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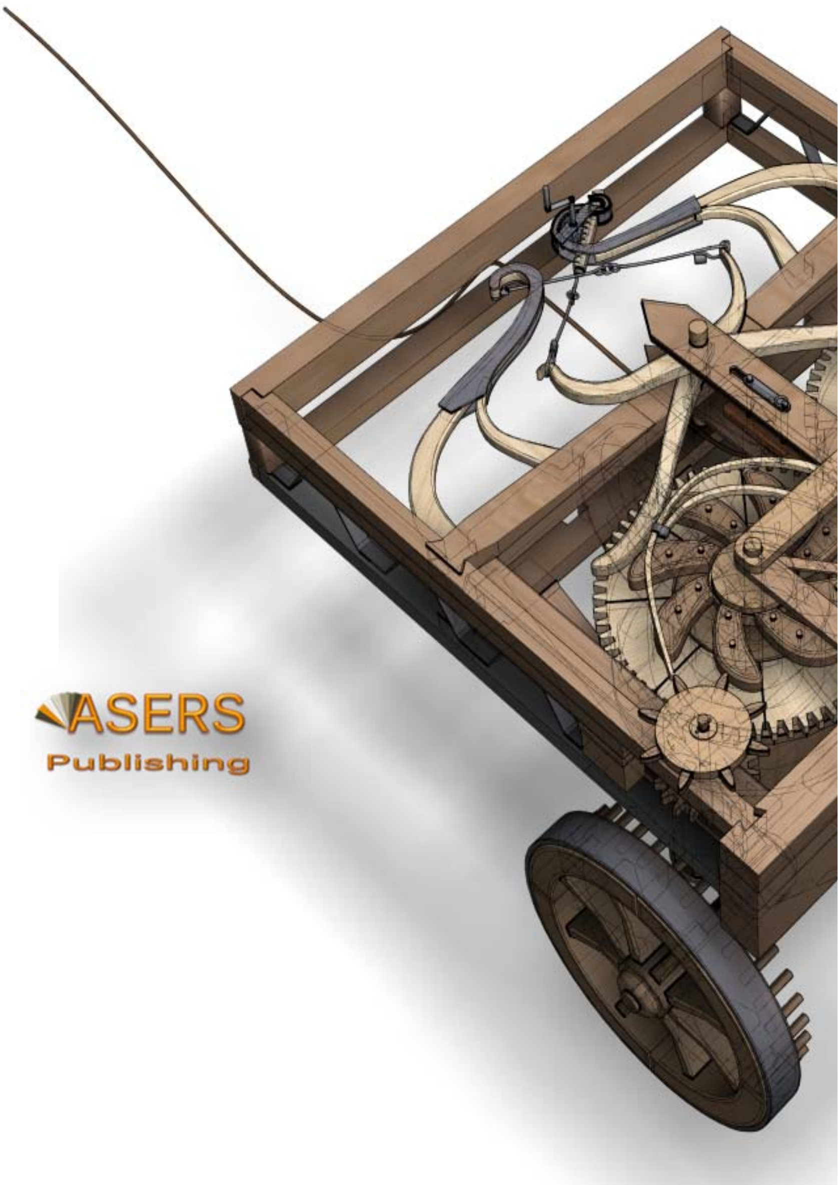

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Uzbekistan's Aquatic Environment and Water Management as an Area of Interest for Hydrology and Thematic Tourism

Jacek RÓŻKOWSKI
University of Silesia in Katowice, Poland
jacek.rozkowski@us.edu.pl

Mariusz RZĘTAŁA
University of Silesia in Katowice, Poland
mariusz.rzetala@us.edu.pl

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Abstract:

The functioning of Uzbekistan's economy is closely linked to the water resources of its huge cross-border rivers: the Amu Darya and the Syr Darya, as well as to the groundwater present within their basins. Both natural lakes and artificial reservoirs (*e.g.* the Aydar-Arnasay system of lakes, the Kayrakkum Reservoir, the Chardarya Reservoir) are present there, which retain significant amounts of water, and large canals with lengths of up to several hundred kilometres which involve complex hydraulic structures are used for irrigation purposes. All these are components of a water management system which needs optimisation; as much as 80% of agricultural land is irrigated, with 70% of the water being lost due to inefficient irrigation systems. The consequence of this allocation of river flows and the overuse of water in irrigation systems has been the disappearance of the Aral Sea (1960 year – 68,900 km^2, 2017 year – 8,600 km^2) and the inflow of water into the Sarygamysh Lake as well as the reduction of Uzbekistan's groundwater resources by about 40%. The intensive development of irrigated agriculture is associated with changes in surface and groundwater quality caused, inter alia, by the increased use of chemicals in agriculture and the discharge of collector-drainage waters into river systems as well as their reuse. The extent of environmental degradation in some areas (especially in the Aral Sea region) is unique on a global scale. The origins of Uzbekistan's other hydrological tourist attractions are related to attempts to ensure the availability of water for both human consumption and industrial use under conditions of water scarcity in the country's arid and semi-arid climates. Not just the spectacular watercourses and water bodies present there (*e.g.* rivers, lakes, canals), but also small water retention facilities and minor infrastructure elements (*e.g.* wells, springs and retention basins, canals, ditches and flow control structures) are of potential tourist importance.

***Keywords*:** water management; tourism; tourist attractions; Amu Darya; Syr Darya; Aral Sea; Bukhara; Samarkand.

JEL Classification: Q25; Q26; Q53 ; Q56; Z32.

