

Irrigation and Desertification: Ecological Consequences of Arid Land Reclamation in the Aral Sea Basin and Land Degradation Control

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Abstract: Large-scale irrigation in the Aral Sea Basin resulted in the deterioration of ecological situation not only in the irrigated lands, but also in the whole Basin. The secondary salinization has been developed on once-fertile soils; the growing volume of drainage water - a direct consequence of extensive irrigation - has led to a decline in the quality of drinking, ground, and river water, which, in turn, are exacting tolls on human health, agricultural production, and natural ecosystems. Comparison of irrigation practices in Israel and Turkmenistan demonstrates that the main reason of the desertification development in the Aral Sea Basin is irrational utilization of water resources, and not the water deficit. The possible measures on rehabilitation of ecological situation in the region are reviewed.

Keywords: Aral Basin, irrigation; drainage, control desertification

1 The present status of irrigated lands

The Aral Sea Basin includes all the territories of Uzbekistan, Tajikistan, and Turkmenistan, parts of Kazakhstan and Kyrgyzstan, and northern provinces of Afghanistan. Within the borders of the former USSR the total basin area consists of 156.7 million hectares. Agricultural development in the Aral Sea Basin during the past 40 years may be characterized by irrational use of land and water resources through intensive irrigation, overuse of fertilizers and toxic agents and defoliant. Crop rotation was not practiced and two to three times the necessary volumes of irrigation water were applied. Irrigation of 8 million hectares, or about 7% of the total agricultural land, resulted in a sharp degradation of ecological conditions. Regions close to the Aral Sea have been declared an ecological catastrophe zone.

The population of the Aral Sea Basin grew from 7.27 million in 1913 to 33.0 million in 1990, representing a 4.5 fold increase in less than 80 years. In order to provide the increasing population with food, as well as to achieve so-called "cotton independence", construction of the large water management system was initiated in the 1950s, and the area under irrigation increased especially rapidly in 1950—1990. At present a total of 7.9 million ha are irrigated - 4.6 million in the Amudarya River basin and 3.3 million in the Syrdarya River basin. By 1987, there were 915 hydro-technical installations at the water sources including 260 dams, and 967 irrigation systems. The total length of the irrigation network is 323,200 km. In spite of such wide-scale construction of water-use units, antiquated irrigation techniques of gravity irrigation are still applied. With such technology, the losses of water reach up to one-fifth of the total delivered water – from 125.4 km³ of water allocated for irrigation in the Aral Sea basin in 1987 water losses amounted to 27.5 km³. Water use for irrigation per hectare in all Central Asian countries far exceeds the biologically required norms for irrigation.

2 Ecological consequences of irrigation

Inefficiency of irrigation systems and excessive irrigation practices has resulted in significant depletion of water resources, increase of groundwater levels, waterlogging and salinization of irrigated lands. Regulation of the flow of Amudarya and Syrdarya Rivers brought to the decrease of the Aral Sea level. As a result, to 1999 the sea level dropped by more than 18 m, the width of the dry bottom exceeds 120 km, and its total area is about 40,300 km² (Breckle *et al.*, 2001). The intensive salt transportation

from this area is one of the most negative manifestations of the Aral disaster. Average annual transfer of salt-dust aerosol from the dried bottom of the Aral Sea is about 1,06 mln. ton (Tolebaev and Bogdanov, 1998). Salt and dust storms cause the increase of the soil, surface, and ground water salinity in the area of salt sedimentation, degradation of the pastoral and agricultural vegetation.

In order to maintain normal productivity of the irrigated lands, 161,800 km of collectors and drains and 6,300 wells for vertical drainage have been constructed providing the drainage on 4.3 million hectares of irrigated lands. The total annual water requirement of the agricultural sector of the Aral Sea Basin is 79.8 km³—44 km³ derive from the Amudarya Basin and 35.9 km³ from the Syrdarya Basin. More than 40% of this volume (33.13 km³/year) is reclaimed as drainage water (DW). At present only 30% of the drainage system is in satisfactory condition. The rest of the system, which consists principally of open shallow horizontal trenches, is not effective and requires reconstruction.

45% of the DW of the region flows chaotically into desert areas adjacent to the zone of modern irrigation. DW flooded the 300,000 hectares of desert; 530,000 hectares have become waterlogged and salinized. About 13 km³ of DW flow annually into natural depressions, which results in formation of 2,350 small and large lakes within the total area of 7,066 km². 330,000 hectares of desert pastures in the zone of influence of these water bodies have degraded. Solonchaks, void of vegetation or vegetated only by halophytic plants, are forming on the area of 4,060,000 hectares (Zaletaev, 1991). About 38% of the DW returns into the river network. The return of such significant volumes of highly saline DW has resulted in increased mineralization of the rivers' water, which is particularly manifested in their middle and lower parts. The salinity of the Amudarya water is 0.9 g/l—1.0 g/l in its upper part, while in the delta area it reaches 2 g/l—3 g/l; for the Syrdarya River these figures are 0.3 g/l and 1.8 g/l—2.2 g/l respectively (Esenov, 1995).

