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R. Salmurzauly[1,2,3*], S.T. Nurtazin[2], A.B. Mirzakul[1,2], S.S. Boltaev[1,2], I.S. Galymzhanov[2], Y.A. Matenov[1,2]

[1]Satbayev University, Kazakhstan, Almaty
[2]Al-Farabi Kazakh National University, Kazakhstan, Almaty
[3]The Scientific Research Institute of Ecological Problems (SRIEP), Kazakhstan, Almaty
*e-mail: ruslan.salmurzauli@gmail.com

CURRENT STATE OF TUGAY ECOSYSTEMS IN THE MIDDLE STREAM OF THE ILI RIVER

Forest ecosystems are one of the most important components of the Earth's biosphere due to their global ecological and socio-economic importance. In hydromorphic landscapes of arid regions of Central Asia with its sharply continental climate, these ecosystems are represented by unique in their biodiversity and environment-forming role coastal tugay forests in river floodplains, flooded lowlands and islands. Among desert, semi-desert and steppe ecosystems, tugay forests are ecosystems with the highest aboveground biomass and biodiversity. Due to the growing reduction of runoff of most rivers in Central Asia due to increased water consumption by agrarian and industrial production and negative climatic changes, the area of tugay forest ecosystems has catastrophically decreased. Ecological restoration of degraded tugay forests is a key factor in combating desertification in arid regions. Taking into account the fact that tugay forest ecosystems are currently represented only by scattered areas exclusively in West and Central Asia, their conservation is of global importance. The results of a comprehensive study using remote sensing and GIS-technologies, field work to assess the successional dynamics of tugay ecosystems in the middle reaches of the Ili River in connection with hydrological and climatic factors are presented in the article.

Key words: tugay ecosystems, remote sensing methods, vegetation degradation, climate change, river flow regulation, ecosystem conservation.

Р. Салмұрзаұлы[1,2,3*], С.Т. Нұртазин[2], А.Б. Мірзақұл[1,2], С.С. Болтаев[1,2], И.С. Ғалымжанов[2], Е.А. Матенов[1,2]

[1]Қ.И. Сәтбаев атындағы Қазақ ұлттық техникалық зерттеу университеті, Қазақстан, Алматы қ.
[2]Әл-Фараби атындағы Қазақ ұлттық университеті, Қазақстан, Алматы қ.
[3]Экология мәселелері ҒЗИ, Қазақстан, Алматы қ.
*e-mail: ruslan.salmurzauli@gmail.com

Іле өзенінің орта ағымындағы тоғай экожүйелерінің қазіргі жағдайы

Жаһандық экологиялық және әлеуметтік-экономикалық маңыздылығына байланысты жер биосферасының маңызды компоненттерінің бірі – орман экожүйелері. Орталық Азияның құрғақ аймақтарының гидроморфты ландшафттарында, оның күрт континентальды климаты бар, бұл экожүйелер биоәртүрлілігімен және өзеннің жайылмаларындағы, су басқан ойпаттар мен аралдардағы жағалаудағы тоғай ормандарының қоршаған орта қалыптастырушы рөлімен ерекшеленеді. Шөл, шөлейт және дала экожүйелерінің ішінде тоғай ормандары – жер үсті биомассасы мен биоалуантүрлілігі ең жоғары экожүйелер. Аграрлық-өнеркәсіптік өндірістің су тұтынуының өсуіне және климаттың теріс өзгеруіне байланысты, Орталық Азияның көптеген өзен ағындарының азаюына байланысты тоғай орман экожүйелерінің аумағы апатты түрде қысқарды. Тозған тоғай ормандарын экологиялық қалпына келтіру – құрғақ аймақтардағы шөлейттенуге қарсы күрестің негізгі факторы. Тоғай орман экожүйелері қазіргі уақытта тек алдыңғы және Орталық Азиядағы шашыраңқы диапазондармен ұсынылатындығын ескере отырып, оларды сақтауда жаһандық маңызы бар. Гидрологиялық және климаттық факторларға байланысты Іле өзенінің орта ағысындағы тоғай экожүйелерінің сабақтастық динамикасын бағалау бойынша ЖҚЗ және ГАЖ-технологияларын және далалық жұмыстарды пайдалана отырып кешенді зерттеу нәтижелері беріледі.

Түйін сөздер: тоғай экожүйелері, ЖҚЗ-әдістері, өсімдік жамылғысының деградациясы, климаттың өзгеруі, өзен ағынын реттеу, экожүйелерді сақтау.

Р. Салмурзаулы[1,2,3*], С.Т. Нуртазин[2], А.Б. Мирзақул[1,2],
С.С. Болтаев[1,2], И.С. Галымжанов [2], Е.А. Матенов[1,2]
[1]Казахский Национальный Исследовательский технический университет им. К.И. Сатпаева, Казахстан, г. Алматы
[2]Казахский Национальный Университет им. аль-Фараби, Казахстан, г. Алматы
[3]НИИ проблем Экологии, Казахстан, г. Алматы
*e-mail: ruslan.salmurzauli@gmail.com

Современное состояние пойменных тугайных экосистем среднего течения реки Иле

Одним из важнейших компонентов биосферы Земли, благодаря своему глобальному экологическому и социально-экономическому значению, являются лесные экосистемы. В гидроморфных ландшафтах аридных регионов Центральной Азии с ее резко континентальным климатом данные экосистемы представлены уникальными по своему биоразнообразию и средообразующей роли прибрежными тугайными лесами в поймах рек, в затапливаемых низинах и островах. Среди пустынных, полупустынных и степных экосистем тугайные леса являются экосистемами с самой высокой надземной биомассой и биоразнообразием. В связи с растущим сокращением стока большинства рек Центральной Азии из-за роста водопотребления аграрно-промышленным производством и негативными климатическими изменениями, площадь тугайных лесных экосистем катастрофически сократилась. Экологическое восстановление деградировавших тугайных лесов является ключевым фактором в борьбе с опустыниванием в засушливых регионах. Учитывая тот факт, что тугайные лесные экосистемы в настоящее время представлены лишь разрозненными ареалами исключительно в Передней и Центральной Азии, их сохранение имеет мировое значение. Приводятся результаты комплексного изучения с использованием методов ДЗЗ и ГИС-технологий, полевых работ по оценке сукцессионной динамики тугайных экосистем в среднем течении реки Или в связи с гидрологическими и климатическими факторами.