Introduction

Among the most important tourist attractions of Uzbekistan are the famous old merchant cities such as Khiva, Bukhara and Samarkand as well as Timur's birthplace Shahrisabz, the country's capital Tashkent and finally Mo'ynoq – a symbol of the Aral Sea environmental disaster (Deliry *et al.* 2020, Nazarov *et al.* 2020, Saidmamatov *et al.* 2020). However, those urban centres together with their territorial hinterland could not have functioned without being able to access water for human consumption and economic purposes (Usman *et al.* 2020, Mukhamedjanov *et al.* 2021). Just like *e.g.* Johannesburg, Pretoria and Cape Town in South Africa are located in places with the most favourable hydrogeological conditions (Vegter 1995), the largest groundwater and surface water resources in Uzbekistan have been found in the Fergana Valley in the vicinity of Tashkent and Samarkand (Kazbekov *et al.* 2007, Rakhmatullaev *et al.* 2012).

The aim of this paper is to describe the aquatic environment and water management in Uzbekistan and to present a blueprint for "water tourism" under conditions of rapid quantitative and qualitative transformations of the country's hydrosphere.

1. Research Background

Given the limited groundwater and surface water reserves in arid and semi-arid climates and the deterioration of their quality, the proper management of these resources is an extremely difficult undertaking. A considerable amount of research aimed at optimising water management in Uzbekistan is currently underway, which is conducted using the latest research methods and tools. In hydrological research, the main focus is on optimising agricultural water management. The studies focus in particular on the Amu Darya River basin, the Fergana Valley and the Zeravshan River basin.

G. Schettler *et al.* (2013) have studied the hydrogeochemical evolution of artesian waters in the Amu Darya River delta. Based on their studies in the Khorezm Province, M. Devkota *et al.* (2015) have presented the advantages of conservation agriculture practices (reduced tillage, crop residue retention, crop rotation) for sustainable irrigated agriculture in semi-arid environments. C. Conrad *et al.* (2016) see great potential for reusing water from small eutrophic lakes, which were identified as a result of their analysis of Landsat satellite data in the Amu Darya River delta; the volume of water in these lakes increases during the growing season due to the inefficient use of irrigation water.

Model-based research on water management is beginning to play an important role as well. F. Akhtar *et al.* (2013) have performed modelling studies (using the AquaCrop and HYDRUS-1D models) in order to develop optimal and deficit irrigation schemes under shallow groundwater conditions in the lower Amu Darya River basin. I. Bobojonov *et al.* (2016) used a stochastic optimisation model to investigate the impact of climate change on the agricultural economy of Western Uzbekistan. J. Jarsjo *et al.* (2017) have used a general circulation model (GCM) and a nitrogen retention-attenuation model to predict the impact climate change would have by 2100 on nitrogen loads in the aquatic systems of the Amu Darya River basin under agricultural intensification conditions. M. Sultanov *et al.* (2018) have modelled soil salinity at the end of the growing season at a cotton research station in the Khorezm Province under irrigated agriculture conditions, using multi-temporal optical remote sensing, environmental parameters and *in situ* data.

U.K. Awan *et al.* (2017) have presented the concept of irrigation response units, using GIS tools, for the efficient management of surface and groundwater resources in the Fergana Valley. V. Dukhovny *et al.* (2018) have presented modified water drainage as a strategy for improved irrigation management of winter wheat in the Fergana Valley. In order to ensure the optimal management of irrigation systems in the Fergana Valley, M. Imbrakhimov *et al.* (2018) have developed a conceptual water balance model for a 10-year period, which will allow the quantification of groundwater status, recharge, drainage and interactions with surface waters. E. Milanova *et al.* (2018) estimated, using global circulation models, water scarcity given changes in climate and irrigation conditions in the Fergana Valley.

M. Groll *et al.* (2015) documented that intensive water abstraction in irrigated cotton agriculture and the discharge of agricultural effluent result in the severe pollution of waters in the catchment of the Zeravshan River, which does not flow into the Amu Darya River under severe water scarcity conditions. R. Kulmatov *et al.* (2018) analysed the environmental and water management risks resulting from irrigated agriculture in a case study of the Navoi Province in the Zeravshan River basin in the Kyzylkum Desert.

2. Study Area, Materials and Methods

Uzbekistan, a country with an area of 447,400 square kilometres and a population of around 33 million, is located in Central Asia, bordering Kazakhstan, Kyrgyzstan, Tajikistan, Afghanistan and Turkmenistan (Figure 1). About 75% of its area is covered by plains – desert steppes (the Turan Depression accounts for the largest part). Between the Amu Darya and Syr Darya Rivers stretches the sandy Kyzylkum Desert. In the north-western part of Uzbekistan part of the Ustyurt Plateau lies, which is a saline desert. To the east and south, the Tian Shan and Alay mountain ranges are situated, which are separated by the mid-mountain Fergana, Zeravshan and Chirchiq-Angren Valleys. Uzbekistan is divided into two parts: one of them is mountainous and the other consists of plains. Tectonically, it is the orogenic belt of the Western Tian Shan with a complex geological structure. The lowland zone occupies the south-eastern part of the Turan Plate and consists of almost horizontal Mesozoic sediments on Palaeozoic bedrock (Encyclopedia 2007b).

