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A state-of-the-art and future perspectives of transboundary rivers in the cold climate – a systematic review of Irtysh River

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ABSTRACT

Study region: Irtysh River Basin, a transboundary river laying in the North hemisphere and serving as a home for around 15 million people in China, Kazakhstan, and Russia.
Study focus: Considering existing pressures of climate change and anthropogenic activities on water resources, this research aims to evaluate recent (2010–2022) trends in research about a state-of-the-art of the river in a matter of relationships between hydrological budget, water quality, biodiversity, and policy issues. A literature review was carried out in English, Chinese, and Russian languages for defining key issues in the river management.
New hydrological insights for the region: Melting of permafrost, glaciers, and snow in the upstream mountains of the River should be considered as one of the key processes in the hydrological budget. However, the high impact of evapotranspiration rate could offset the effect of the increased melting rate along the basin. Efficient operating of existing large dams and reservoirs and the planning of future installations deserves special attention in assurance of the respective water level for restoration of the ecological diversity of the basin. Implementation of water-saving techniques and restoration of tributaries of Irtysh also play a significant role in keeping the resilience of the river. Handling historical and existing contamination will also guarantee restoration of the river health. The basin management still lacks tripartite agreement, however the principles of hydrosolidarity and no-harm effect are followed by involved countries.

1. Introduction

The latest Intergovernmental Panel on Climate Change (IPCC) report has claimed that Climate Change is intensifying the water cycle with consequences, such as more intense rainfall and associated flooding, or more intense drought in many regions. These processes put significant pressure on surface water, including on rivers (Dai, 2016). Main expectations for North and North-East Asia regions are shrinking of permafrost volume with further global warming. Precipitation is projected to continue to increase and cause almost double the annual maximum river discharge with increased flooded area in major Siberian rivers by mid-21st century (IPCC, 2021). Rivers of the Eurasian region have already experienced an increase in drainage into the Arctic Ocean due to increased melting of

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suprapermafrost (Pi et al., 2021). Environmental implications on the hydrological balance of the river basin management in the region, due to the effects of anthropogenic activities and climate change has been well documented in scientific investigations (Xenarios et al., 2021). Thus, these challenges should be mitigated in future with the support of the respective analysis of existing related risks and discussions by key stakeholders.

Irtysh River Basin (here and after IRB, River, or Basin) is a transboundary river spanning 4248 km, originating from the border region between Mongolia and China and flowing through China, Kazakhstan and Russia before joining with Ob river at Khanty-Mansiysk and entering into the Arctic Ocean. From Khanty-Mansiysk upwards, the IRB occupies a drainage area of about 165×10^4 km^2 with a drainage area distribution of Mongolia (< 1%); China (2.9%) Kazakhstan (53.1%) and Russia (44%) (Xia et al., 2015). The main territory of the Basin serves as a living space for approximately 15 million people. The River is the main source of water in the region, which brings its highest value in social, economic, industrial, energy generation, and irrigation activities (Krasnoyarova et al., 2019).(Fig. 1).

The previous research represented rich and contradictory history of the River basin management and its consequences. Huang et al. (2013) detected that climate has changed in the Irtysh River Basin during the first half of the 1970 s with the increase of the annual minimum temperature by more than 2 °C. Yang et al. (2012) investigated the impact of the man-made reservoirs on a parameter of ecological flow along the whole length of the River and concluded that the minimum instream ecological flow is increasing from upstream to downstream. The flows in May-July are larger than in other months. Some studies state that the hydrological regime of the river at the lower reaches was mildly affected by the reservoirs at the upper reaches for the period 1936–1999, while anthropogenic activities and climate change did not have a significant influence on the annual runoff of the River (Huang et al., 2012). Research by Galperin and Chigrinets (2017) revealed that the sum of runoff from both China and regional tributaries was considered enough for domestic use and even for transferring water to Balkhash Lake in case of emergency. Even possibilities to import water for Aral Sea (Schuiling and Badescu, 2010), or for Syr Darya River (Medeu et al., 2019) from Irtysh have been investigated. At the same time, there have been some debates about ambitious, but hardly realistic, projects to restore Irtysh itself (Torkunov et al., 2011) by transferring water from other sources; for example, from Katun river, a tributary of the Ob River (Krasnoyarova et al., 2019). Hrkal et al. (2006) highlighted a concern about the future of Irtysh in 2006 with regards to the impact of anthropogenic activities on the river, including: ecological issues, such as a close location of the Semipalatinsk nuclear polygon, the influence on water quality from the industrial complexes in the cities situated within the riparian zone of the Basin; a transboundary status of the river; and impact of the created