Ключевые слова: тугайные экосистемы, методы-ДЗЗ, деградация растительного покрова, изменение климата, зарегулирование речного стока, сохранение экосистем.

Introduction

One of the most important components of the biosphere is forest ecosystems, which are of global ecological, social, and economic importance. For hydromorphic landscapes of arid regions of Central Asia with its sharply continental climate, tugay forests form the main element of natural vegetation in the river floodplain [1-3].

Tugay forests are not only characterized by exceptional biodiversity in the arid zone, but also provide important food, regulating, and ecosystem services. They have significant environment-forming, soil-fixing, and ameliorative properties and generally stabilize the ecological situation in the river floodplains of arid territories [4-6].

Under natural conditions tree and shrub tugay forests are undergoing changes of dynamic states, which depend entirely on the nature of water availability in the territory and climatic changes [7]. In the past, tugay forests were widespread in Central Asia, but as a result of a sharp increase in water consumption, primarily for irrigation, the total area of tugay forests has dramatically decreased. Modern tugay forests of Central Asia show signs of degradation and desertification, halophytization and simplification of structure, reduction of species diversity and decrease in productivity [8]. Thus, if in the early 1930s the area of tugay lower reaches of the Amu Darya River amounted to 300,000 ha, by the beginning of 1994 there were only 27,000 ha [10]. Today, the area of tugay in Central Asia is less than 10% of the area occupied by them in the 1960s [11,12].

In Kazakhstan, natural tugay forests have survived only in localized areas within the Shu, Ili, and Syr Darya river basins. A similar trend of the sharp decrease in the areas of tugay forests in recent times is characteristic of West and Central Asia. Against the background of the global trend of floodplain forests reduction, the disappearance of tugay forests is occurring at a catastrophic rate [13].

Reduction of the tugay area leads to the loss of many valuable, rare, and relict species of plants and animals, to the reduction of water protection, water regulation, bank protection, and meliorative role of tugay forests, to the deterioration of human habitat, and to the reduction of certain types of economic activity. The general direction of tugay transformation is shifted towards halophytization and desiccation; loss of typical (conditionally indigenous) tugay tree-shrub communities is observed everywhere, not only groups of associations, but also completely separate formations of tugay vegetation disappear; tree-shrub tugay is replaced by various variants of grass and halophytic communities, which previously were not widespread [14-16].

Numerous studies have identified the main reasons for the reduction of tugay forests, among which the regulation of river flow, reduction of water availability and changes in the natural hydrological regime of rivers, leading to changes in groundwater regime and flooding, which is the main cause of widespread degradation of tugay ecosystems [17-19].

Thus, the analysis of long-term changes in the flow of the transboundary Ili River, one of the three largest waterflows of Kazakhstan, in the basin of which about 4.5 million people live, shows that approximately from the 1970s began a period of increased water availability of the river, which continues to the present time. However, the Ili River flowing from northwest China is steadily decreasing as the area of land used for agriculture along the Ili River in China has increased by 30% over the past 20 years. Intensive water consumption is also taking place in Kazakhstan. Over the past 60 years, the glaciers of the Zailiisky Alatau, as well as other mountain ranges in Central Asia, have been shrinking at a rate of about 1% per year in terms of ice volume. If these rates continue in the future, the vast majority of glaciers may completely melt by the end of this century [20-23].

Since the climate is one of the main factors shaping ecosystems, the analysis of climatic changes as applied to the assessment and prediction of the dynamics of terrestrial ecosystems of both floodplain and watershed areas is an extremely important task today. Since vegetation plays an edificatory role in ecosystems, a significant reduction in floods during the growing season and an increase in winter discharges lead to ice jams, freezing of shallow water a long period of time, as well as freezing and soaking of perennial floodplain grass meadows. The established trends in climate change also affect natural vegetation: both zonal and floodplain [24,25].

Our goal was to assess the current state of tugay ecosystems of floodplain areas of the middle flow of the Ili River. To achieve this goal, we solved the following tasks: to describe the main vegetation types of tugay ecosystems depending on the hydrological regime, meteorological conditions and the nature of the impact of anthropogenic factors. Changes in floodplain ecosystems, including riparian forests, were determined using modern Earth remote sensing methods (ERS) with reference to ground data.

Materials and methods

Study Region

The study area is located in the Ili depression and occupies floodplain ecosystems with a length of about 140 km down the middle flow of the Ili River from the Kazakhstan-China border (43°48'12.79"-79°55'43.16 "E) to the Kapshagay water reservoir (43°50'44.76 "N – 78°30'47.23 "E). The Iliysk depression divides the mountain systems of the Zailiisky and Zhetysu (Dzungarian) Alatau (Fig. 1).

