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MEASURES FOR INCREASING PRODUCTIVITY OF WATER AND AGRICULTURAL LAND RESOURCES IN SOUTH KAZAKHSTAN – MAKTAARAL DISTRICT CASE STUDY

K. Amanbayeva[1], Józef Mosiej[2✉], E. D. Zhaparkulova[1], K. Zhanumkhan[1]

[1] KazNAU (Kazakh National Agrarian University)
[2] Warsaw University of Life Sciences – SGGW

ABSTRACT

Aim of the study
The aim of the study is to present environmental problems related to the intensive cultivation of cotton in the climatic conditions of Central Asia. This problem has been related to the pressure to increase yields by systematically increasing the applied irrigation rates. At the same time, other problems arise, such as ownership changes, water charges, and other issues.

Material and methods
Case study method was used in the present work.

The material was collected by co-authors from Kazakhstan during many years' experimental and monitoring work.

Results and conclusions
The results of field studies concerning the analysis of the condition of irrigated land on the flagship Makhtaaral facility showed a systematic deterioration of soil physical indicators as well as:
- a reduction in the drainage efficiency of irrigated land,
- an increase in the groundwater level above the critical depth,
- an increased level of soils salinity,
- an impact of washing on soil alkalisation.

Keywords: Aral region, surface irrigation, cotton, soil degradation, soil salinity

INTRODUCTION

Large-scale irrigation projects are theoretically beneficial; however, there are examples of outstanding failures, which were partly responsible for environmental disasters. We believe that irrigation per se does not necessarily lead to land degradation. Even in the famous case of the Mesopotamian plains, the idea that ancient Sumerian irrigation caused irreversible salinization is far less evident than it is often assumed in the public discussion. However, some irrigation projects in arid lands ended disastrously indeed. One of the best-known examples is the former Lake Aral. Irrigated agriculture in the vicinity of the lake's basin had been operating for many centuries. It was practiced mainly in the areas with rich soils, with a deep groundwater table, or with fresh groundwater where irrigation requirements were minimal. A major part of the irrigated lands was located in river valleys, in deltas, and in foothills close to the mountains. The irrigated plots were small and

✉e-mail: jozef_mosiej@sggw.edu.pl

widely apart from each other. Therefore, natural drainage served well enough, whereas artificial drainage, in the form of ditches, was rarely used. The principal irrigated crops were cereals and alfalfa. They occupied more than half of the total irrigated area in the Aral Sea basin. Cotton occupied less than 20–30% and rice no more than 5–15% of the irrigated area, depending on the year (Aydarov, 1985; Dukhovny, 1989; Anselm, 2012; Bekbayev et al., 2015).

During the twentieth century, the population of the Lake Aral basin doubled, and irrigation was intensively developed, leading to almost a tripling of the irrigated area. The basic sources of irrigation water are two large rivers, the Amu-Darya and Syr-Darya. Large irrigation systems covering hundreds of thousands of hectares were built mainly in the steppe and desert parts of the Lake Aral basin, far from the riverbeds, where the groundwater table was very deep (more than 30–50 m).

Cotton became the main crop, following the government's decision to increase raw cotton production. That led to increased irrigation requirements and to amplified use of mineral fertilizers, pesticides, and defoliants. In addition, the area of rice cultivation expanded significantly (Ikramov, 2002).

The irrigated area of the Republic of Kazakhstan decreased sharply: while in 2000 the area of irrigated lands was 2153.27 thousand hectares, in 2016 it already amounted to 1426.32 thousand hectares. In turn, the main factors leading to the deterioration and reduction of irrigated land in the Republic of Kazakhstan are economic (deterioration of the provision of household with working assets) and organizational (the collapse of large farms) (Yunussova and Mosiej, 2016).

Use of river water for large-scale irrigation at a specific time in history (i.e., the Stone Age and Bronze Age) was possible only in places where the soil was soft enough, the riverbanks were not too steep and rocky, and the current was not too fast. Therefore, because of these physical conditions, even in the subtropical desert-steppe, steppe and forest-steppe zones, many rivers, including the Tigris (adjacent to the Euphrates), the Aral and Kura, Syr Darya and Amu Darya, etc., could not be the basis of irrigation civilizations until much later.