The climate is temperate, extremely arid, subtropical in the south. The average temperature in January ranges from –10°C in the north-west to 3°C in the south-east and in July it ranges from 26°C to 32°C, respectively. Annual precipitation varies from 80 mm in the lowlands to more than 1,000 mm in the mountains, averaging about 260 mm (Encyclopedia 2007b). On average, 95% of the area receives less than 300 mm of precipitation per year, with most rainfall occurring from December to April. The dominant process in this dry region is evapotranspiration, which could potentially amount to 1,500–2,000 mm/year (Rakhmatullaev *et al.* 2012).

Uzbekistan lies in the Aral Sea basin. In the northern part, the basin of the Syr Darya River is situated (with a 385 km long reach of the river in Uzbekistan), which is supplied by the Kara Darya River, with the Chirchiq River tributary. In the southern part, there is the Amu Darya River Basin (with a 945 km long reach of the river in Uzbekistan), with the Surxondaryo River tributary and the Zeravshan (455 km long in Uzbekistan) and Qashqadaryo Rivers. The total discharge generated by rivers in Uzbekistan is estimated at 9.54 km^3/year. Uzbekistan includes the southern part of the Aral Sea. The country also has numerous reservoirs, the largest of which are the Kayrakkum Reservoir (with a capacity of 4.2 km^3) and the Chardarya Reservoir on the Syr Darya River. There are 52 reservoirs in Uzbekistan with a total capacity of about 19 km^3. The largest lakes are the Aydar Lake with a capacity of 30 km^3 (1995 data) and the Sarygamysh and Sudoche Lakes with capacities of 8 and 2 km^3, respectively (Rakhmatullaev *et al.* 2012).

Figure 1. Study area location: 1 – national borders; 2 – rivers; 3 – lakes and reservoirs; 4 – canals; 5 – agriculture on irrigated land; 6 – orchards and vineyards in river valleys, mountain pastures; 7 – extent of the Aral Sea in the mid-20th century; 8 – cities and major towns.

Source: made by authors.

In Central Asia, where mountain ranges are adjacent to deserts, V.N. Ostrovsky (2007) distinguishes two types of waters on the basis of their origins – autochthonous and allochthonous. Autochthonous waters arise from the in-situ infiltration of precipitation. Allochthonous waters, which are typical of deserts, are associated with water inflows from mountain systems. The effective groundwater recharge is estimated at 5–22.5% of precipitation (Rakhmatullaev *et al.* 2012).

In lowland areas of Uzbekistan, complex hydrogeological conditions are present. Quaternary aquifers, covered by areno-argillaceous formations, may either be hydraulically connected or form discontinuous, isolated water-bearing layers. Isolated aquifers of the artesian type are present in sandstone formations of the Cretaceous in the Aral Sea area. Deep aquifers are sometimes highly mineralised. Many shallow aquifers are saline (with a mineral content of 1–10 g/L) or are involved in salinisation processes. The salinisation results from agricultural management and is also related to the sodium-rich nature of the solonetz and solonchak soils. Groundwater mineral content tends to decrease with depth. Changes in mineral content are correlated with increases in groundwater levels due to irrigation (Rakhmatullaev *et al.* 2012).

There are 99 major groundwater reservoirs in Uzbekistan, with fresh groundwater being abstracted from 77 of those for use as drinking water. Groundwater resources in Uzbekistan are estimated at 23–27 km^3/year. The main sources of recharge are natural ones: subsurface flow, infiltration from river channels and precipitation. Underground inflow and precipitation account for 10 km^3 per year (37% of total groundwater resources), while 63% of the recharge comes from anthropogenic sources (infiltration from irrigation canals and reservoirs as well as seepage from irrigated areas). Groundwater resources with mineral content of up to 1 g/L are estimated at approximately 8.91 km^3, and with mineral content of up to 5 g/L at 24.09 km^3. The largest groundwater resources are located in the Fergana Valley (35%), Tashkent Province (26%) and Samarkand Province (18%). Renewable groundwater resources amount to 8.34 km^3, of which 50% is drinking water (Kazbekov *et al.* 2007, Rakhmatullaev *et al.* 2012).

The main cross-border aquifers are the area around the Tuyamuyn Reservoir and the canals supplying water between Turkmenistan and Uzbekistan; the mountain forelands of the Mirzacho'l with cross-border aquifers lying between Kazakhstan and Uzbekistan; the area in the Zeravshan River basin between Tajikistan and Uzbekistan (Rakhmatullaev *et al.* 2012); the area in the Fergana Valley between Kyrgyzstan and Uzbekistan (Howard and Howard 2016).

Water circulation conditions are diverse. Near-surface groundwater in deltas of major rivers is the fastest to respond to recharge; these resources are estimated to account for 12% of the total groundwater resources in Uzbekistan. The water exchange period in intermountain depressions and river valleys, and meanders and alluvial fans in mountain foreland areas ranges from 18 to 50 years, and in artesian basins from 95 to 1,500 years (these figures are estimated to apply to 75% and 13% of total groundwater resources, respectively) (Kazbekov *et al.* 2007, Rakhmatullaev *et al.* 2012).

Research on the aquatic environment and water management as well as the inventory of water bodies and hydraulic structures of potential importance for tourism development in Uzbekistan were carried out in 2018–2020.

The research was carried out using the following methods: library research, research of online materials, analysis of documents and literature, map analysis; with respect to the field recording of hydrological phenomena and facilities related to so-called water tourism, heritage inventory and hydrological mapping methods were also used. The scope of field studies was limited to the Uzbek part of the Syr Darya and Amu Darya River basins and the border areas of neighbouring countries.