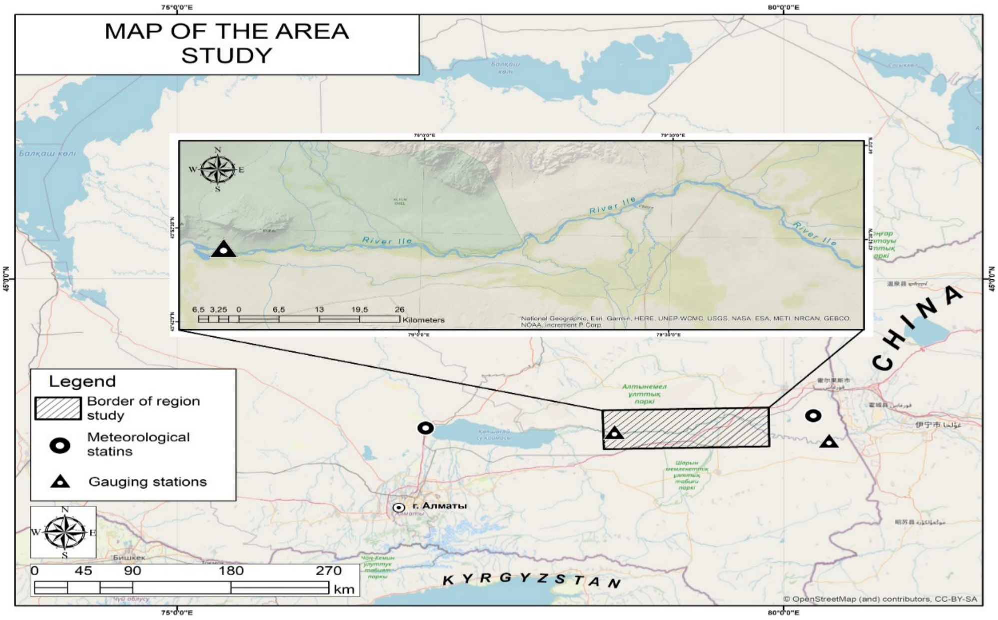

Figure 1 – Location map of the study region

The western part of the depression with a length of about 300 km is located within Kazakhstan. Its absolute heights vary from 800 m in the east near the city of Kulja (PRC) to 400-350 m in the west. The Ili River flows in the most lowered central part of the depression. The natural conditions of the Ili Depression are extremely diverse. Its marginal high parts, especially the zone of outcrop cones at the foot of the Zailiysky and Dzungarian Alatau with snows and glaciers feeding numerous rivers and streams, have well-developed natural irrigation, so they represent diverse grass and cereal meadow steppes on chernozems with deciduous tree species.

In addition, the study area is characterized by a significant diversity of ecosystems, among which there are terrestrial natural ecosystems (weakly modified by human activity), terrestrial anthropogenic-transformed (with changes in soil and vegetation cover) and aquatic ecosystems (rivers, lakes). This is caused by climate change and mainly by the peculiarities of geomorphology, geology and hydrogeology of the area.

One of the main key factors in the reduction and degradation of floodplain ecosystems is the steady decline in water availability of the Ili River, primarily due to the growth of water consumption by the PRC, as well as the withdrawal of tributaries of the Ili River on the territory of the Kazakhstan. This trend is likely to continue in the future, which will entail corresponding risks for floodplain ecosystems of the Ili River.

Remote sensing methods

Earth remote sensing data, methods of their decryption, as well as classification of space images with a subsequent compilation of thematic GIS maps were used in the study. In mapping and classification of floodplain ecosystems we used multi-temporal multispectral space images from SENTINEL-2 spacecraft with spatial resolution of 10 meters. The selection of space images followed all standard quality criteria (minimum cloud cover, image clarity and full coverage of the study region), as well as the time of imagery, oriented to the purpose of use and the time of field work. The study used 8 satellite images from 2016 to 2023, in addition, radar space data from Shuttle Radar Topography Mission – SRTM (30 meters) radar systems were used to map aquatic and floodplain landscapes. All used space images were taken from open official catalogs of the US space agency – NASA (http://landsat.gsfc.nasa.gov) and European Space Agency (https://sentinel.esa.int/web/sentinel/sentinel-data-access) (Table 1).

Table 1 – List of Earth Remote Sensing data used

Nomenclature	Date of photo	Names of spacecrafts
S2A_MSIL1C_20160717T053642_N0204_R005_T44TLP	17.07.2016	Sentinel-2 (S2MSI2C)
S2A_MSIL1C_20170722T053641_N0205_R005_T44TLP	22.07.2017	Sentinel-2 (S2MSI2C)
S2A_MSIL1C_20180727T053641_N0206_R005_T44TLP	27.07.2018	Sentinel-2 (S2MSI2C)
S2A_MSIL2A_20190712T053651_N0213_R005_T44TLP	12.07.2019	Sentinel-2 (S2MSI2A)
S2A_MSIL2A_20200726T053651_N0214_R005_T44TLP	26.07.2020	Sentinel-2 (S2MSI2A)
S2A_MSIL2A_20210731T053651_N0301_R005_T44TLP	31.07.2021	Sentinel-2 (S2MSI2A)
S2A_MSIL1C_20220726T053651_N0400_R005_T44TLP	26.07.2022	Sentinel-2 (S2MSI2C)
S2A_MSIL2A_20230721T053651_N0509_R005_T44TLP	21.07.2023	Sentinel-2 (S2MSI2A)
SRTM1N43E078V3	23.09.2014	SRTM
SRTM1N43E079V3	23.09.2014	SRTM
SRTM1N43E080V3	23.09.2014	SRTM

Pre-processing and classification of the satellite images and further making of the thematic maps were carried out using the widely used GIS applications SNAP; QGIS: ENVI 5.0; ArcGIS.

To assess the state of the vegetation cover of the study region widely used vegetation indices were applied, such as NDVI (Normalized Difference Vegetation Index) and NDWI (Normalized

Difference Water Index), which are linear and fractional-linear combinations of three spectral channels: 665 nm (red spectral range); 560 nm (green spectrum range), 705 nm (near infrared spectrum range), calculated by the formula:

$$NDVI = \frac{\rho Nir - \rho R}{\rho Nir + \rho R} \quad (1)$$

$$NDWI = \frac{\rho G - \rho Nir}{\rho G + \rho Nir} \quad (2)$$

where:

ρNir – pixel value in the near infrared channel of the spectrum;

ρR – pixel value in the red channel of the spectrum;

ρG – pixel value in the green channel of the spectrum;

We used the NDVI index to assess the condition of floodplain ecosystems, as well as for seasonal comparative analysis [26]. Multi-channel spectral indices, in particular the NDWI water index [27], as well as thematic classification, linear separation and single channel classification using separation threshold [28] have been used in remote sensing of the water surface area of floodplain reservoirs and watercourses.

For the classification of floodplain biocenoses, a "dynamic threshold segmentation" algorithm was used where the basis for riparian vegetation was multi-temporal NDVI series and for aquatic ecosystems was NDWI [29]. Threshold ranges were extracted automatically, the threshold range set for NDWI was: ≥ 0.1 – ≤ 0.99; for NDVI: ≥ 0.26 – ≤ 0.99 (Fig. 2).

