Analysis of Changes in the Ecological Space of the Ili River Delta (due to Reduced Flow of the Ili River)

Moldakhanova, Nailya
Department of Chemical Processes and Industrial Ecology, Satbayev University

Alimkulov, Sayat
Institute of Geography and Water Security

Smagulov, Zhanibek
Laboratory of Water Resources, Institute of Geography and Water Security

https://doi.org/10.5109/6781031

出版情報：Evergreen. 10 (1), pp.29-35, 2023-03. 九州大学グリーンテクノロジー研究教育センター
バージョン：

Analysis of Changes in the Ecological Space of the Ili River Delta (due to Reduced Flow of the Ili River)

Nailya Moldakhanova[1,2,*], Sayat Alimkulov[3], Zhanibek Smagulov[2]
[1]Department of Chemical Processes and Industrial Ecology, Satbayev University, Almaty, Republic of Kazakhstan
[2]Laboratory of Water Resources, Institute of Geography and Water Security, Almaty, Republic of Kazakhstan
[3]Institute of Geography and Water Security, Almaty, Republic of Kazakhstan

*Author to whom correspondence should be addressed:
E-mail: nail.moldakh@gmail.com

(Received January 18, 2023; Revised February 20, 2023; accepted March 22, 2023).

Abstract: The construction of the Kapchagay Reservoir led to the withdrawal of a portion of the water from the river, which reduced the water flow, the situation has gradually been resolved, but the water level in the lake and the flow still need to be monitored. The purpose of the study was to investigate trends in the characteristics showing the state of the ecosystem. A more detailed analysis of changes in meteorological conditions observed in the region according to weather stations revealed significant changes in the water regime and average annual flow of the river. These indicators were obtained at special weather and hydrological stations located along the riverbed and the surrounding area. Climatic changes and anthropogenic factors have had some impact on the flow rate. Rising temperatures and rainfall have affected the glaciers of the Tien Shan Mountain system, increasing the amount of water in the Ili River. At the same time, water intake for agricultural needs had no noticeable effect. Changes in the flow rate are directly related to the biocenosis of the region. The area outlying the river and lake and the delta may become arid due to declining water levels. In this case, the space next to the water will be used more actively. For this reason, it is very important to monitor changes in the flow, as the entire ecosystem depends on the water level. The construction of the Kapchagay Reservoir has certainly had some impact on the water level of the lake and the volume of water flowing into the river, but at this point, the effect of the reservoir has been overridden by the sensitivity of the glaciers. At this point, it is impossible to predict exactly how the situation will unfold, but it is recommended to pay close attention to it.

Keywords: Balkhash Lake; Kapchagay Reservoir; river water flow; delta ecosystem

1. Introduction

The Ili River has its source in the Tien Shan Mountain system at an altitude of 3540 m above sea level in the People's Republic of China (PRC) and is formed by the confluence of the Tekes and Kunge rivers. The riverbed has many channels extending from it throughout the territory of the Republic of Kazakhstan. The delta is 8000 km^2 in size and is formed by the mouth of the Ili River flowing from the south into Lake Balkhash, namely, it is western part. Lake Balkhash became the largest lake in Central Asia after the Aral Sea (a drainless salt lake) dried up[1]. Approximately 70-80% of the lake's annual inflow is provided by river Ili. The Ili Delta is the largest natural wetland complex in Central Asia, which has a constant inflow of water, due to which it continues to be classified as an undisturbed biocenosis. The distinctive features of the delta are numerous sprawling arms of rivers and lakes, between which lie barchan fields[2),3)].

The Ili River has a huge impact on the ecosystem and biodiversity of this region, and its delta is a prime example of a wetland complex in Central Asia. The Ili River is a cross-border river shared by Kazakhstan and China. Two source rivers form Ili, Kunes (on the territory of the PRC)[4]. The other tributaries originate from the southern slopes of the Jungar Alatau mountain range and the northern slopes of the Uzinkar (Ketemen) range, which belongs to the north-eastern part of the Tien Shan. Both ranges belong to both the Kazakh and Chinese Republics. In Kazakhstan, several more rivers flow into the Ili, the largest of them are Charyn (Sharyn) and Chilik (Shilik)[2].