3. Study Results

3.1. Water Management Problems

Climate conditions and the uneven distribution of water resources force irrigation in agriculture and limit its development. Staple crops grown in Uzbekistan are cotton and wheat as well as maize, vegetables and fruit. The irrigated area increased from about 1.3 million hectares to 4.2 million hectares between 1900 and 2000, with the total agricultural area in Uzbekistan now amounting to around 5.2 million hectares. It is estimated that due to inefficient irrigation systems, 70% of water is lost between the river and the crop (Rakhmatullaev *et al.* 2012). Historical changes in irrigation significantly increased water losses through evapotranspiration, while climate change in the 20th century did not significantly affect regional water loss to the atmosphere. However, projected climate change may further increase net water loss to the atmosphere (Jarsjo *et al.* 2012).

Total water abstraction increased steadily from 45.5 km^3 to 62.8 km^3 between 1975 and 1985, mainly due to irrigation development. In the early 1990s, water abstraction started to decline as a result of water conservation in agriculture and the recession in the industrial sector. In 1994, total annual water abstraction in the entire economy was approximately 58.05 km^3. The largest amount was abstracted from surface waters (46.16 km^3), followed by groundwater (7.39 km^3) and withdrawal from return flow collector-drainage for irrigation purposes (4.5 km^3). In 2002, the water withdrawn, which amounted to over 17 million m^3/day, was distributed as follows: 6.9 million m^3/day as drinking water, 1.9 million m^3/day for industrial purposes, 4.5 million m^3/day for irrigation and 3.8 million m^3/day for drainage. As much as 60% of drinking water was abstracted from groundwater, which accounts for just 10% of total water resources. In 2002, 27,000 wells were in operation. Between 1965 and 2002, groundwater resources declined from 40.7 million m^3/day by about 40%). Water scarcity is most evident in the western and southern parts of the country where groundwater resources have been depleted due to intensive agricultural development (Kazbekov *et al.* 2007).

Long-term transformations of groundwater quality were caused by intensive development of irrigated agriculture, the allocation of river flows (massive infrastructure development which mainly occurred after 1965) and the degradation of natural environment in some regions. The average increase in aquifer pollution in the irrigated areas was about 5.7 km^2/year. As a result of the deterioration in their quality, Uzbekistan's groundwater resources were reduced by 0.26 km^3/year between 1965 and 1995. From 1965 and 1995, the volume of polluted water rose by 7.8 km^3, which was equivalent to 28.8% of total groundwater resources (Kazbekov *et al.* 2007).

As a result of discharge of collector-drainage waters into river systems, their reuse and the increased use of chemicals in agriculture, renewable groundwater resources in certain regions were polluted by salts, nitrates and pesticides (Rakhmatullaev *et al.* 2012).

As a result of seepage from inefficient drainage systems, the groundwater level of exposed aquifers began to rise, intensifying the dissolution of salts contained in the upper part of soil profiles (Jarsjö and Destouni 2004). In the lower part of the Amu Darya River valley, groundwater levels rose from 15–20 m b.g.l. in the 1980s to 1.0–1.5 m b.g.l. in the 2000s. The spatial distribution of groundwater salinity points to a relationship with the type of aquifer rock and the distance from the river along the main irrigation channels. Groundwater pollution proceeds gradually from upstream to downstream river reaches. In the lower part of the Amu Darya River basin, groundwater quality has also deteriorated in rural areas due to underdeveloped sanitation systems. According to the national environmental protection agency, around 35–38% of the fresh groundwater resources tested are not fit for drinking (Rakhmatullaev *et al.* 2012).

Rising groundwater levels have started to threaten famous historical monuments in Samarkand, Bukhara and Khorezm, which were built mainly of mud bricks. The national authorities have constructed a network of monitoring wells. In Bukhara, 173 monitoring wells and 181 vertical drainage wells have been drilled in order to pump approximately 0.021 km^3 of groundwater, which has allowed the water table to be maintained at approximately 2.1 m b.g.l. (Rakhmatullaev *et al.* 2012).

3.2. Hydrological Tourist Attractions of Uzbekistan

The nature of Uzbekistan's hydrological tourist attractions is conditioned by the country's "struggle for water" in its semi-arid climate – both with respect to drinking water and that used for economic purposes. Not just spectacular watercourses and water bodies (*e.g.* rivers, lakes, canals), but also small water retention facilities and minor infrastructure elements (*e.g.* urban canals, historical wells, springs and retention basins), subject to various types of human pressure and often undergoing rapid transformation, are of potential tourist importance there. Uzbekistan's great cross-border rivers – the Amu Darya and the Syr Darya – have a huge impact on the functioning of the country's economy (agriculture, including cotton and rice growing, as well as energy production). The peculiar phenomena of Uzbekistan are its lakes – ephemeral water bodies, which are in some cases subject to degradation resulting from human activity (*e.g.* the Aral Sea) and in other cases arise as a result of economic activity – intentionally (*e.g.* the Kayrakkum and Chardarya Reservoirs) or unintentionally (*e.g.* the Sarygamysh Lake, the Aydar-Arnasay system of lakes). Great canals with lengths ranging from 100 to 400 km (the Amu-Bukhara Canal, the Great Andijan Canal, the Great Fergana Canal) serve irrigation purposes and supply water to urban areas. Small but distinctive hydraulic infrastructure is skilfully integrated into this canal network.