Before the wide application of irrigation the salts accumulation in the region made up 314 mln. ton per year and concentrated mainly in the Aral Sea. As a result of irrigation development and involving of the deep-laid salts into circulation, the salts accumulation currently exceeds 400 mln. ton per year, and disperses over the vaster territory. According to the preliminary assessment, only in Amudarya River Basin the annual carry-over with DW is estimated as 87 million ton, 24 million ton of which is accumulated in the closed lakes, and the rest flows into the rivers and returns again to the irrigated fields (Rubinova, 1998).

Thus, the construction of the drainage network with the purpose to prevent salinization of irrigated lands has increased the salts income with DW into the rivers. In turn, the deterioration of the irrigation water quality demanded the intensification of the percolative regime, increase of the irrigation rates, and, consequently, the more intensive drainage. The stable feedback has appeared, which towards 1990 caused the depletion of water resources, development of soil salinization processes, and, finally, the reduction of productivity of irrigated lands.

3 Advanced agriculture versus desertification

Turkmenistan. The arable lands in Turkmenistan constitute the area of 12,198 thousand hectares, 2,000 thousand hectares of this amount are currently under irrigation. Water resources of Turkmenistan make up 25 km³/year—26 km³/year including 22 km³/year of Amudarya River, smaller rivers, and groundwater. Irrigated area has being increasing rapidly since 1960 - from 434 thousand hectares in 1960 to 1,453.4 thousand hectares in 1992, i.e. by 3.4 times. Simultaneously volume of irrigation water increased from 8.065 km³ to 24.737 km³, which is more than 90% of the assured water resources of the country. The volume of DW increased by 66 times – from 100 million m³ to 6,616 million m³.

85% of the total 36,657 km irrigation network are open and unlined canals. Thus, water losses during transportation to the fields come to 6.3 km³, or 28% of the total water for irrigation. Gravity irrigation is used on the 99% of the fields. As a result, 5.7 km³ of water is lost annually for evaporation and filtration in the agricultural fields. The general efficiency of the irrigation system is 45%, which conditions the total annual losses of the irrigation water about 12 km³. All this volume of water goes to feed the ground water leading to the rise of the latter and to intensification of salt accumulation processes.

The average unit rate of collector and drainage network in the irrigated areas of Turkmenistan is 20 m per hectare. Drainage network covers only 42% of irrigated lands, but the volume of drainage flow

from this area reaches up to 5 km^3 — 7 km^3 per year. Consequently, 80,000 hectares of once productive rangeland are permanently flooded by DW, 150,000 hectares are flooded periodically, 2,300,000 hectares are moderately waterlogged and 450,000 hectares are strongly waterlogged (Babaev and Babaev, 1994). The return of the drainage flow into the rivers and irrigation canals affected the quality of irrigation water. Salinity of water in the Karakum canal doubled during the last years – in 1990—1994 the salt entry into the canal increased by 38%. The area of 275 newly formed lakes – collectors of highly salinized and polluted DW is $4,286 \text{ km}^2$.

By 1998 the irrigated lands of Turkmenistan were distributed in the following way by the depth of ground water: (1) with depth of ground water less than 1.5 m – 12.8% of the total irrigated lands, (2) 1.5m — 2.0 m – 25.7%, (3) 2 m—3 m – 41.2%, and (4) more than 3 m – 20.2%. In 1986—1998 the percentage of the farming lands with ground water level less than 2 m increased from 7 to 41%. In the 41.1% of irrigated area the ground water has salinity 1g/l—3 g/l; ground water with salinity less than 1 g/l was observed in the area of 60,200 hectare (3.5%), more than 5 g/l – on the area of 688,000 hectare (39%). 95.9% of the total irrigated lands in Turkmenistan are salinized, from this moderately salinized are 57.2%, heavy and very heavy salinized – 11.6%. The heavy salinized area has increased by 225,000 hectares during 1988—1999 (Orlovsky *et al.*, 2001).

So, the irrigation practices in the Aral Sea Basin, which is characterized by low coefficients of efficiency of water use (0.4-0.6) even together with intensive drainage, leads to the drastic activation of geochemical flows, irrational use of water resources, deterioration of their quality, and, consequently, to the wide development of soil salinization.