Although various studies have been carried out on the ecological impact of reservoirs on natural water bodies[5),6)], the process of formation of delta-like landscapes in estuaries has not been considered in sufficient detail. Previously, this phenomenon has been studied, in most cases, solely from the point of view of decreasing the carrying capacity of a body of water through siltation[7)-9)] . However, the issues involved in this process are much more diverse, complex, and important for the development of natural complexes, increasing their biodiversity, and preserving the environment of the whole region. In most cases, large reservoirs around the world, particularly those located in arid, subarid, and sub-humid zones, form new (inland) deltas with specific soil and vegetation cover and rich fauna after their construction[5]. In arid climates, the construction of new reservoirs creates conditions similar to delta formation processes – a delta is formed where a river flows into a large body of water[10)] . As a result, new forms of relief are formed due to the presence of hydrophilic plants and the accumulation of organic matter, in other words, hydrological and morphological processes occur. This study examined the process of changing the ecological space of the Ili River after the construction of the Kapchagay Reservoir on it. The purpose of the study was to investigate trends in the characteristics showing the state of the ecosystem.

2. Literature review

The Ili River can be divided into three parts: the eastern upper part is located on the territory of the Xinjiang Uygur Autonomous Region (XUAR) of the Republic of China and the main part of the basin flows into it; the middle and lower parts lie on the territory of the Republic of Kazakhstan, Almaty region. The Ili River is 1439 km long, up to 22 km wide and 45 m deep, with an estimated total flow of 20.6 km^3 as of 2004. The river's water is often withdrawn upstream in China and Kazakhstan for irrigated agriculture and domestic use, accounting for about 90% of total water withdrawals[11)]. Water is a scarce resource in Central Asia, and many catchments span international boundaries, among them that of the Ili River, which China and Kazakhstan share. Since 1970, the natural hydrological regime of the Ili River, both absolute flow rates and cycles, has changed due to the construction of reservoirs such as that at Kapchagai, as well as natural climatic cycles and the growth of water consumption in the basin. The Ili River is also used in energy production at the Kapchagay Hydroelectric Power Plant (HPP). The use of river water supply for energy, agricultural and drinking purposes occurs on a relatively large scale in China[12)]. During the last 300 thousand years, the delta of the Ili River has changed its position 5 times. Under the influence of sedimentary and tectonic processes, the top and front of the delta gradually shifted to the northwest, turning counter clockwise, up to the present shore of Lake Balkhash. At the same time, the delta area also underwent changes, namely, it decreased in size[13)].

Currently, the Ili River delta is located on the western shore of Lake Balkhash. Lake Balkhash is the fifth largest isolated reservoir in the world, located in Central Asia in the south-east of Kazakhstan. It is an important water body with rich aquatic flora and fauna and especially diverse birdlife. The economic value of the lake is mostly represented by local fisheries and bathing resorts. The hydrological balance of Lake Balkhash is mostly controlled by climate conditions in the upper reaches of its main tributary, the Ili River, and the generated discharge entering the lake[14)].The lake is located at an altitude of 342 meters above sea level and is 605 kilometres long from east to west, with a width ranging from 9 to 74 kilometres. The total area of the Lake Balkhash basin is 413000 km^2, and it can be divided into two parts, the largest of which (85.9%) belongs to the Republic of Kazakhstan and the smaller (14.1%) – to China. In the last century, due to fluctuating water levels in Lake Balkhash, changes in climatic conditions and surface runoff, a drought occurred in the Balkhash basin. Drought can be both meteorological, resulting from changes in precipitation and evapotranspiration, and hydrological or agricultural due to changes in water flow and soil conditions[15)]. The Ili River is the main water source for Lake Balkhash, and the water resources entering the lake basin from Ili are approximately 10.9 km^3/year. About 3 km^3/year comes from other mountain rivers. Runoff mainly comes from precipitation and snow and ice melt, which are vulnerable to climate change[16)].

Lake Balkhash is exposed to the threat of exaggerated anthropogenic water subtraction due to an accelerated infrastructural and demographic boost that doubled the irrigated farmlands in the Chinese part of the catchment in less than 20 years. Due to the lake's hydrology, catchment rock and hydrochemical conditions, the water of the Eastern Balkhash has high concentrations of potassium and magnesium, unfavourable for hydrophones. Any further increase in salinity will soon cause a considerable diminution of the lake's biomass. The ichthyofauna of the lake has been intensively manipulated during the twentieth century, with the introduction of new species and the decline of the original ones. The substitution of the native fish fauna by introduced species caused a decrease in valuable commercial fish in the lake and a decrease in the total fish catch. Thus, Lake Balkhash faces serious environmental risks today and its near future depends on the collective will and decisions of the responsible agencies[17)].