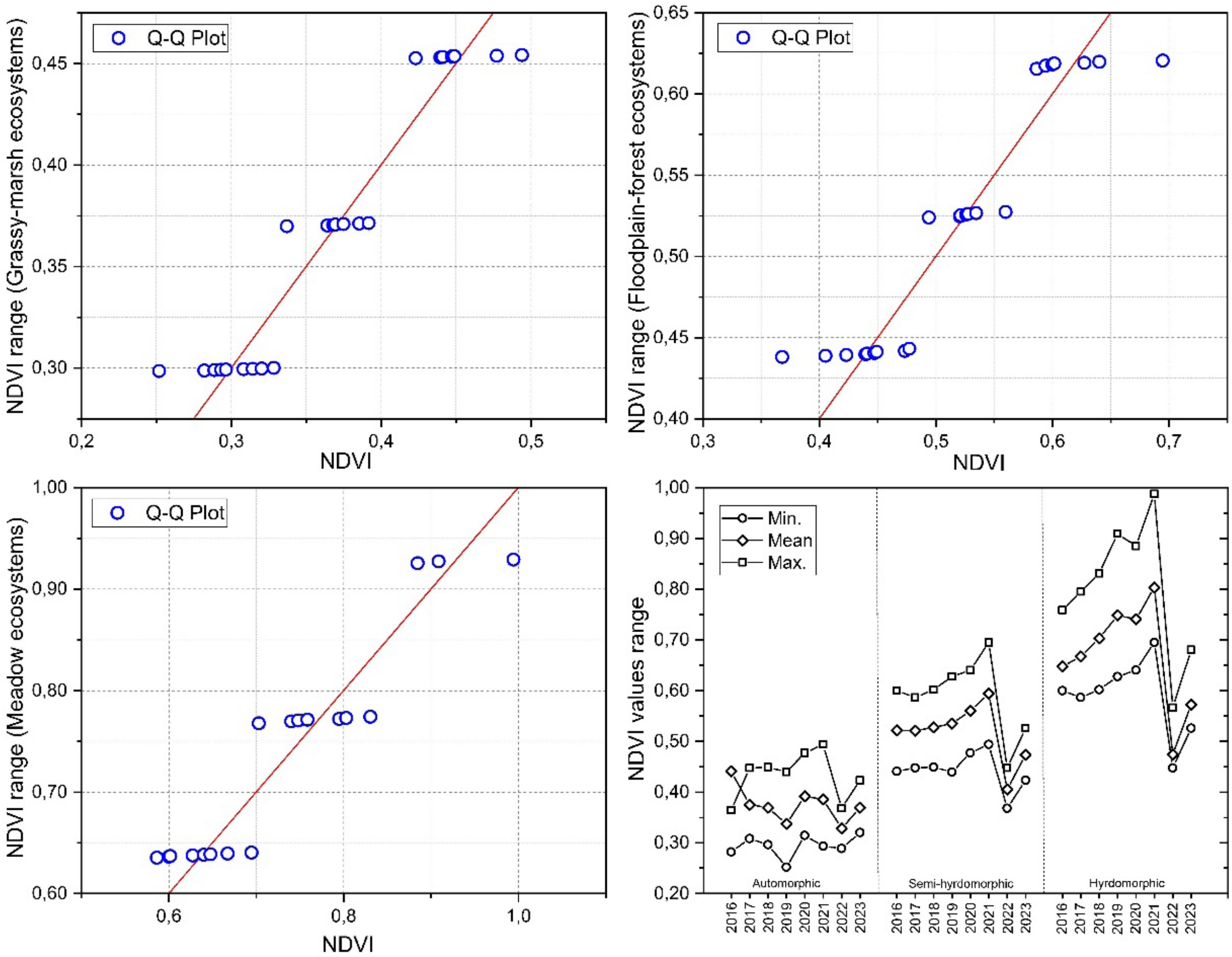

Figure 2 – NDVI threshold values for different types of floodplain hydromorphic ecosystems

As a result of clustering, the resulting data were post-processed to correct vector contours of floodplain ecosystems and tugay forest boundaries using ArcGIS software, and the accuracy of the classification was verified using high-resolution satellite imagery, field research data, and land use data.

In addition to remote sensing techniques, a set of field works was carried out in 2022-2023 in the study region. During the field researches the data on vegetation cover and landscape features at 63 representative sites from different types of tugay biocenoses were collected. The obtained field data on land cover in the form of GPS key points were mapped on space images for further classification of the main biocenoses.

To analyze the dynamics of the hydrological regime of the middle flow of the Ili River (for the period 2000-2020), the data of RSE "Kazhydromet" from the gauging stations "Dobyn Wharf", located 25 kilometers below the border with the PRC (43°45'29. 88 "N, 80°13'50.09 "E) and gauging station No. 164 located 164 kilometers upstream of the Kapshagay HPP dam (43°50'11.87 "N, 78°49'42.54 "E). The regime of precipitation and surface temperature in the survey area was considered by 2 meteorological stations: MS Kapshagay (43°55'20.42 "N 77° 5'50.33 "E) and MS Zharkent (44° 8'40.78 "N, 79°59'28 "E) (Fig. 1).

Results of the study

Climatic changes in the study region

Atmospheric precipitation regime in the survey area was considered for 2 meteorological stations (MS Kapshagay, MS Zharkent) for the period 2001-2022. In the annual course of precipitation, the maximum falls on spring months with an average value of 105 mm. and the secondary maximum is noted in the fall (October-November), where the long-term average precipitation is equal to 60 mm. The minimum precipitation occurs in August-September and in January-February throughout the study area. In general, warm period (TP) precipitation prevails during the year. Analysis of the linear trend in the time course of annual precipitation amounts and precipitation amounts for warm and cold periods (WP) for both meteorological stations under consideration shows a negative trend (Fig. 3).