The Aral Sea is an endorheic relict salt lake in Kazakhstan and Uzbekistan, situated in the Turan Depression. As a result of human pressure, it has been degraded and fragmented into four separate water bodies: the North Aral Sea, the Barsakelmes Lake (former bay) and the south-western and south-eastern basins. The south-eastern basin is shallow, highly saline and ephemeral. The Aral Sea began to experience quantitative degradation in the 1960s as a result of the waters from the Amu Darya and Syr Darya Rivers (which used to feed the lake) being abstracted for irrigation purposes in connection with cotton growing. Uzbekistan is currently the 6th largest exporter of cotton in the world. Inefficient irrigation caused up to 70% of water taken from the Syr Darya and Amu Darya Rivers to be lost. It is estimated that 20 to 50 km3 of water had infiltrated into the ground by 1960. Some Amu Darya River waters flow into the Sarygamysh Basin located west of the river, where they feed the saline Sarygamysh Lake. In 1960, the area of the Aral Sea amounted to 68,900 km2, but by 2017 it had decreased to 8,600 km2. The lake's capacity decreased from 1,064 km3 in 1960 to 399 km3 in 1999, and the water table dropped by 13 metres. The amount of Amu Darya and Syr Darya River water used for irrigation doubled between 1960 and 1980, as did the scale of cotton production (Figure 2). The water from the Amu Darya and Syr Darya Rivers has also been used for growing rice. In semi-desert areas, monocultures of plants with high water requirements were established. Excessive farming and improper water management inhibited the lake's recharge from rivers.

In the 1980s, the fish processing industry in the Aralsk region collapsed. Before the lake had disappeared, the livelihoods of most of the population depended on fishing and tourism. When the lake began to dry up, 100,000 people emigrated from its vicinity, some settling on the shores of the Caspian Sea. Most of the fauna inhabiting the waters of the Aral Sea died out as a result of the increase in salinity (up to 24‰), while the incidence of diseases such as tuberculosis, typhoid and anaemia grew significantly among the inhabitants of the region. It is estimated that the cost of collapse of the agri-food economy and tourism, and above all the cost of the humanitarian aid required averages two billion U.S. dollars per year. The desert formed at the bottom of the drained lake is called Aral-kum. It covers an area of 50,000 km^2 and is contaminated with the pesticides and fertilisers that had previously flown into the water body. The most important climate and environmental consequences of the drying up of the Aral Sea include mesoclimatic changes (a trend towards a continental climate), the degeneration of river delta ecosystems, an increase in the incidence of sand and salt dust storms, the shortening of the growing season, a decrease in agricultural crops and the contamination with crop protection products flushed from the fields by irrigation canals.

Figure 2. Agricultural crops in the Amu Darya River valley: a – cotton crops; b – cotton, c – rice fields, d – maize crops.

Source: photo by J. Różkowski and M. Rzętała.

In 1993, Kazakhstan, Uzbekistan, Turkmenistan, Kyrgyzstan and Tajikistan established the Aral Sea Rescue Fund. In 2003, a project supported by the World Bank was launched to revitalise the northern part of the Aral Sea. In August 2005, the Kökaral Dam, which separated the waters of the North Aral Sea from the southern part, was completed. The dam was built in a narrow section of the lake, forming an extension of the Kökaral Peninsula. The level of the North Aral Sea, which is fed by the Syr Darya River, has risen and its salinity has decreased. By 2015, the water table had risen by 12 metres and the shoreline had come within 15 km of its initial position from before the disappearance of the lake. This allowed the partial restoration of biodiversity, the return of some residents and the gradual revival of the fishing and processing industries. To date, there have been no plans to revitalise the southern part of the lake. The eastern basin of the lake disappeared completely in May 2009. The western basin is much deeper, and constructing a canal that would drain the rivers of the Amu Darya River directly into this basin could reduce its salinity and thus enable the resurgence of fishing in the region. It should be noted that in geological history, water levels in the Aral Sea underwent large fluctuations and the lake most probably dried up and then filled with water again repeatedly.

The Amu Darya River is a cross-border river flowing through Uzbekistan, Turkmenistan and Afghanistan, with a length of over 1,400 km and a basin area of about 465,000 km^2. Its sources are the Panj and Wakhan Rivers and its other tributaries are the Kofarnihon, Surxondaryo, Sherobod and Kunduz Rivers. As an allochthonous (transit) watercourse, the Amu Darya River flows between the Karakum and Kyzylkum Deserts. It flows into the Aral Sea basin where it forms a delta. Near the mouth of the river, the town of Mo'ynoq was situated, which is now depopulated and partially abandoned due to the ongoing process of disappearance of the Aral Sea since the mid-20th century (Figure 3). The waters of the Amu Darya River are excessively used to irrigate agricultural land via numerous canals, with some of the waters also reaching the depression of the Sarygamysh Basin where a large body of water – the Sarygamysh Lake – formed in the 20th century. The considerable amount of water abstracted from the Amu Darya River along its course has resulted in the gradual reduction of the river's water resources, even leading to the complete disappearance of water flow before its outlet to the lake. Other consequences of the river's use for economic purposes have been the pollution of its waters as a result of the inflow of pollutants from agricultural land and urban sewage.

Figure 3. Amu Darya River in the vicinity of Nukus

Source: photo by M. Rzętała.