3. Materials and methods

To assess the impact, a statistical analysis of long-term data on hydrometeorological indicators, such as river flow, lake water level, temperature, and precipitation, was carried out. It is worth noting that fluctuations in the water level of Lake Balkhash have been observed but based on analysis of changes in its parameters over the past 85 years, it is clear that the probability of a drop below 341 m is very low[18),19)].

To obtain data on the amount of monthly, seasonal, and annual precipitation and temperature, reports from previous years and up-to-date information from weather stations were used. Direct registration of all indicators, including metrological and the volume of water runoff, was carried out at special weather stations and posts located on the Ili River. Previously, hydrological observations in the Ili River delta were carried out at 16 hydrobiological stations forming the network, and also by the Institute of Geography of the Kazakhstan Hydrometeorological Service. The recorded indicators at these posts covered the water flow at the inlet and outlet of the delta[20)]. In this study, material from 4 hydrological stations was used, the locations of which are indicated in Figure 1. The indicators of the annual flow of the river were formed based on available data from the hydrological station. Gaps in observations were levelled by using similar points, which were hydrological measuring stations located along the river. The correlation coefficients between the runoff indicators at different stations ranged from 0.70 to 0.93.

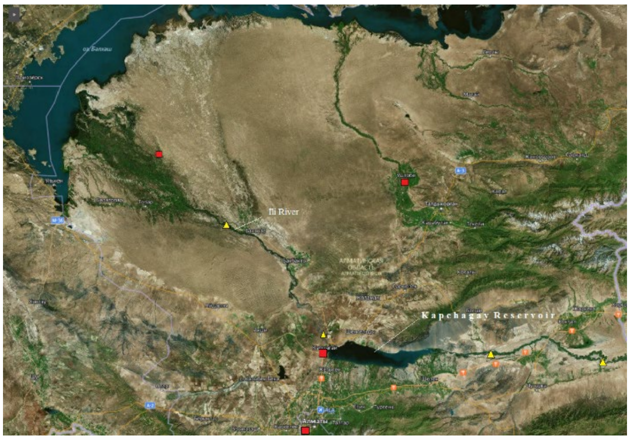

Fig. 1: A map of the Ili River with hydrological and weather stations located on it

Note: Yellow triangles indicate hydrological stations, and red squares indicate weather stations.

While the difference integral curve considers the fluctuations of the flow in relatively short periods of time and is constructed by summing the deviations of the modular coefficients from the middle. Its ordinates are calculated as:

$$\sum_1^i (K-1) \tag{1}$$

where: $K = Q_i/Q^{-}$.

The difference integral curves allow determining the flow volume (relative to the mean value) for any time interval, for which reason they can be used when selecting individual hydrological stations as the points on which the curve will be plotted. Analysis of climate change in the study area used data from four meteorological stations: Almaty, Kogaly, Usharal and Bakhty. It is worth noting that observations of climatic parameters have been conducted at the Almaty Meteorological Station since the end of the 19th century, but not permanently. The location of this weather station has since changed. The indicator of the average annual air temperature tended to increase with periodic fluctuations of values in certain periods since the beginning of observations. The study of the ecology of the Ili River delta itself was carried out based on measurements made at measuring stations: "164 km upstream Kapchagay HPP" located in the upper part of the Ili River of Kapchagay HPP[21)].

4. Results and discussion

Ili River water is actively used in energy, agriculture (irrigation), fishing and utilities, and industry. The impact of these factors was taken into account along with the main one – Kapchagay reservoir. The findings of the Kazakh researchers[18] are based on data from meteorological stations of Almaty, Kogaly, Usharal and Bakhty, and cover a broader time from 1881 to 2015, while Chinese studies date back to the time period from 1931 to 2015. The Almaty meteorological station is located next to the Kapchagay reservoir, while Usharal and Bakhty lie in the north-eastern part of the study area. The Kogaly village weather station is located in the centre of the region, northeast of the Kapchagay reservoir.