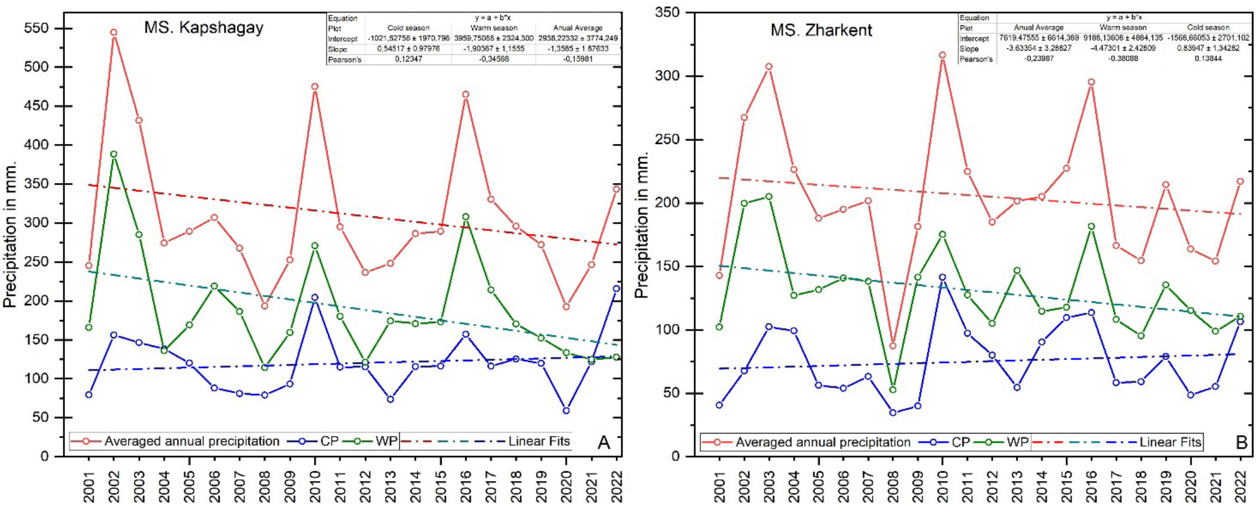

Figure 3 – Averaged annual precipitation sums at MS Kapshagay (A) and Zharkent (B);

Maximum negative values of the linear trend coefficient were observed at the Kapshagay MS (-3.8 mm/year). In the warm period of the year, the character of precipitation change approximately corresponds to the annual one with a negative trend (-4.7 mm/year). In Zharkent there is also a pronounced negative trend in average annual precipitation (minus 1.4 mm/year). In the cold period of the year, a weak positive trend (0.57-0.88 mm/year) is observed according to the data of the meteorological station. Despite the large variability of atmospheric precipitation from year to year in the period under observation (2001-2022) can be noted anomalously rainy years: 2002, 2010 and 2016 where an average of 40% more precipitation from the mean annual value of 310 mm. There is also a change in the ratio of warm and cold period precipitation, if in the last decade (2001-2011) the ratio was 37/63%, in the last ten years (2012-2022) the percentage of cold period precipitation increased by 5% – i.e. 42/58%.

The main characteristics of the temperature regime are average annual and average monthly air temperature values, as well as absolute maximum and absolute minimum. The deviations of the actual temperature from its long-term average (norm) provide insight into the temperature variability. The initial material for the study included long-term data (2000-2022) on air temperature at 2 meteorological stations (MS) located in the study area: Kapshagay and Zharkent.

Winter months show the highest inter-annual variability, while summer months show the lowest. Thus, the long-term average air temperature can vary in January from -0.1 °C to -9.7 °C, and in July from 22.6 °C to 25.5 °C. Temperatures of the warm period of the year, especially summer temperatures, are quite stable, their inter-annual variability is minimal compared to other months of the year (Fig. 4).

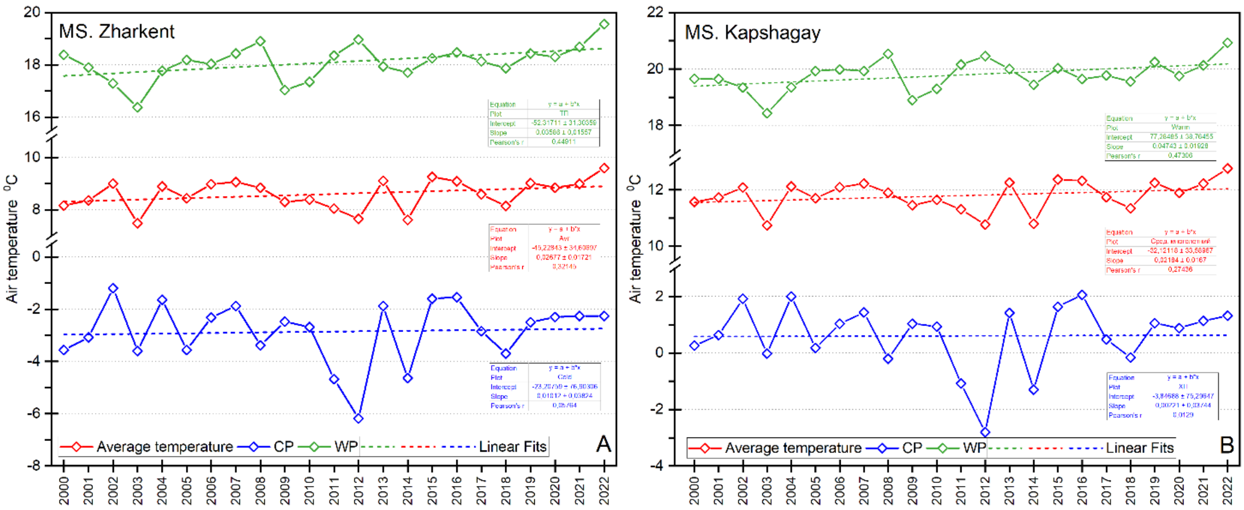

Figure 4 – Graphs of multi-year dynamics of mean annual temperatures at MS Kapshagay (A) and Zharkent (B);

The first general feature to note is the positive trend in surface air temperature anomalies for the mean annual temperature and the absence of any trend for the cold period. Thus, the mean annual temperature in Kapshagay increased by 0.25°C/10 years, and the temperature of the warm period increased by 0.4°C/10 years; the temperature for the cold period remained unchanged and amounted to 0.02°C/10 years. However, it should be noted that the temperature of the summer season is less variable compared to the temperature of other seasons. Zharkent is characterized by the following temperature changes: the average annual temperature increased by 0.3°C/10 years, the warm period (WP) temperature increased by 0.5°C/10 years, and the thermal regime of the cold period by 0.1°C/10 years. Figure 4 shows the time course of surface air temperature for annual mean, cold period and warm period according to MS Kapshagay and Zharkent (Fig. 4).