The efficacy of irrigation was the highest in places where deep sediment from floodwaters formed the soil. Crops began to flourish when plough tillage was introduced (first by donkeys, and later by oxen). This technology remained virtually unchanged for several millennia.

It was by the end of the fourth millennium BC in Egypt and Sumer (southern Mesopotamia) that crop yields multiplied greatly, by a factor of ten or even twenty. It meant that every farmer could produce much more than was required for his own needs. This led to favourable developments in cattle breeding, which in turn led to an even greater rise in people's living standards. Each community was able not only to support its workers but also the disabled members of the community and the dependents, e.g., children and old men. They were able to create a reserve of food and to free a part of the workforce from agricultural labour.

The Maktaaral irrigation massif is an example and a showcase of the irrigated agriculture of Kazakhstan. The irrigated area is 147 122 ha (Anselm, 2012). In 2014, cotton was grown on an area of 85 987 ha. This is 58.5% of all cotton grown in Kazakhstan. In the remaining areas, vegetables, melons, and fodder plants are grown. Crop yields have decreased by 1.5 to 2 times compared to the years up to 1980 (Vyshpolsky et al., 2005). The reason for this has been an increase in the severity of degradation processes affecting the irrigation systems (Bekbayev, 2002; Qadir et al., 2009). Therefore, in this irrigation system, with the constant increase in the size of degraded areas and water scarcity, increasing the productivity of land and water resources is of utmost practical importance. Currently, crops only use 35–40% of the water obtained from irrigation systems. The remainder is qualified as losses resulting from the processes of infiltration, evaporation, and gravity runoff (Ibatullin et al., 2009). Significant technological losses of water in the irrigation network and irrigation fields inevitably lead to the salinity or alkalization of the soils in the irrigated areas and to the contamination of water sources (Qadir et al., 2008).

Therefore, in the irrigation systems of Maktaaral district, it is necessary to identify the main factors influencing the flow rate of the degradation processes. This problem can be solved by accelerated reconstruction of irrigation systems and landscape management of the irrigated areas (Borowski, 1982). Applying the methodology of management of irrigated landscapes provides the selection of economically feasible construction and technology solutions for the improvement of irrigation systems.

CHARACTERISTICS OF THE STUDY AREA

Irrigated lands of Maktaaral district of South Kazakhstan region are located on the left bank of the Syr Darya River in Kazakhstan part of Golodnostepsky district in the middle reaches of the Syr Darya river. The North-Western part of the massif is limited by Shardara reservoir; in the East it is bordered by Uzbekistan, in the South – by the Central Golodnostepsky collector, and in the lower West, by the Arnasai (Anselm, 2012 and 2014). The climate of Golodnaya Steppe is sharp continental. The average annual temperature is +12.5°C, the average temperature in July is +27–+30°C, and in January, between –3 and 7°C. Air humidity in the Golodnaya Steppe is very low, especially in the summer months. The annual amount of precipitation ranges from 175 to 425 mm. The moistest period of the year is spring, receiving more than 40% of the annual precipitation.

In the remaining areas, vegetables, melons, and forage have been grown. Crop yields have decreased by 1.5 to 2 times compared to the 1980s (Vyshpolsky et al., 2005). The reason for this is the intensification of degradation processes in the irrigation systems (Bekbayev, 2002; Qadir et al., 2009). Therefore, in these irrigated areas, along with the constant increase in the area of degraded land and growing water shortage, both soil fertility and the quality of water resources used for irrigation decrease. Currently, crops only used 35–40% of the water taken from the irrigation systems, the rest being lost to infiltration, evaporation, and discharge (Ibatullin et al., 2009). Significant amounts of technological water losses in the irrigation network and irrigation fields inevitably led to the degradation (salinity and alkalization) of the irrigated land, and to the contamination of water resources (Qadir et al., 2008).

