Average groundwater table (cm) in the Navbakhor field for the period 26.08 – 10.10.2013

The average GW table in the field #1 is deeper (168 ±60 cm, with wells 1-3 excluded) than in the field #2 (147 ±37 cm). The only reason for the shallower GT table in the field #2 compared to that in the field #1 is the irrigation of the vegetables in the 1-ha land parcel. The GW table is the shallowest near the pond (Figure12, a), which is indicative of the hydraulic connection between the GW flow and the pondwater. The GW salinity ranges widely from 2.44 till 13.25 dS m^{-1}. The overall average GW salinity is 6.36 ±3.54 dS m^{-1}, with higher GW salinity levels in the field #1 (7.38 ±4.25 dS m^{-1} vs. 5.46 ±2.70 dS m^{-1} in the field #2). The map of the GW salinity measured at 26.08.2013 is shown in Fig.12, b.

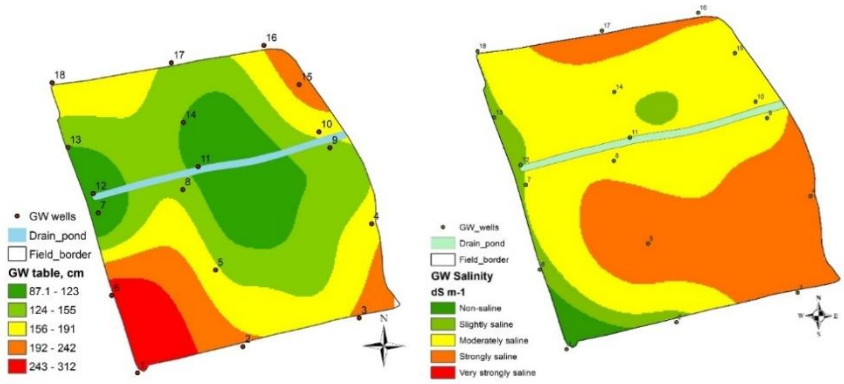


Fig. 12.Groundwater table, cm below land surface and groundwater salinity, dS m^{-1} (c) in the Navbakhor field. Measurement date: 30.10.2013

Relationship between soil salinization and environmental variables. To explain soil salinization in the research field, a statistical correlation between soil salinity at the different profiles and such environmental variables as the field topography and GW table was established. To assess the correlation coefficient, the grid cell values of the interpolated maps of the soil salinity and the other two variables were extracted. However, the higher correlation between variables at some places within the domain under analysis may be compensated by the low or absent correlation in the other areas, rendering the low overall coefficient. To account for this fact, a model developed by Park et al (2003) was used to analyze and visualize a spatial correlation between the variables at specific smaller areas within the domain (Fig.13).This model places a square moving window of user-defined size and the gridsize of this window(thus reflecting the spatial extent and resolution) on the maps of the analyzed dependent and independent variables. ThePearson correlation coefficient within the moving window is calculated repeatedly from the upper left to the lower right corner of the raster data.