Thus, researchers from Kazakhstan have found the following fluctuations in the mean annual temperature over time at the weather station in Almaty (787 meters above sea level): from 1881 to 1911 it was ≈ 7.2°C, from 1911 to 1940 the value rose to 8.5°C and from the early 1970s, there was the most intense increase, which by the period 2010-2015 had reached 10.7°C. At the Kogaly weather station (1410 m above sea level), an average annual air temperature has also been observed since the 1970s, and in the period 1928-1976 the indicator was close to 4.4 °C, and in 1977-2015 it reached 5.35 °C. According to data from the Bakhta weather station, the average annual temperature changed from -1.9°C in 1933-1970 to -0.8-0°C in 1970-2000. And at the Usharal weather station, the indicator increased from 6.40°C to 7.50°C in the same time intervals. To summarise the research on this indicator, two observations can be made based on both studies. Firstly, the average annual temperature has increased significantly since the end of the 19th century, and secondly, the greatest changes affected the south-eastern region, which indicates a high rate of snow melting in the Tien Shan Mountain system.

According to Kazakh researchers, the average annual precipitation over the study period according to the Almaty weather station also increased from 580-600 mm in the 1928- the 1950s to 740 mm by the period of 2010-2015, the increase began in the early 1960s. At the Kogaly weather station, the average annual precipitation has been increasing since the late 1950s – in 1928-1955 it was 476 mm, and by the period of 1956-2015 it had grown to 545 mm. According to two other weather stations, Usharal and Bakhty, the average annual precipitation decreased in the period from the 1970s to the 1990s, but the general trend of this indicator has been tending to increase. At the same time, the results of Chinese researchers found a decrease in precipitation in the area of Lake Balkhash and the upper watershed of the Ili River, but the overall pattern suggests a statistically significant increase in average annual precipitation. Moreover, the indicator increased most clearly in the spring and summer periods, while in winter its increase was less noticeable. The trend towards an increase in the average annual amount of precipitation was, as in the case of the temperature index, much more pronounced in the south-eastern regions as opposed to the north-western areas[22]. To summarise the results of both studies, it is safe to say that average annual precipitation has increased over the past 100 years, but to different degrees in different parts of the region.

In addition to global climate change, studies have also shown changes at the level of individual factors, such as average annual precipitation and air temperature. The values of these indicators have increased especially strongly over the past forty years, which has led to an increase in the volume of river runoff. In addition to natural factors, agricultural activity also had an impact on the volume of river flow. To carry out the analysis, Kazakh researchers constructed total integral curves per the values of the restored conditionally natural annual runoff, taking into account the influence of economic activity. Standard methods for estimating statistical parameters and total integral flow curves were also used. The hydrological characteristics of rivers whose watercourses are actively used in agriculture were compared with rivers that have a natural water regime. A study of total integral curves of conditionally natural flowing rivers has led to the observation that the average annual flow of the main watercourse of the Ili River has been increasing since the 1970s. In addition, an increase in this parameter is also observed on the tributaries of the Ili River. The values of the increased annual flow of the river are estimated by the difference between the previous conditionally natural period before 1970 and the last forty years. Flow volumes at different time intervals are shown in Table 1.

As for the investigations conducted by Chinese researchers, their findings are based not only on changes in the volume of river flow, but also consider changes in population density over the past twenty years, as well as transformations in the vegetation cover of the riverbanks. Changes in the types of vegetation cover in the studied region from 1992 to 2015 were as follows: the largest land cover is pastures, occupying about 69% of the entire territory, followed by agricultural land, bare land and four other types of land cover, including reservoirs, forests, wetlands and building land, which account for a smaller proportion of the total area. Thus, the results of both studies indicate that agricultural land and population growth have an impact on the volume of runoff, provoking a tendency to increase the volume of water consumed from the river, but despite anthropogenic factors, the flow rate has increased, indicating that this parameter is not seriously affected by the above-mentioned factors.