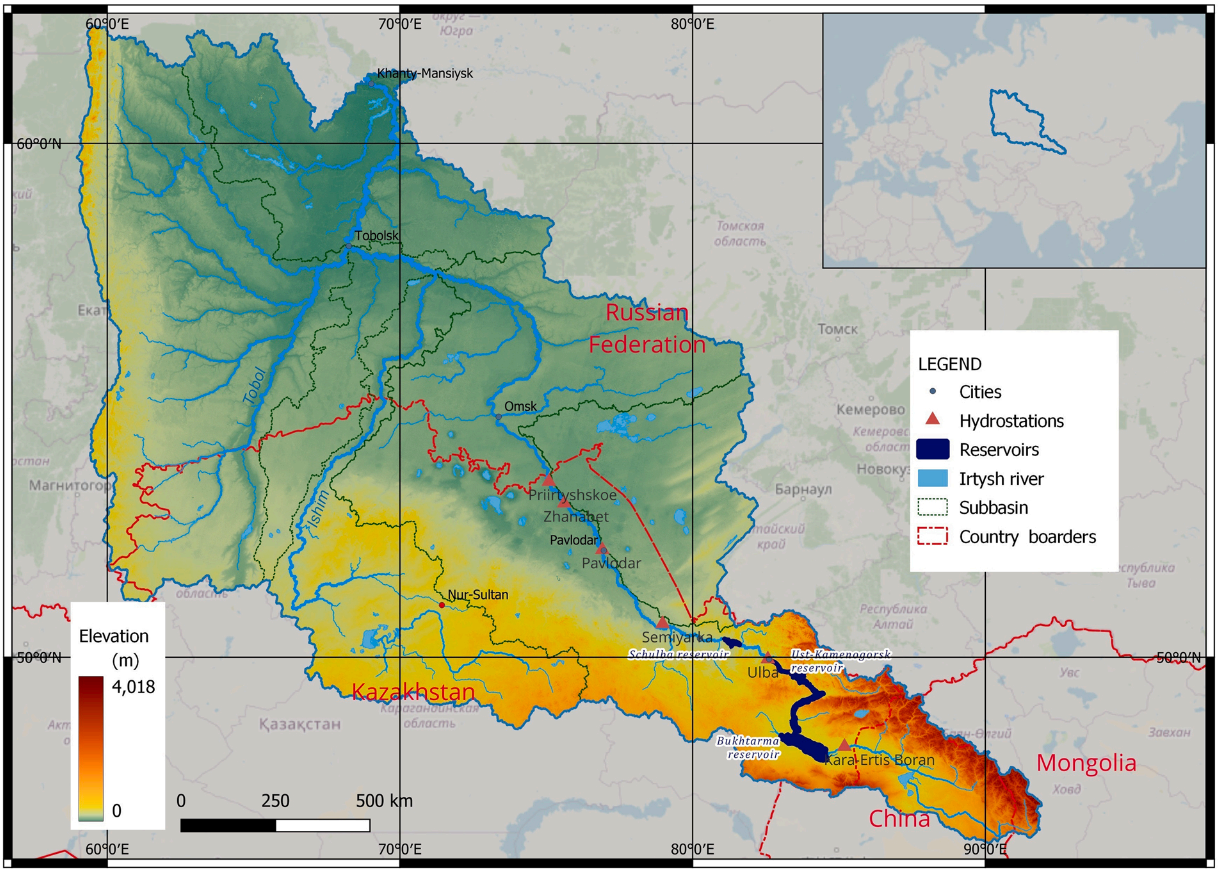

Fig. 1. Map of the Irtysh River Basin. HydroBASINS tool was used to identify the boundaries of the Basin (Lehner and Grill, 2013).

dams along the stream.

Presently, there are major concerns regarding the future of the River, which can be characterized by two group of origins. The first group is related to the potential impact of climate, particularly the effects of increased precipitation and intensive snowmelt (Padalko, 2021). The second group is related to the transboundary nature of the River and the potential increase in consumption, especially upstream (Zhiltsov et al., 2018). These factors may lead to the contradictory consequences in future: from potential depletion of water in the Basin to the potential flooding in the region. Both scenarios may deteriorate the health and functionality of the river and demands improved management of the River, based on reliable monitoring and investigations within the IRB.

Hülsmann et al. (2019) have stated that management and assessment of water resources should be performed considering the perspective of ecosystem, with regards to interlinkages between water-related sectors and resources in a comprehensive way. The similar approach of comprehensive evaluation of the pressure on water–energy–food–ecology systems in Central Asia has been proposed by Qin et al. (2022). An idea is to investigate relationships between energy and food sectors on the one hand, and environmental degradation and increasing pressure on regional finite water resources, on the other hand. Guidelines from United Nations Environment Programme (UNEP) for Vulnerability Assessment of Freshwater Resources to Environmental Change propose the following framework to evaluate the status of surface water bodies (Huang and Cai, 2009). According to this framework, an intensive study on relevant literature is used to diagnose the issues about 1) estimation of the amount of water resources in both state and trends; 2) water development/supply and use data, including a description of infrastructure, and analysis of water use by sectors; 3) ecological health data with the main focus on water quality and with interest for biodiversity, and 4) management capacity with investigating institutional and transboundary issues. All the approaches aim to define actions needed for the efficient management of the water resources.

This paper presents an attempt to evaluate existing risks and future perspectives of the Irtysh River by reviewing the most recent research trends in empirical investigations of the Basin. Authors aim to assemble available information about the current status of Irtysh River from the perspective of the "ecosystem" approach, when hydrological status of the water body is evaluated by research in

Table 1
Selected research paper and topics investigated.