The Sarygamysh Lake is currently an endorheic saline water body on the border of Uzbekistan and Turkmenistan, located within the Turan Depression, in the Sarygamysh Basin depression, which in the geological past was repeatedly flooded by river waters and its lower parts became ephemeral lakes. The Sarygamysh Lake was primarily fed by the waters of one of the branches of the Amu Darya River. The excessive use of those waters for irrigation in agriculture was the direct cause of the lake's complete disappearance in the early 20th century. All that remained were salt marshes. The water flowed again into the Sarygamysh Lake from the main channel of the Amu Darya River through a network of canals which was extended in the 20th century, resulting in the re-emergence of this water body, which now has an area of about 5,000 km^2 and a maximum depth of about 50 metres. The water table is at around 60 metres b.s.l. Its waters currently exhibit very high salinity and are contaminated with pesticides and herbicides which flow with runoff from cotton-growing areas. Thus, the modern-day Sarygamysh Lake is a new body of water created by the retention of water discharged from the irrigation systems which function within the Sarygamysh Basin. Nature protection areas with bird sanctuaries and nesting sites have been established on the lake.

The Syr Darya River is the longest river in Central Asia, a cross-border watercourse flowing through Uzbekistan, Tajikistan and Kazakhstan, with a basin area of 219,000 km^2. The Syr Darya River originates in the eastern part of the Fergana Valley at the confluence of the Naryn and Kara Darya Rivers (the total length of the Syr Darya River after including the Naryn River as its upper reach is more than 3,000 km). The Syr Darya River runs through the Fergana Valley and the eastern part of the Kyzylkum Desert and then flows into the Aral Sea basin where it forms a delta corresponding to the former extent of the lake. Is main tributaries are the Chirchiq and Arys Rivers (both right-hand tributaries). The average discharge 181 km from the mouth of the river is 406 m^3/s. The Syr Darya River waters are intensively used for irrigation, among others via the Great Fergana Canal. In the Fergana Valley, there is the Kayrakkum Reservoir with an area of 513 km^2, and the Kayrakkum and Farkhad hydropower plants operate there. Near Tashkent, there is the Chardarya Reservoir with an area of 900 km^2 (Encyclopedia 2007a).

The Kayrakkum Reservoir (whose Tajik name is Bahri Tajik) is an reservoir impounded by a dam on the Syr Darya River in Tajikistan whose backwater zone reaches the territory of Uzbekistan in the western part of the Fergana Valley. It is about 55 km long, up to 20 km wide and covers an area of 513 km^2. Its maximum capacity is about 4.2 km^3, its average depth is 8.1 m and its greatest depth is 25 m. It was first filled with water in 1956–1958, primarily for irrigation purposes, and is now also used for fishing (http://bse.sci-lib.com/article057705.html).

The Chardarya Reservoir is an artificial reservoir on the Syr Darya River on the border of Kazakhstan and Uzbekistan. The reservoir is about 70 km long, 20 km wide and covers an area of 900 km^2. Its maximum volume is 5.9 km^3 and its average depth is 6.5 metres. The Reservoir was filled with water from 1965 to 1968. It was created in connection with the construction of a hydropower plant and dam at Chardarya. The purpose was to improve water supply in irrigated areas and prevent flooding along the Syr Darya River. This facility is used for electricity generation and is also important from the point of view of fisheries development.

The Aydar Lake is situated near Nurata in Uzbekistan. It has formed in a saline depression where only the ephemeral Lake Tuzkan had previously been present in the spring. During the catastrophic Syr Darya River flood in 1969, the floodgates of the Chardarya Reservoir were opened and almost 60% of the river's average discharge (21 km3) overflowed into the depression of the Arnasay Plain. Since 1969, Lake Aydar has regularly received the waters of the Syr Darya River when the Chardarya reservoir overflowed and as a result, the largest lake in Central Asia (after the Caspian Sea) has formed. Today, the lake has an area of 3,000 km2, a length of about 250 km and a width of 8 to 15 km. The average total dissolved solids concentration in its water is 2 g/L. Commercial fishing currently takes place on the lake. The lake system provides between 760 and 2,000 tonnes of fish per year (according to 1994–2001 statistics). In addition to the fauna found in the Kyzylkum Desert, many species of water birds live around the lake which migrate from the Aral Sea. In 2010, 1,760 people lived in the rural areas around the lake (https://en.wikipedia.org/wiki/Aydar_Lake).

The Tuzkan Lake is part of the Aydar, Arnasay and Tuzkan lake system. The endorheic, brackish Lake Tuzkan dried up repeatedly in the past. Until the late 1960s, it was a natural lake. In 1969, as a result of the discharge of water from the Chardarya Reservoir, the Aydar Plain was filled with water and merged with the natural lake. It is the southernmost lake in the Aydar-Arnasay system and is joined with the Aydar Lake to the northwest. The length of the lake is 35 km and its width ranges from 22 to 25 km.

The Amu-Bukhara Canal is located in southern Uzbekistan and partly in Turkmenistan. It starts on the right bank of the Amu Darya River near Türkmenabat and runs north through the Kyzylkum Desert to the area of the so-called Bukhara Oasis where it terminates, springing numerous branches. The canal, with all its branches totalling approximately 400 km in length and a maximum throughput of 270 m3/s, was built in the years 1965–1976. It was constructed to increase the water supply for agriculture in the Bukhara Oasis and also to enhance water supply for Bukhara and the surrounding villages. There are 65 hydraulic structures on the canal, including 11 pumping stations which feed water upstream into the old Zeravshan River irrigation system. In the 1980s, 294,000 hectares of land were irrigated (https://agricultural_dictionary.academic.ru/1477/АМУ-БУХАРСКИЙ_КАНАЛ#sel=).