Trends of changes in the hydrological regime of the Ili River for the period 2001-2020

The main complex factor determining the features of the natural complex of the Ili River floodplain located in the arid zone is the hydrological regime and, first of all, the nature of spring and summer floods, which have been artificially regulated since 1970. Therefore, ecological grounding of the regime of artificial regulation of water flow and tracking the consequences of such regulation is of great importance in the monitoring system in this region [30-32].

To analyze the dynamics of the hydrological regime of the lower reaches of the Ili River (for the period 2001-2020), data from the gauging station “Dobyn Wharf” and gauging station No. 164, located 164 kilometers upstream of the Kapshagay HPP dam, were used.

According to water discharge measurements at the Dobyn gauging station, there was a significant decrease in the flow of the Ili River, in particular, the amount of water coming from China decreased by 30%. Despite the noticeable decrease in the total flow during the period under consideration, we can highlight the anomalously high-water years – 2010 and 2016, with an average annual water flow of 594 and 641 m³/sec, respectively. Dry years include 2014 and 2020, where the average flow was below 350 m³/sec (Fig. 5).

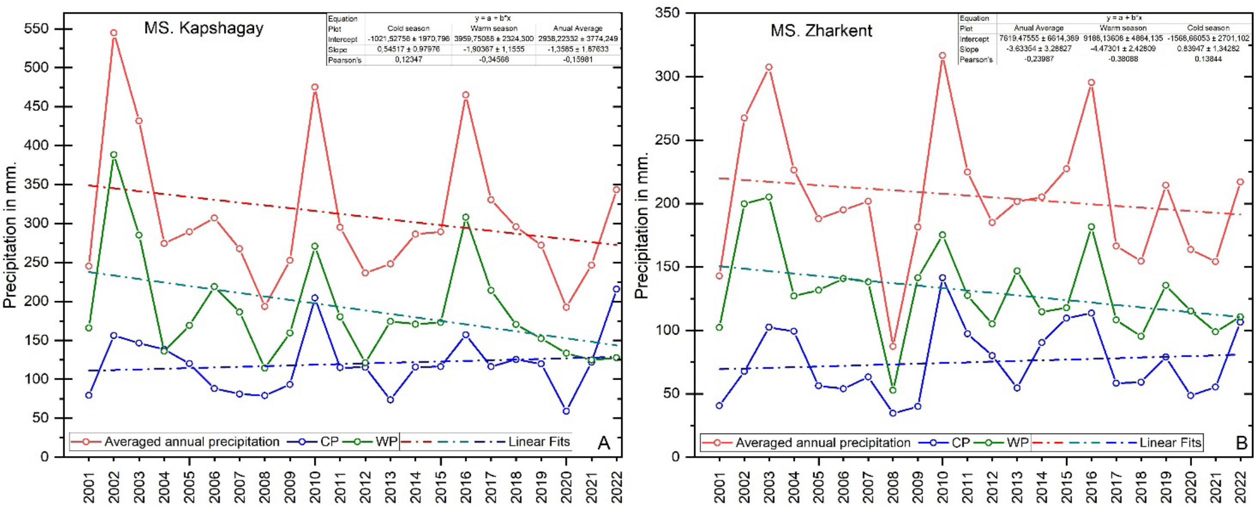

Figure 5 – Combined graph of average annual and average monthly water discharge in m³/sec (based on data from "Dobyn Wharf" hydropost)

According to long-term data for the last 20 years, the following periods can be distinguished: spring flood (April-May, with an average monthly discharge of 422 m³/sec), three-month summer flood (with an average monthly discharge of 573 m³/sec) and seven-month autumn-winter low water (with an average monthly discharge of 367 m³/sec). The maximum average monthly water flow, more than 600 m³/sec, is observed in July during the most intensive melting of snow and glaciers.

When considering the variability of distribution within the annual runoff, the most informative are the distinctions of high-water years from low-water years. According to our observations over the last 10 years, the high-water years can include 2015-2017, where the average discharge of the three-month summer flood reached 860 m³/sec, whereas in the last three years (2018-2022) it decreased almost three times reaching a minimum of 290 m³/sec (Fig. 5).

The problem of reducing water flow in the Ili River as a transboundary river is extremely complex and has no unambiguous solutions. Against the background of global warming and reduction of glacier reserves, the issue of water allocation between Central Asian countries becomes even more complicated and urgent.

Dynamics of floodplain ecosystems in the Ili River delta

Tugay belongs to special so-called intrazonal hydromorphic ecosystems, predated to river valleys and deltas, as well as to the shores of lakes and reservoirs and areas of groundwater and subsurface water outflow. As in the case of "zonal" ecosystems, the spatial distribution of intrazonal ecosystems reflects latitudinal and altitudinal zonality.

Using space data and remote sensing methods with subsequent linkage to ground data, we have identified 3 subtypes of hydromorphic ecosystems in the study region:

- meadow ecosystems formed on alluvial soils of meadow series and often used as hayfields;

- grassy-marsh ecosystems, confined to soils of the marsh series, formed under excessive moisture on negative relief positions;

- floodplain-forest ecosystems, formed in streamside areas on primitive alluvial meadow-tugay soils.

In addition to the above ecosystems, the authors also determined the dynamics of changes in aquatic ecosystems including channels and floodplain lakes (Figure 6).