MATERIAL AND METHODS

The decrease in the efficiency of the drainage system resulted in an increase in the level of groundwater salinity. At the same time, the high mineralization of water used for irrigation might have contributed to the intensification of soil degradation processes in its root layer. The monitoring of changes in the physicochemical properties of irrigated soils was conducted by the South Kazakhstan Reclamation and Hydrogeological Expedition. It demonstrated that under the influence of anthropogenic factors (irrigation systems) and natural factors, qualitative and quantitative changes occur in the structure of the soil root layer (Anselm, 2012). In particular, the organo-mineral composition of soils, especially their salinity, changes rapidly. However, it should be noted that this level

Fig. 1. Water Resources of the Aral Sea Basin (with the Syr-Daria and Amu-Daria rivers), featuring the Maktaaral case study area (marked in red, close to Samarkand)

is functionally dependent not only on the technical condition of the irrigation systems but also on the quality of the water used, on groundwater level, and on the method of irrigation (Shitikov, 2003; Saparov, 2013).

RESEARCH RESULTS

Experience in the operation of irrigation systems shows that the dynamics of the salt regime of soils depends not only on the technical condition of the irrigation and collector-drainage network, but also on the irrigation technology and water availability of irrigated lands. In such cases, the effectiveness of irrigated agriculture depends on the water content of irrigation sources, the technical condition of the irrigation network, the irrigation technology, crop farming (agricultural technology, crop rotation, fertilizer systems), and the perfection of irrigation systems operation services. Therefore, in the current situation on the irrigated lands of the Maktaaral district, non-compliance with the irrigation technology of agricultural crops, low technical condition of the irrigation networks, and the growing mineralization of irrigation waters, the rates of degradation processes increased.

A comparative analysis of the degree of soil salinity, selected from various places of irrigated lands of the Maktaaral district in 1982–1987 and 2005–2009, showed an increase in the rates of soil salinization processes. The results of the studies that the Kazakh Scientific Research Institute of Water Economy conducted in the 1980s showed that in 72% of the samples taken in various places of the Maktaaral district, the content of toxic salts and chlorine ions did not exceed the toxicity threshold; in 13% of the samples, the soils had weak salinization; in 8% of the samples, salinization was average; and in 5% of the samples, the degree of salinization was high. To characterize the salt regime of irrigated lands in the Kazakhstan part of the Maktaaral district, table 1 shows the content of the total reserves of salts, reserves of toxic salts, and chlorine ions. The accumulative nature of salts in the root zone of soils predetermined the growth of saline irrigated lands.

In the current ecological and reclamation situation in the Makhtaaral district, it has been demonstrated that the problem of development of irrigated agriculture in a sustainable way can be solved by the reequipping the irrigation network and facilities, improvement of the physicochemical properties of the soil by its loosening, desalinization, desolining, as well as introducing organic and mineral fertilizers. Of course, it is important to improve and introduce new water saving irrigation technologies. From economical point of view, it is necessary to increase drainage of irrigated land, and to utilize ground and drainage waters by using them for irrigation and sub-irrigation.

Increasing water availability of irrigated land and utilizing groundwater can be achieved by matching the drainage mode (vertical, horizontal) with the irrigation regime, i.e., through integrated management of surface and groundwater. For example, expanding the range of horizontal drainage by building retaining structures would create conditions for the integrated management of surface and groundwater, thus increas-

Table 1. Dynamics of the degree of salinization of soil and ground (in the layer of 0–100 cm) by administrative district, for the period 1995–2015

Irrigation regions	Years of observation	Irrigation area, thousand hectares	Including salinization			
			none or low salinization		medium and high salinization	
			ha	%	ha	%
Makhtaaral district	1995	125.4	93.6	74.6	31.8	25.4
	2000	125.3	89.2	71.2	36.1	28.8
	2005	138.8	92.2	6.4	46.6	33.6
	2015	151.0	92.4	61.0	58.6	39.0

ing water supply of irrigated land with seepage water for sub-irrigation. These processes are better regulated against the background of vertical drainage due to the coordination of its mode of operation with the depth of groundwater.

Unfortunately, so far the methods of integrated management of surface and groundwater have not been given due attention, therefore, the filtering measures were often used in places where their efficiency is low, whereas in places of urgent need, typically they were not used. For this reason, work on the reconstruction of irrigation systems did not provide the expected level of water saving or increase the yield of cultivated crops, while the idea of saving water was discredited, as in itself it did not improve the condition of irrigated land.

On lightly saline and irrigated lands prone to salinization, where groundwater salinity rises to 5 $g \cdot dm^{-3}$ and becomes poorly suitable for plants, the problem of water saving should be solved by increasing the efficiency of the irrigation network and irrigation equipment.