Table 1. Water flow characteristics of the Ili River according to data from two hydrometeorological stations[15)]

Years of observations	Q, m^3/s (Flow volume)	N (number of years)
Kapchagay Hydrometeorological Station		
1911-2015	561	105
1911-1970	467	60
1971-2015	685	45
Difference in m^3/s (%)	218 (47%)	
Ushzharma Hydrometeorological Station		
1939-2015	588	77
1939-1970	468	32
1971-2015	673	45
Difference in m^3/s (%)	205 (44%)	

The average annual values of the flow rate index in the lower reaches of the Ili River have increased by 45% over the last 50 years since 1970, and the maximum value reached over the whole period (about 100 years) exceeded 1000 m^3/s. According to the findings of Chinese scientists, between 1982 and 2013, there was a significant increase in the evaporation rate over the entire land area (statistical significance of more than 95%). At the same time, the evapotranspiration of Lake Balkhash has decreased significantly. A significant increase in the average annual evaporation rate between the time 1982-1997 and 1998-2013 occurred in the following areas: part of the region belonging to China; the delta of the Ili River; the middle of the Ili River basin; to the north of the studied region. Thus, as shown in Table 2, the average annual seasonal evaporation rate was 317.01 mm with a tendency to increase (the statistical significance of which is more than 95%). At the same time, in winter there was a tendency for a significant decrease with a deviation of 0.09 mm/year. That is, winter was the only season with a downward trend, while the values of the total evaporation rate increased.

Table 2. Indicators of precipitation, temperature, and evaporation of the Ili River in different seasons

Meteorological factor	Season	Average value	Angular coefficient	P-value
Precipitation (1931-2015)	Annual value	273.16	0.442	0.029
	Spring	86.45	0.019	0.862
	Summer	76.24	0.059	0.550
	Autumn	61.08	0.164	0.042
	Winter	49.53	0.188	<0.001
Temperature (1931-2015)	Annual value	5.58	0.026	<0.001
	Spring	6.65	0.026	<0.001
	Summer	20.18	0.014	<0.001
	Autumn	6.28	0.024	<0.001
	Winter	-10.70	0.037	<0.001
Evaporation (1931-2015)	Annual value	317.01	1.68	<0.001
	Spring	89.09	1.00	<0.001
	Summer	153.08	0.64	<0.01
	Autumn	61.51	0.22	<0.01
	Winter	13.26	-0.09	<0.1

The results of the analysis of Kazakh researchers coincide with those obtained earlier by other researchers[23)-25)]. The novelty of this study lies in the observation regarding the factors that influence the flow rate. Significant fluctuations in the difference integral curve, based on data from several hydrological stations in the Ili River catchment, have been observed since 1970, which cannot be explained by anthropogenic factors alone. It has been suggested that climate change, namely the melting of glaciers in the last 10-15 years, has affected the increase in the volume of the river flow[26)-27)]. This theory coincides with the conclusion made by Chinese scientists. It is therefore appropriate to say that there is a high probability that this assumption will turn out to be correct.

At the same time, the loss of the Ili River water flow due to economic activity is primarily associated with the creation of the Kapchagay reservoir, which also had a significant impact on the change in the level of Lake Balkhash. The operation of the Kapchagay reservoir affected the flow of the Ili River and other rivers, significantly reducing their average annual flows, for example, for the Ili River, the water flow decreased to 13.4 km^3/year from 1970 through 1986. Moreover, the Ili River is the main river that controls the water level in Lake Balkhash, which has fluctuated between 340.50 m and 343.02 m over the past 85 years. Since 1970, after the commissioning of the Kapchagay reservoir, the lake level began to decline, and by 1986 it fell from 343 m to 340.7 m above sea level due to the retention of part of the water in the reservoir. Other factors also influenced the flow of the Ili River: upstream it was increased by higher precipitation and meltwater; however, the expansion of agriculture (0.74 10^3 km^2/year from 1992 to 2015) and population growth led to an increase in water consumption, which significantly reduced the water resource[21]. At the same time, temporary losses of the river flow due to the cost of filling the reservoir, and an increase in evaporation, contributed to an increase in the volume of water in the basin. Currently, the water level in Lake Balkhash is essentially restored to the levels of the 1960s and 1970s. It is worth noting that Lake Balkhash strongly depends on the Ili River, and periodic fluctuations in its level confirm a strong connection between the lake and the flow rate[28)].

The selected weather stations were located in different parts of the entire studied territory of the Ili-Balkhash region (Fig. 2). Meteorological data from these stations showed an upward trend in air temperature and precipitation, as well as an increase in the water content of the river. However, turning back to the changes in the water regime of the Ili River after the Kapchagay hydropower dam was built in 1969 and the filling of the Kapchagay Reservoir began in the mid-1970s, it is worth clarifying the details. According to the Kapchagay HPP data, between 1970 and 1986 there was a period of filling, during which the flow rate of the Ili River decreased to 426 m^3/s (13.4 km^3/year). Over time, the river's flow has settled and become more evenly distributed over the seasons, increasing the flow during low-water periods, and decreasing it during floods. During 1976-1980, due to regulation measures, the maximum water flow directed to the Kapchagay reservoir decreased from 1200-2000 m^3/s to 783-924 m^3/s, and the minimum increased to 102-155 m^3/s.