The Great Andijan Canal is a gravity irrigation canal constructed between 1966 and 1970 in the Fergana Valley in eastern Uzbekistan. It begins near the Uchqo'rg'on hydropower plant on the left bank of the Naryn River and runs towards the south, crossing the Naryn and Kara Darya Rivers, and subsequently towards the south-west through the central part of the Fergana Valley, terminating in the so-called North Baghdad Collector. The length of the canal is 109 km. Its primary function is to supply water for agriculture in the Fergana Valley, specifically irrigating about 140,000 hectares of land with an average throughput of about 200 m^3/s and a maximum throughput of 330 m^3/s (https://agricultural_dictionary.academic.ru/1699/БОЛЬШОЙ_АНДИЖАНСКИЙ_КАНАЛ#sel=1:2,1:2).

The Great Fergana Canal is also an irrigation canal, which is 345 km long (283 km in the territory of Uzbekistan and 62 km in the territory of Tajikistan), up to 4 metres deep and 25 to 30 metres wide, irrigating the southern part of the Fergana Valley. The canal was built in 1939–1940. It is fed by the Naryn River at 18–267 m^3/s and by the Kara Darya River at 14.7–165 m^3/s depending on the season. The canal begins near the Uchqo'rg'on hydropower plant and runs towards the south, then towards the south-west and west towards the Syr Darya River, crossing its left-hand tributaries and finally flowing into the Syr Darya River in the Khujand area. The primary function of the canal is to irrigate agricultural land, especially cotton fields, and thus it has significantly contributed to the disappearance of the Aral Sea (https://dic.academic.ru/dic.nsf/enc_geo/963/Большой).

The spectacular hydraulic projects in Uzbekistan are accompanied by numerous small retention facilities and minor hydraulic structures such as wells, springs, pools, canals, ditches, damming structures, flow regulation facilities, ponds, facilities for breeding fish and other aquatic organisms as well as retaining walls, boulevards, quays, piers, jetties and harbours, facilities enabling transport between river banks and systems for draining excess rainwater. These are small water infrastructure elements which form part of the overall water management system and at the same time are potentially important for the development of tourism as examples of water facilities with a long tradition of use in the country's everyday life and economy (Figure 4). Tourists in Uzbekistan should pay special attention to its canals and ditches, wells, springs, pools and ponds.

Figure 4. Small hydraulic structures in a mulberry paper factory: a – ditch bringing water to the factory; b – water wheel; c – grinder driven by the energy of flowing water; d – small pond.

Source: photo by J. Różkowski and M. Rzętała.

In Uzbekistan, numerous small canals and ditches are present whose role – mainly in irrigation – is to enable the so-called "water shunting". By means of those canals, surface water is transported locally to augment the resources of other natural watercourses, canals, ponds, small reservoirs, and indirectly also groundwater (Figure 5). Final stages of this water supply system are arable fields, plantations, greenhouses, water points and watering holes. Plots of land used for agriculture which are filled with water up to the edges of the small levees that bound them are a common sight. The small polders created in this manner provide efficient irrigation from dusk to dawn, *i.e.* during the period when the least water is lost to evaporation.

Springs and wells play a major role in meeting local water needs in arid and semi-arid areas. Groundwater outflows to the surface or the presence of these waters in holes artificially drilled or dug in surface formations are the basis for the functioning of oases in desert and semi-desert conditions, and in other areas they provide one of the sources of water supply. Thus, these locations are of socio-economic importance (*e.g.* for settlement, agriculture and as a factor conditioning the location of industrial facilities). Occasionally, medicinal properties are attributed to waters in springs and wells or such sources are treated as places of worship.

Pools and ponds are small retention facilities whose origins can be considered in terms of their morpho- and hydrogenesis. Morphogenetically, these are usually man-made depressions (former mineral workings, areas surrounded by levees or dams or simply ponds dug for a specific purpose) and less often natural ones (*e.g.* deflation basins, oxbow lakes). The presence of water in such pools and ponds is a consequence of groundwater drainage; they are also fed by periodic precipitation and inflows from storm water drainage systems and additionally as a result of water transfers via canals, ditches and pipelines. These pools and ponds are mostly multipurpose in nature. They fulfil natural and landscape functions (*e.g.* as bird nesting and breeding sites which also shape the local climate and microclimate and are a stage in the self-purification of water). At the same time, they have economical uses as sources of water supply for various purposes (industrial, municipal, agricultural), places of recreation and tourism destinations as well as locations for breeding fish and other aquatic organisms.

Figure. 5. Small retention facilities and hydraulic structures: a – a canal in Samarkand, b – a spring below the Tomb of Daniel in Samarkand, c – a well in Sardaba, d – a pool in Bukhara, e – a pond in Bukhara, f – part of an urban irrigation system in Bukhara.

Source: photo by J. Różkowski and M. Rzętała.

Conclusion

Uzbekistan, which occupies an area of almost 0.5 million km^2 in the heart of Central Asia and has a population of about 33 million, must ensure the proper management of groundwater and surface water reserves given their limited amount in its arid and semi-arid climates and the deterioration of their quality. Scientific research, also conducted by international teams, is mainly aimed at optimising water management in agriculture where as much as 80% of agricultural land is irrigated, with water losses between the river and the crop reaching 70% due to inefficient drainage systems. As a result of their intensive exploitation, groundwater resources had declined by about 40% in the 2nd half of the 20th century, especially in the western and southern parts of the country. The changes in groundwater quality were caused, inter alia, by the intensive development of irrigated agriculture (the discharge of collector-drainage waters into river systems and their reuse, the use of agricultural chemicals), the allocation of river flows and the degradation of the natural environment in certain regions. It is estimated that up to 40% of Uzbekistan's fresh groundwater resources may be unfit for drinking.