Israel

The management of the water supply system and the irrigation network in Israel is an example of a successful attempt to establish a modern irrigated agricultural sector on a national scale, and, at the same time, minimize that rate of environmental hazards. Since 1948, the total area under cultivation has increased by a factor of 2.6 to approximately 445,000 hectares, and irrigated area has increased by a factor of 8 to 240,000 hectares. During the same period, agricultural production has expanded 16-fold. The total renewable water potential of Israel is less than 2.0 km^3 per year, a quantity sufficient to irrigate about 10% of the gross area. By the year 1999, total water resources came to 2.151 km^3 . The increase of 0.151 km^3 came mainly from the treated wastewater (Statistical Abstract of Israel, 2000). 0.47 km^3 per year are withdrawn through the National Water Carrier - the main distribution system for water from the Kinneret Lake to the south of the country. The carrier is a combination of underground pipelines, open canals, interim reservoirs, and tunnels. The main consumers are the agriculture, domestic and industrial sectors. Throughout the 1970s and 1990s, water allocations to agriculture stood at about 1.30 km^3 annually, about 60%—72% of total water consumption. The lack of water is the most severe constraint on Israeli farmers. This deficiency influences agriculture in two ways: (1) by limiting the amount of land which can be cultivated; and (2) by inducing farmers to use both land and water as efficiently as possible. Toward this latter goal, highly mechanized, high-input methods and water-saving irrigation systems are employed. At present, over 80% of the irrigated area in Israel uses micro-irrigation techniques (drip, mini-sprinkler and underground irrigation), with an irrigation efficiency of 90%—95%. The remaining irrigated area uses sprinklers with an irrigation efficiency of 75% to 80%. Gravity irrigation, which has an efficiency of 50 % to 60% and widely practiced in Turkmenistan, has not been used in Israel since the mid-1960s. In Israel, where drip irrigation is widely practiced, the 1995 average agricultural water use per hectare was $5,700 \text{ m}^3/\text{yr}$ (Shanan, 1998) (as compared with $17,000 \text{ m}^3/\text{ha}$ in Turkmenistan), down from $8,600$ — $9,000$ in 1950—1952 while crop productivity per unit of water increased more than twofold, from 1.2 to 2.5 kilogram per cubic meter. Water use in the agricultural sector fell from over 70% of total in 1948 to about 50% of total use the late 1990s. The total annual water consumption fell from 600 m^3 per capita in 1960 to under 350 m^3 per capita in 1998 (as compared with $4,300 \text{ m}^3$ per capita in Turkmenistan), while population grew from just over one million in 1948—1949 to 6, 105 million in 2000, along with improvement of living standard.

Experience in Israel has demonstrated how water-use efficiency can be increased by improvements in irrigation efficiency, increased crop productivity, and changes in the types of crops grown. Fresh water can also be saved by switching to irrigation with treated wastewater or brackish water.

Another way of saving water in agriculture is by shifting production from crops with high water

needs to crops with lower ones. This process was partly responsible for reducing average per hectare water use over the past four decades.

Brackish water is very useful for intensive aquaculture in desert. Finally, the use of treated local or transported wastewater in subsurface drip irrigation of orchards and forage could dramatically increase the production of the study area's drylands in a sustainable manner.

About 0.10 km³ of the treated sewage water is transported annually via a separate pipeline called the "Third Negev Pipeline" to the western Negev for irrigation. Due to the high degree of purity of the treated water, it can be used for all crops without any health risk.

Greenhouse agriculture is an important aspect of Israeli agriculture today and many farmers attain record yields. For example, tomato plants are produced in individual pots and can develop as creepers reaching 15 meters in length and producing up to 320 tons/ha. Using computer-controlled drip "fertigation" (applying fertilizer with the irrigation water) economizes on water and fertilizer use, and prevents soil salinization and groundwater pollution. Israel depends on irrigation and fertilization to increase its crop yields. The country meets most of its food requirements through domestic production, using about 1.250 km³ of water and over 100,000 tons of fertilizers annually. As a result, about 5 million tons of field crops, 1,2 billion liters of milk, 1,6 billion eggs, and 1,2 billion flowers are produced annually (The Environment of Israel, 1998).

4 Conclusion

The increased salinity of irrigation water and deterioration of its quality are among the main reasons of secondary salinization. Irrigation by low quality water inevitably leads to the increase of the flushing (percolative) regime, and, consequently, to the necessity of drainage for governing the water and salt regimes. Thus, the irrigation system in Central Asia looks like as an exclusive circle: existing irrigation system inevitably causes soil salinization, and the applied methods to combat salinization (drainage) leads to the further intensification of salt processes. Water consumption per capita in Turkmenistan exceeds that of Israel by 13 times (4,500 m³ and 350 m³ respectively), and unit discharge of irrigation water per hectare in Turkmenistan is 3 times more than in Israel. It can be concluded that deterioration of ameliorative state of irrigated lands and ecological conditions of adjacent to oases lands is not caused by the deficiency of water resources in Aral Basin, but only by irrational utilization of the latter.

A complex of management options are required to improve ecological situation in the Aral Sea Basin:

- the areas under irrigation should be lessened and in the first place those, salinized in their virgin conditions;
- the crop structure in the irrigated areas should be changed: the areas under water demanding crops (cotton and rice) must be decreased;
- complex reconstruction of irrigation systems is needed to: increase the irrigation efficiency, diminish the volume of drainage water and minimize the return of drainage water into the rivers, decrease the irrigation unit discharge, decrease the level of groundwater;
- such reconstruction should be implemented in the whole Aral Sea Basin.

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