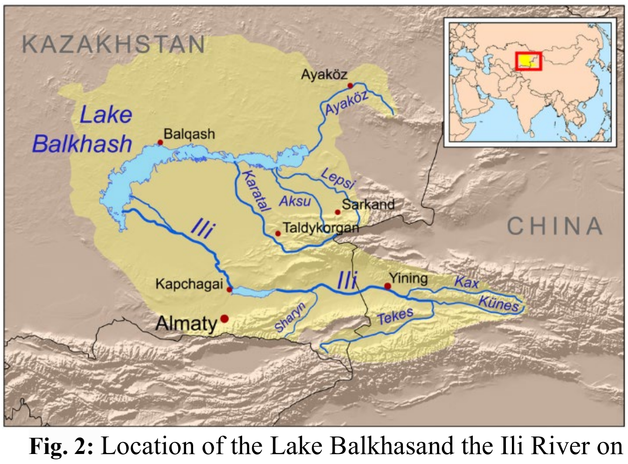

Fig. 2: Location of the Lake Balkhasand the Ili River on the map.

A decrease in the river flow causes the level in the lake to drop, which in turn provokes many negative consequences, such as degradation of wetlands, increased salinity in the lake, etc. To control the ecology of the region, a regular assessment of the composition of water produced at a river hydroelectric power station is necessary[29),30)]. Climate change and human activity strongly affect the state of water resources in the studied area. Since the 1970s, the average temperature in Central Asia has risen to twice that of the world average. Such changes directly affect the maximum thickness of the snow cover and its duration, as well as the reduction of glacial masses[31)]. Economic development and an increase in population density in recent years have led to significant changes in the distribution of vegetation over the soil cover, thereby increasing the burden on the water resources of the Ili River. Most of the agricultural land is located in the upper and middle of the river, thereby becoming dependent on the volume of flow due to the need for irrigation, especially during high air temperatures[32)] .

Next, further details on the delta of the Ili River will be considered. A significant part of the river flow is either lost to the processes of infiltration, evaporation, and transpiration in the area of the river delta since the delta itself is located in a zone of insufficient moisture[33), 34)]. Until the 1970s, the average long-term flow rate decrease in the delta was ~ 3.82-3.86 km^3/year. Taking atmospheric precipitation into account, the maximum decrease in volume was about 3.51-3.74 km^3/year. Between 1970 and 1987, due to water flow regulation measures, the magnitude of the decrease in the Ili River delta changed: water loss by evaporation on the open water surface decreased as the surface area of lakes decreased and water loss from wetlands and arid valleys increased. Ultimately, the reduction in the flow volume in the delta amounted to 3.1-3.2 km^3/year. The intensity and direction of Ili River delta development are currently determined by the flow regulation regime of the Kapchagay Reservoir. To preserve the natural potential of the delta, the water flow into the delta should be approximately 13.6-14.0 km^3/year, seasonal subsidence is 14.5 km^3/year, and the water level in Lake Balkhash is about 341-341.5 m.

5. Conclusions

The following conclusions were drawn from this study. Over the last hundred years, the air temperature has risen significantly, most notably in the south-eastern region, which may, in turn, have affected the rate of snowmelt in the Tien Shan Mountain system. At the same time, the amount of precipitation has increased. The increase in the above-mentioned indicators has led to an overall increase in river flows. Rapid population growth and agricultural expansion in both the Kazakh and Chinese parts of the river basin have greatly increased the demand for water resources, which has also affected both the Ili catchment area and water levels in Lake Balkhash. However, their impact was negligible, as not only did the flow volume not decrease, but it also increased. There has been a significant rise in average annual evaporation on the Chinese side, in the Ili River delta, the middle part of its basin and to the north of the study area. The flow in the delta of the Ili River depends on the volume of water coming from the Kapchagay reservoir and determines the ecosystem of the adjacent territories.