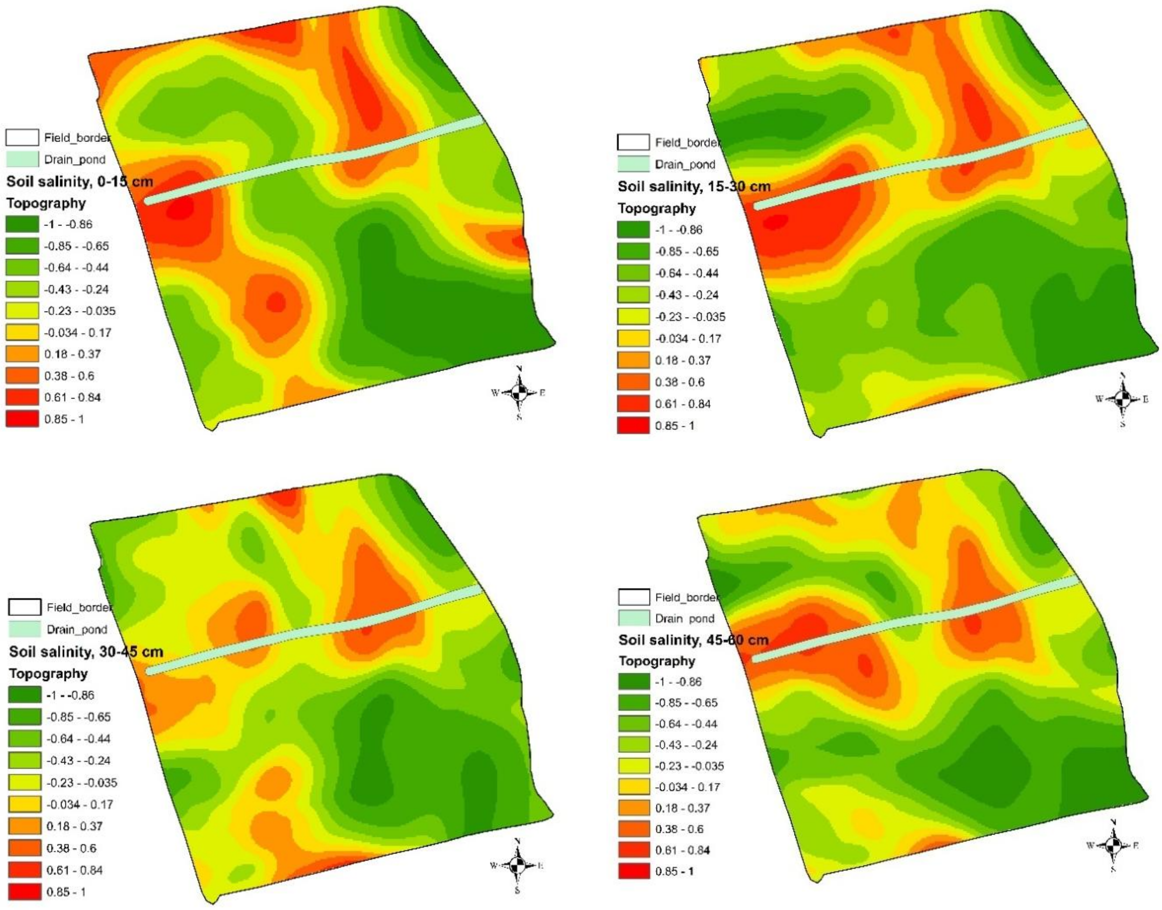


Fig.13. Maps showing spatial Pearson correlation coefficients of soil salinity at different profiles and topography in the Navbakhor research field

The strong relationship between the soil salinization on the one hand, and topographic differences and GW table on the other, is evident. The higher salinization levels in the middle of the research field can be explained by local micro-topographic depressions and so, shallower GW table. The negative correlation of soil salinity and GW table is due to the fact that the values of shallower GW are lower, and of deeper GW - higher.

Subsurface evaporation basin. The water level in the basin reflected the GW level (Fig. 14). Following the start of irrigation, the water level in the pond raised reaching its maximum levels at the 27.09.2013.

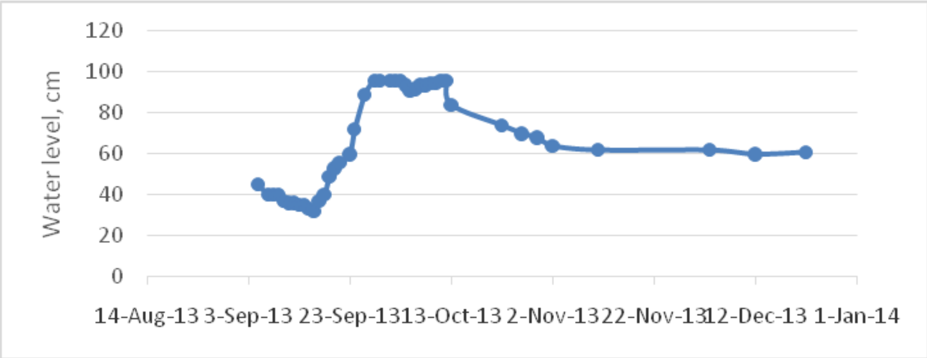


Figure 14. Water level of the subsurface evaporation basin during 2013

Phenological measurements. The winter wheat was sown at 14.09.2013. Ca. 59-66 % seeds emerged in 25.09.2013. Wheat tillering appeared on the 42th day, at 9.11.2013. Table 2 shows the phenological observations.

Table 5.Phenological observations of winter wheat in the research field

№	Seeds. gramper м^2	Number of seeds perм^2	Date of observation. 2013				
			22.09	23.09	24.09	25.09	Emergence. %
	1st trial						
1	220	500	275	289	302	325	65.0
2			285	300	325	330	66.0
3			245	276	295	305	61.0
	Average						64.0
	2nd trial						
1	220 г	500	250	265	271	296	59.2
2			266	285	300	317	63.4
3			248	280	299	313	62.6
	Average						61.7
			3rd trial				
1	220 г	500	275	289	302	295	59.0
2			285	300	330	305	61.0
3			242	271	280	294	58.8
	Average						59.6
	Overall average						61.7

Table 6. Date of tillering of the winter wheat at the research field

Trials	Tillering dates	Days
1	5.11.2013	40
2	7.11,213	42
3	9.11.2013	44
Average		42

CONCLUSION

The results of the studies could be used by policy makers to specify further activities within improving water management plan in the MIP or similar areas. The evaluation of the impact of interventions was conducted with help of RS/GIS analyses. For this purpose long-term Landsat satellite images were used. Field studies were initiated at two sites: from July 2013 subsurface evaporation basin studies were initiated at Novbahor farm, Bayaut district and Licorice studies from September 2013 in Galaba farm, Bayaut district of Uzbekistan. Licorice demo site was also established in Nukus district of Karakalpakistan.

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