On saline lands where groundwater salinity exceeds 5 $g \cdot dm^{-3}$ and becomes physiologically unsuitable for plants, the groundwater level during the growing season needs to be maintained deeper than the zone of influence of the capillary rim, i.e., below 2.5 m from the ground. On such lands, drainage rates (either natural or artificial) are directly dependent on the efficiency of the irrigation network and irrigation equipment. Capital investments for anti-filtration measures should be determined minus the costs that need to be invested in the operation of drainage and wastewater utilization.

At the present stage of operation of the irrigation systems, the water content of irrigation sources is steadily decreasing, particularly in the basins of Transboundary Rivers. In addition, investments are limited. It is recommended that the problem of sustainable development of irrigated agriculture should be solved primarily with funds for low-cost measures that will ensure water saving and quality improvement of irrigated land. In all cases, technical decisions to change the existing level of efficiency of the irrigation network and irrigation techniques, the use of groundwater for sub-irrigation, and drainage works should be made based on the analysis of soil salinity, groundwater regime, technical irrigation network conditions, drainage (natural and artificial) irrigated area, farming culture, and so forth.

CONCLUSIONS

1. The results of the analysis of the soil-ameliorative state of the irrigated lands in the Makhtaaral district demonstrated the deterioration of the physical condition of the soil, reduction of drainage of irrigated lands, rise of the groundwater level above critical depth, soil salinization, soil alkalization, and ability to use wastewater for irrigation and flushing.
2. Development of a system of measures to improve the physicochemical properties of the soil and increase the water availability of irrigated lands requires research connected with processes of moisture and salt transfer when changing the parameters of irrigation technology for the reduction of leaching.
3. Determination of the size of losses from canals and irrigated lands. The dynamics of the groundwater level is particularly important for establishing soil salt transfer parameters, checks, and one-time leaching rates when washing saline soils.
4. Establishment of ion-exchange sorption processes with a change in the rates of chemical amelioration and water salinity, setting limits on the use of groundwater for sub-irrigation – setting limits for the use of collector wastewater for irrigation and irrigation, taking into account the degree of soil salinity.
5. Introducing mathematical modelling to support decisions on the scale of the Aral Sea catchment area to solve important problems, such as:
   - Implementing resource-saving irrigation technologies for cotton crops,
   - Developing effective technologies for desalination of saline soils,
   - Chemical melioration of alkaline soils,
   - Assessment of the possibility of using groundwater for irrigation,
   - Assessment of the possibility of using drains from drainage for irrigation and washing of salty soils,
   - Implementing measures to improve the efficiency of the irrigation system.

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DZIAŁANIA ZWIĘKSZAJĄCE EFEKTYWNOŚĆ WYKORZYSTANIA ZASOBÓW WODNYCH I GLEBOWYCH W POŁUDNIOWYM KAZACHSTANIE NA PRZYKŁADZIE SYSTEMU NAWADNIANEGO MAKTAARAL

ABSTRAKT

Cel pracy

Celem pracy jest przedstawienie problemów środowiskowych związanych z intensywną uprawą bawełny w warunkach klimatycznych Azji Środkowej. Problem ten związany był i jest z presją na zwiększenie plonów przez systematyczne zwiększanie stosowanych jednorazowych dawek polewowych. Jednocześnie nakładają się na to inne problemy, takie jak zmiany własnościowe, opłaty za wodę i inne.

Materiał i metody
W pracy wykorzystano metodę studium przypadku.
Materiały zostały zebrane przez współautorów z Kazachstanu w ramach długoletnich prac eksperymentalnych i monitoringowych realizowanych w zorganizowanych ekspedycjach badawczych.

Wyniki i wnioski
Wyniki badań terenowych dotyczące analizy stanu nawadnianych gruntów na flagowym obiekcie Maktaaral wykazały systematyczne pogorszenie się wskaźników fizycznych gleby oraz:
- zmniejszenie skuteczności odwodnienia gruntów nawadnianych,
- wzrost poziomu wód gruntowych powyżej głębokości krytycznej,
- wzrost zasolenia gleby,
- wpływ przemywania na alkalizacja gleby.

Słowa kluczowe: zarządzanie wodami, degradacja gruntów, Region Morza Aralskiego, zasolenie gleb, monokultura bawełny