Farther away from the delta, the area becomes arider due to a decrease in overall water flow, while immediately adjacent to the delta, due to spring floods, the terrain changes with a slope towards swampy. The main difference between this and previously conducted studies is the integration of findings by Chinese and Kazakh scientists based on data including both a long period before the construction of the Kapchagay Reservoir and an equally long period afterwards. Thus, the study showed the picture both before and after. Also, the study area included a very broad region, which included the Ili River, Lake Balkhash, and the Kapchagay reservoir. Because of the presence of both a natural site of river flow accumulation and an artificial one, the study was able to compare their impact on the river itself and on the ecology of the area around it. Among the main hydrological and environmental issues, it is possible to assume a reduction of the volume of fresh water in Lake Balkhash due to increased water withdrawal from the Ili River (in both Kazakh and Chinese parts of the river basin); desertification, air, and surface water pollution; groundwater depletion; and degradation of the soil and vegetation cover under the influence of intensive anthropogenic pressure.

References

1) UNEP (2014). http://www.unep.org/pdf/UNEP_GEAS_JAN_2014.pdf.
2) Dostay, Z., Alimkulov, S., Tursunova, A., and Myrzakhmetov, A., "Modern hydrological status estuary of Ili River", *Arabian J. Geosci.*, **6** (*8*) 3041–3047 (2012).
3) Abfertiawan, M.S., Gautama, R.S., Kusuma, S.B., and Notosiswoyo S., "Hydrology Simulation of Ukud River in Lati Coal Mine", *Evergreen*, **3** (*1*) 21–31 (2016).
4) Thevs, N., Beckmann, V., Akimalieva, A., Köbbing, J.F., Nurtazin, S., Hirschelmann, S., Piechottka T., Salmurzauli R., and Baibagysov, A., "Assessment of ecosystem services of the wetlands in the Ili River Delta, Kazakhstan", *Environ. Earth Sci.*, **76** (*1*) 1–12 (2017).
5) Nilsson, C., Reidy, C.A., Dynesius, M., and Revenga, C., "Fragmentation and flow regulation of the world's large river systems", *Sci.*, **308** (*5720*) 405–408 (2005).
6) Dams and development: a new framework for decision-making (2000). http://awsassets.panda.org/downloads/wcd_dams_final_report.pdf.
7) Starodubtsev, V.M., "Formation of a new delta-like object in the Kapchagai Reservoir on the Ili River", *Water Resour.*, **44** (*1*) 12–15 (2017).