Figure 6 – Aerial photo of general view of floodplain ecosystems of the Ili River valley

The vegetation cover of meadow ecosystems is directly related to river activity and occupies the first floodplain terrace, where some relief elements are flooded annually and others are flooded sporadically or not at all, i.e. areas of dry meadows alternate with flooded or marshy meadows. Diversity of meadow communities is usually found with predominance of coarse-stemmed and soft-stemmed grasses: bushgrass (Calamagrostis epigeios), common reed (Phragmites australis), needlegrass (Achnatherum calamagrostis), reed canary grass (Phalaris arundinacea), couch grass (Elytrigia repens), barley (Hordeum bogdanii). They form both monodominant communities and in various combinations with each other, often with a considerable admixture of grasses and weeds: bushgrass-cough grass-herb, cough grass-reed-herb, cough grass, bushgrass, barley grass, reed-dogbane, canary grass-cough grass. Licorice and bramble thickets are found in large areas (Fig. 7).

Grassy-marsh ecosystems are represented on the coast of the Ili River channel and islands (in the form of rather dense reed thickets), formed as a result of meandering of its channel, as well as periodic, mainly early-spring flooding on fluvial-marsh, meadow-marsh, marsh-meadow, less often floodplain meadow soils. Common reed here forms monodominant communities with projective cover of almost 100% and height of 1.5-2.0 m. In these ecological conditions, together with reed communities, cattail, spikesedge, spikesedge-marsh, reed-spikesedge, reed-cough grass communities are found (Fig. 8).

Figure 7 – Grass – herb community on meadow soil of the Ili River floodplain

Figure 8 – Reed-cattail communities of the Ili River floodplain

Regarding the floristic composition of ecosystems represented in the surveyed region, it should be noted that floodplain-forest ecosystems (riparian forests) are represented by the largest number of species. As a rule, they are confined to riverbed areas and belong to the type of semi-hydromorphic intrazonal ecosystems. Their main edificators are xeromesophilic mesothermal trees – turanga poplars (Populus Diversifolia (Populus euphratica), P. ariana, P. pruinosa), oleaster (Elaeagnus turcomanica, E. orientalis), willow (Salix songarica), often wrapped with vines (Cynanchum sibiricum, Clematis orientalis), as well as large shrubs and tall grasses: tamarisk (Tamarix ramosissima, T. meyeri, T. floror. meyeri, T. florida, T. laxa, T. elongata, etc.), common salt tree (Halimodendron halodendron), reed (Phragmites australis), reed grass (Calamagrostis dubia, C. epigeios, C. pseudophragmites), cough grass (Elytrigia repens), dogbane (Trachomitum scabrum) (Fig. 9).

Analysis of satellite images allowed to observe the dynamics of changes in the area ratios of the main subtypes of hydromorphic ecosystems with the subsequent creation of thematic GIS maps of the study area (Fig. 10).

Figure 9 – Tugay forests

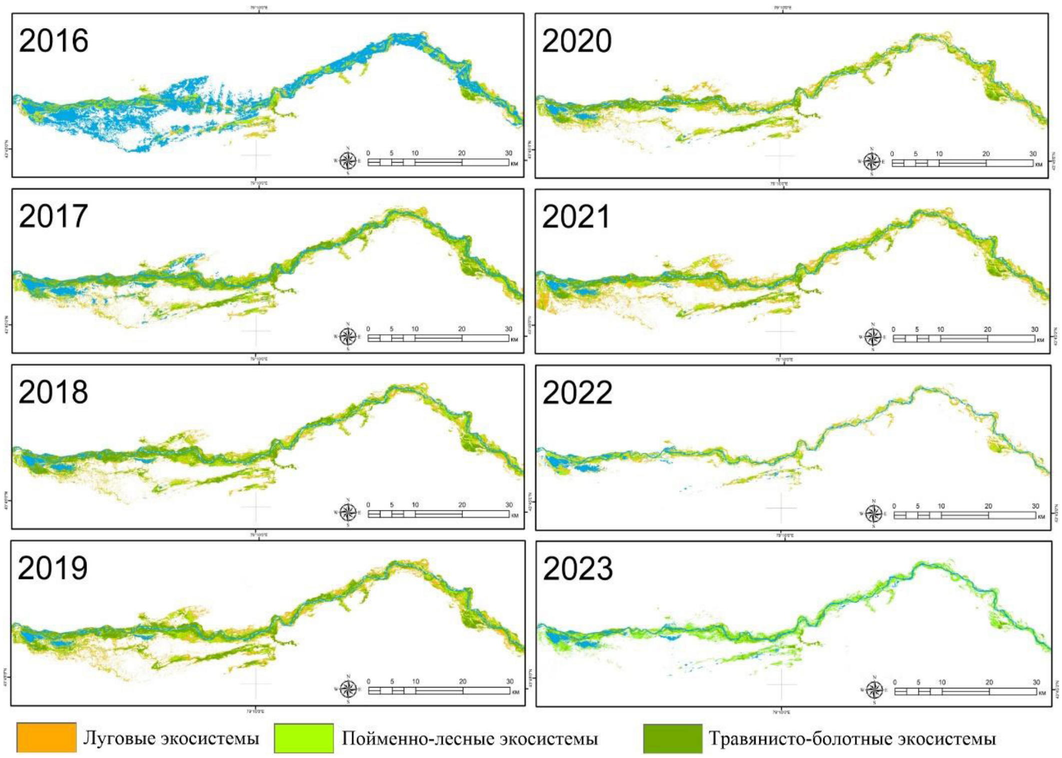

Figure 10 – Thematic GIS maps of changes in the main types of hydromorphic ecosystems of the river floodplain

Among the studied time series, 2016 is distinguished with anomalous high water content with the average monthly flow for the summer months – 1118 m^3/sec, while it reached a maximum of 1350 m^3/sec in July. A sharp increase in water availability by 45% in a short time resulted in extensive flooding not only of floodplain terraces but also of over-floodplain coastal semi-hydromorphic ecosystems. According to the data from gauging station No. 164, during the summer floods the river level rose by almost 1.8 meters, and the flooded area according to calculations of authors in the study area amounted to almost 298.4 km^2 (Fig. 11).