The nature of Uzbekistan's hydrological tourist attractions is conditioned by the country's "struggle for water" in its semi-arid climate. They are structures built to regulate the flow of surface waters which interact with groundwater resources. Uzbekistan's great cross-border rivers – the Amu Darya and the Syr Darya – which are recharged in mountainous areas meet the water demand of the desert parts of the country and have a huge impact on the functioning of its economy. Lakes and artificial water reservoirs which provide retention capacity play an auxiliary role in this process. The overexploitation of water in the Syr Darya and Amu Darya River basins has led to the extreme anthropogenic degradation of the Aral Sea and has simultaneously caused the formation of the Sarygamysh Lake. The catastrophic flood of the Syr Darya River in 1969 resulted in the formation of the Aydar-Arnasay system of lakes. Impressive artificial reservoirs used for irrigation (the Kayrakkum Reservoir) and power generation (the Chardarya Reservoir) blend into the mountain landscape. Great canals with lengths ranging up to several hundred kilometres (the Amu-Bukhara Canal, the Great Andijan Canal and the Great Fergana Canal) which feature complex hydraulic structures serve irrigation purposes as well as supplying water to semi-arid areas. The water shunting system is complemented by skilfully integrated small hydraulic infrastructure, which is characteristic of Uzbekistan. This consists of numerous small retention facilities and hydraulic structures (*e.g.* springs and wells, pools, canals, ditches, flow control structures), which are part of the water management system and are also potentially important from the point of view of tourism development.

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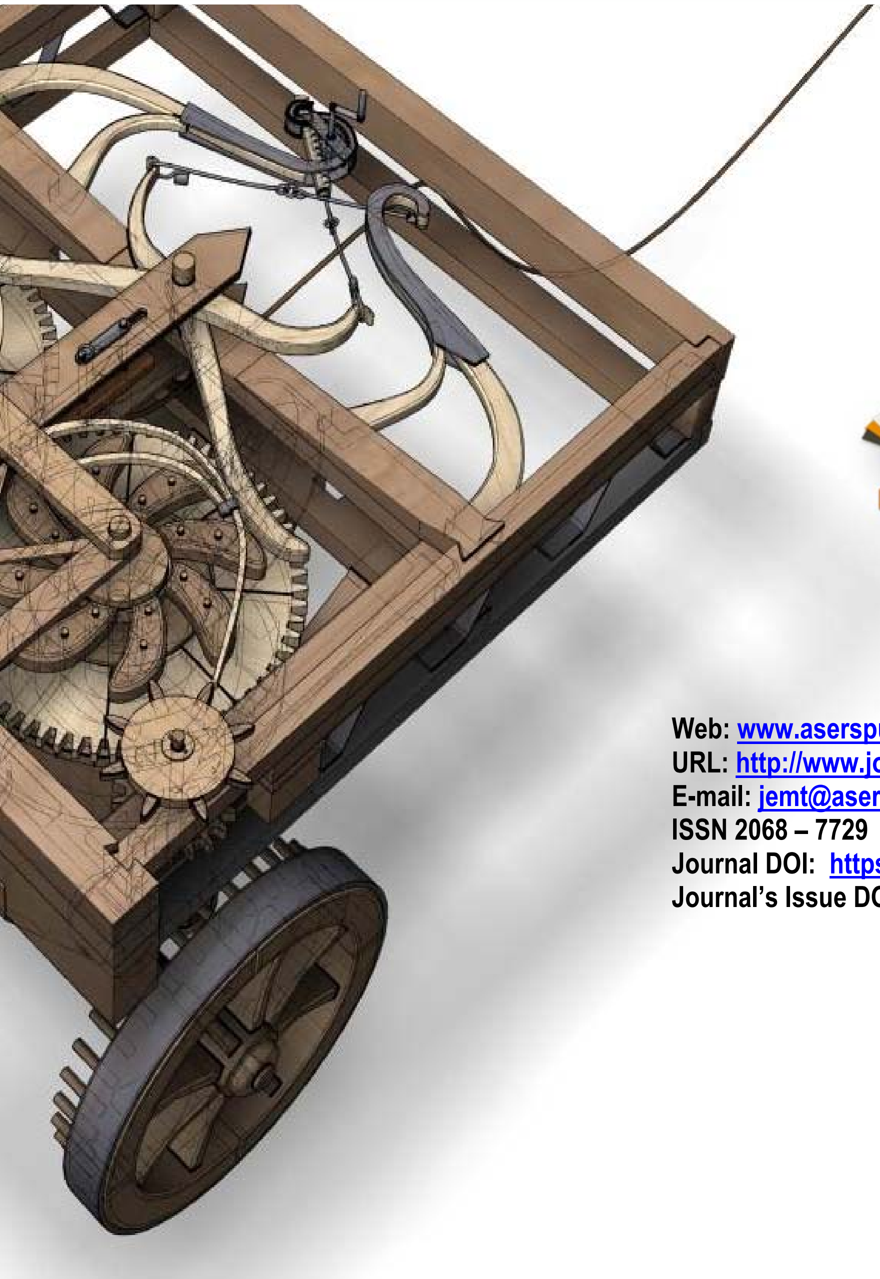

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