8) Starodubtsev, V.M., and Struk, V.S., "New wetlands formation in large reservoirs as a recreational resource of big cities. World Water Week in Stockholm. Responding to Global Changes", *Water Urbanizing World*, **1** 253–254 (2011).
9) Starodubtsev, V.M., and Truskavetskiy, S.R., "Desertification processes in the Ili river delta under the influence of anthropogenic pressure", *Water Resour.*, **38** (*2*) 248–251 (2011).
10) Mikhailov, V.N., "*Hydrology of river mouths"*, Moscow, Moscow State University Publishing House (1998).
11) Zonn, I.S., Zhiltsov, S.S., Semenov, A.V., and Kostyanoy, A.G., "Transboundary rivers of Kazakhstan and China", *Econ. & Manage.*, **4** (*27*) 24–35 (2018).
12) Nurtazin, S., Thevs, N., Iklasov, M., Graham, N., Salmurzauli, R., and Pueppke, S., "Challenges to the sustainable use of water resources in the Ili River basin of Central Asia", In: *E3S Web of Conferences (Vol. 81, p. 01009)*, EDP Sciences (2019).
13) Deom, J.-M., Sala, R., and Laudisoit, A., "The Ili River Delta: Holocene Hydrogeological Evolution and Human Colonization", In: *Socio-Environmental Dynamics along the Historical Silk Road (pp. 67–94),* Cham, Springer (2019).
14) Mischke, S., Zhang, C., and Plessen, B., "Lake Balkhash (Kazakhstan): Recent human impact and natural variability in the last 2900 years", *Journal of Great Lakes Research*, **46** (*2*) 267-276 (2020).
15) Yang, X., and Li, Y., "A Bayesian copula-based spatio-temporal method for multivariate drought risk analysis: A case study of the Balkhash Lake Basin" (2021). https://cutt.ly/7GNXW4j.
16) Yang, L.E., Bork, H.R., Fang, X., and Mischke, S., "*Socio-Environmental Dynamics along the Historical Silk Road",* Cham: Springer Nature (2019).
17) Sala, R., Deom, J. M., Aladin, N. V., Plotnikov, I. S., and Nurtazin, S., "Geological history and present conditions of Lake Balkhash", *Large Asian Lakes in a Changing World: Natural State and Human Impact*, 143-175 (2020).
18) Abdrahimov, R., Amirgaliyeva, A., Tastambek, K., Zhumalipov, A., and Polyakova, S., "Annual River Runoff of the Ile-Balkhash Basin and Prospects of Its Assessment Due to Climatic Changes and Water Economy Activities", *GEOMATE J.*, **18** (*69*) 230–239 (2020).
19) Volchek, A.A., and Parfomuk, S.I., "Modeling of water level fluctuations on the example of Lake Balkhash", In: *Natural environment of Polesie: Features and prospects of development (pp. 89–99)*, Minsk, Nauka (2017).
20) Long-term data on the regime and resources of land surface waters (2021). https://cutt.ly/RGNVlan.
21) Isupova, M.V., "The effects of the Ili River runoff and water regulation function of the delta on the changing water level of Balkhash Lake depending on the delta forest coverage", *Water Resour.*, **46** (*1*) S29–S42 (2019).
22) Sala, R., Deom, J.M., Aladin, N.V., Plotnikov, I.S., and Nurtazin, S., "Geological history and present conditions of lake Balkhash", In: *Large Asian Lakes in a Changing World (pp. 143–175)*, Cham, Springer (2020).
23) Zaikov, B.D., "Average runoff and its distribution per year on the territory of the USSR", *Proc. Natl. Res. Univ. Main Dep. Hydrometeorol. Serv. USSR*, **IV** (*24*) 67–95 (1946).
24) Abdrasilov, S.A., "*Channel processes and the formation of intra-continental deltas (on the example of the Ile River Delta)",* Almaty: Rauan (1994).
25) Samakova, A., "*Problems of hydrometeorological stability in the basin of Lake Balkhash"*, Almaty, Kaganat (2003).
26) Swaminathan, G., and Saurav, G., "Development of Sustainable Hydroponics Technique for Urban Agrobusiness", *Evergreen*, **9** (*3*) 629–635 (2022). doi: 10.5109/4842519.
27) Abirham, Y.T., Thu, K., Miyazaki, T., and Takata, N., "Comparative Study of Thermal Water Pumping Cycles", *Evergreen*, **8** (*1*) 239–248 (2021).
28) 23Shen, B., Wu, J., Zhan, S., Jin, M., Saparov, A.S., and Abuduwaili, J., "Spatial variations and controls on the hydrochemistry of surface waters across the Ili-Balkhash Basin, arid Central Asia", *J. Hydrol.*, **600** 126565 (2021).
29) Ali, M. B., Zakaria, K. A., Sivakumar, D., and Hadzley, A., "Automatic Sliding Gate System using Tap Water Pressure", *Evergreen*, **8** (*2*) 408–413 (2021).
30) Kuriqi, A., Pinheiro, A.N., Sordo-Ward, A., and Garrote, L., "Influence of hydrologically based environmental flow methods on flow alteration and energy production in a run-of-river hydropower plant", *J. Cleaner Prod.*, **232** 1028–1042 (2019).
31) 25Che, Y., Zhang, M., Li, Z., Wei, Y., Nan, Z., and Li, H., Energy balance model of mass balance and its sensitivity to meteorological variability on Urumqi River Glacier No. 1 in the Chinese Tien Shan. *Sci. Rep.*, **9** (*1*) 1–13 (2019).
32) Singh, P. L., Sikarwar, B. S., "Parametric Performance of Condensation Factors for Extracting Potable Water from Atmosphere", *Evergreen*, **8** (*3*) 586–592 (2021).
33) Korniichuk, N.M., Metelska, M.O., and Kyrychuk, G.Y., "Ecological and geographical characteristics of algal communities on gastropod shells of the river Uzh", Biosyst Divers., 25 (3) 186-190 (2017).
34) Shcherbak, V.I., and Korneychuk, N.N., "Influence of hydrological and morphological characteristics of the Teterev river on the structure of phytomicroepilithon", Hydrobiol J., 42 (5) 25-38 (2006).