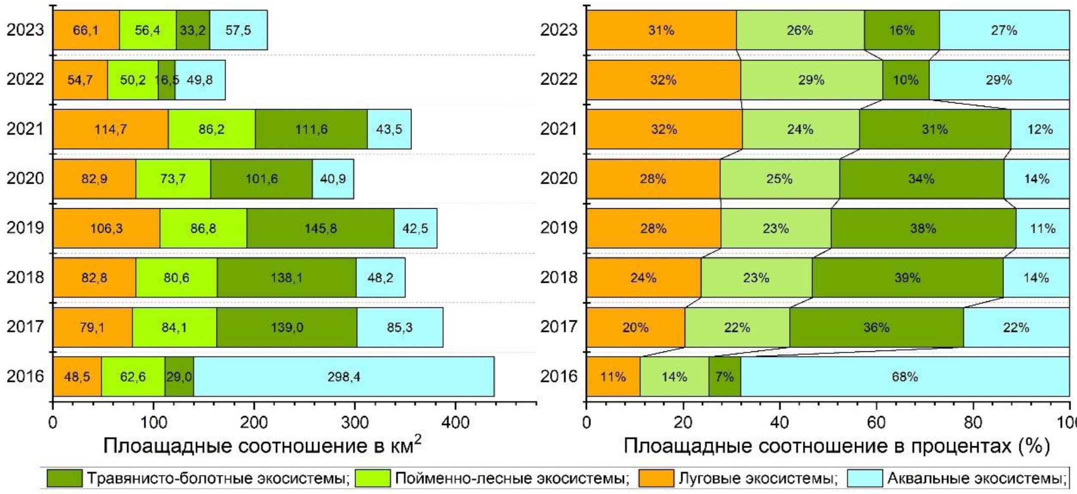

Figure 11 – Area ratios of the main subtypes of hydromorphic ecosystems of the Ili River floodplain over the last 8 years in km^2 and percent.

A similar abnormally high summer flood occurred in 2010, but then the flooded area was 24% smaller and amounted to 230 km^2. Field work conducted in the lower reaches of the Ili River in 2012 showed that after flooding, in areas with light soils, where the salt content in soils decreased as a result of washout.

Rich development of mesophytic vegetation was also noted – there appeared areas of grass, bushgrass (Elytrigia repens), cough grass (Calamagrostis epigeios), grass-herb (Glycyrrhiza uralensis, Leumus multicaulis) meadows, abundant renewal of tugay vines, especially bugle vine (Calystegia sepium) and Chinese clematis (Clematis orientalis). In the areas with heavier soils, among dogbane-wildrye-licorice (Glycyrrhiza uralensis, Leumus multicaulis, Trachomitum lancifolium) meadows there were spotted saline areas with halophytic-annual-saline (Suaeda linifolia, S.heterophila, Saussurea salsa, Limonium otolepis, Puccinellia dolicholepis) cenoses.

Marsh-meadow and alluvial-meadow soils with heavier mechanical composition are literally cemented after flooding, i.e. soil drying processes are preserved, as a result of which the vegetation cover does not fully recover cough grass and bushgrass meadows, typical for these massifs under natural flood regime.

Such flooding is very important for maintenance of groundwater level and for sustainable development of floodplain hydromorphic ecosystems, in particular, tugay forests.

In the following three years (2017-2019), the average annual river flow decreased to an average of 383 m^3/sec, resulting in a sharp decrease in aquatic ecosystems. At the same time, floodplain hydromorphic ecosystems, unlike aquatic ecosystems, did not undergo much change due to groundwater accumulation in 2016.

In 2020, water flow during summer months amounted to 165 m^3/sec, which is a record low for 20 years of observations. Such dramatic negative changes led to drying of meadow soils with subsequent salinization. The field studies conducted by authors in 2022-2023 on the middle reaches of the Ili River, as well as data obtained from space images show the continuing decrease in water availability in summer floods, which in turn negatively affected floodplain ecosystems, in particular riparian forests.

Conclusion

The main factor affecting the state of biotic components of tugay ecosystems in the floodplain of the middle reaches of the Ile River is the reduction in the range of fluctuations in water flow rates and levels in the annual cycle, due to flow regulation in the interests of irrigated agriculture in the PRC and Kazakhstan, as well as due to climatic changes.

According to water flow measurements at the border Dobyn gauging station, in recent decades, and especially since 2018, the average annual flow of the Ili River coming from China has decreased by 30%, despite a significant increase in the total annual flow in the basin, associated with the melting of glaciers and snowfields as a result of climate warming. Naturally, this circumstance negatively affects the state of the considered riparian ecosystems.

At the same time, in the 22-year period under consideration there can be distinguished anomalously high-water years – 2010 and 2016 with average flow rates of 594 and 641 m^3/sec, respectively. Dry years include 2014 and 2020, when the average annual discharge was below 350 m^3/sec. Analysis of thematic GIS maps of changes in the main types of the studied hydromorphic ecosystems of the Ile floodplain showed that the abnormally high-water year 2016 with high precipitation caused large-scale flooding in the floodplain areas and an increase in the area of hydromorphic ecosystems up to 298.4 km^2. The water level rise in the Ili River during the warm period of this year reached 1.8 meters and at this time, as it is evident from the results of field surveys, even the upper floodplain was flooded over a significant area. It should be especially noted that the high water level and prolonged flooding of the floodplain in 2016 caused a significant expansion of the total area of hydromorphic and semi-hydromorphic tugay ecosystems. Notably, this increase in area had an unexpectedly long-term effect that persisted until 2022, despite the low water period that began in 2017. Preliminarily, it can be said that high levels of flooding of floodplain ecosystems can provide a 2–4-year lag in the maintenance of normal state of ecosystems in the area. This could be a significant argument in formulating decisions in managing regulated flooding of the middle reaches and upper stream of the Ili River.

The results of the research show that under the conditions of decreasing flow of the Ili River due to the growth of irrigated land area, combined with pronounced regional climate warming and decreasing precipitation, preservation of unique tugay ecosystems on the Ili River is possible only under the coordinated interstate environmental policy of PRC and Kazakhstan.

Conflict of Interest

All authors have read and are familiar with the content of the article and have no conflict of interest.

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