Issues	Area	Author (s)
Hydrological issues		
Water storage and impact of influencing parameters	The whole basin	Huang et al. (2021)
	China	Yang et al. (2020a)
	Russia	Gusev et al. (2019)
	Kazakhstan	Fugazza et al. (2020)
Snowcover trends in the headwater	China	Zhang et al. (2017a);Yang et al. (2019);Gao et al. (2021);Wu et al. (2021)
River management and water balance	The whole basin	Padalko (2021)
	China-Kazakhstan	Smagulov et al. (2019)
	Russia	Alekseev (2018);Li et al. (2018);Zonn et al. (2018);Kondratyeva et al. (2021)
Impact of dams and hydropower reservoirs	China	Zhang et al. (2021)
	Kazakhstan	Huang et al. (2014);Beysembaeva et al. (2016)
Water quality		
Trends in water quality	Kazakhstan	Burlibayeva et al. (2016)
	Russia	Kondratyeva et al. (2021);Gulchenko and Bazhenova (2016)
Assessment of potential impact from sources of contamination	Kazakhstan	Solodukhin et al. (2015);Guney et al. (2021);Issakhov and Zhandaulet (2021)
	Russia	Mihailova et al. (2019)
Assessment of already affected areas	China	Deng (2014);Jia et al. (2019)
	Russia	Popova (2019);Chemagin (2020)
Biodiversity		
Value of biodiversity systems of the River and belonged ecosystems	China	Wang et al. (2017);Sun and Zhou (2020)
	Kazakhstan	Beysembayeva and Bazarbekov (2015)
Fish assemblage and influencing factors	China	Zheng et al. (2018)
	Russia	Borisenko et al. (2013);Mochek et al. (2015);Chemagin (2018);Chemagin (2019)
Potential for fisheries	Russia	Korentovich and Litvinenko (2018)
	China	Zhang et al. (2016);Zhang et al. (2017b);Ding et al. (2019);Xie et al. (2019);Luan et al. (2021)
Opisthorchiasis	Kazakhstan	Sultanov et al. (2014);Proskurina et al. (2020);Akhmetov and Maralbayeva (2020)
	Russia	Liberman (2020);Liberman and Voropaeva (2018)
Rare species	China	Yang et al. (2020b)
	Kazakhstan	Babushkin et al. (2021);Krupa and Aubakirova (2021)
	Kazakhstan-Russia	Bolotov et al. (2020)
	Russia	Bazhenova et al. (2019)
Policy		
The status of the cooperation between China and Kazakhstan	China-Kazakhstan	Biba (2014);Stewart raf (2014);Kukeyeva et al. (2015);Ho (2017);Park et al. (2020); Ziganshina and Janusz-Pawletta (2020)
The water relations between Kazakhstan and Russian Federation	Kazakhstan-Russia	Boklan and Janusz-Pawletta (2017);Vinokurov et al. (2018);Rybkina and Sivokhip (2019)
No tripartite agreements regarding the River	The whole bassin	Vasilenko (2015);Zhiltsov et al. (2018);Krasnoyarova et al. (2019)

the topics of water quantity, water quality, biodiversity, and policy issues (local and transboundary). Accordingly, the main objectives of this study are to identify actual challenges and to consider following pathways needed for management of the River.

2. Methodology

The rationale for performing this review was to cover all available and relevant sources of information in three languages: Chinese, Russian, and English. The first source of information was on macrolevel, generated by reports from governmental, quasi-governmental, and intergovernmental organizations. They included primary data about characteristics of regions, belonging to the River, including socio-economical, such as population, industry, agriculture, etc.; hydro-climatic, such as precipitation, discharge, water quality, etc.; and information about agreements, commitments, and plans to manage the River on the regional and transboundary scale. The second source of information was a traditional literature review on peer-reviewed English language journals in Scopus with additional selection of some publications in Russian and Chinese languages from local scientific databases. As the problem of predatory publishing exists in the countries of interest (e.g., Machacek and Srholec, 2021), the main criteria for choosing selected publications were consideration of the sources of the publications: they might be peer-reviewed and have reliable bibliometric and historical reputation on a regional level and recommended by local governmental committees for control in the sphere of education and science. Publications in scientific journals excluded from scientific databases were not reviewed. Either the articles, content of which have been considered as discredited due to their unfit information with officially available data and/or another research. To obtain the freshest picture, publications covering a study period between 2010 and 2021, were chosen for this review.

In total, 64 research paper have been selected as eligible for chosen criteria (Table 1). As a result of performed review, key topics of the hydrological issues include (i) interactions between water bodies dynamics and geo-meteo-climatic factors, such as precipitation, temperature, evapotranspiration, Oscillation, land-use changes, etc.; (ii) snowcover mass trends in the headwater of the River; (iii) investigations of the River management and its effect on water balance; with the particular focus on (iv) the impact of dams and hydropower reservoirs. Research on water quality issues cover (i) investigations of current trends in water quality in the River; (ii)

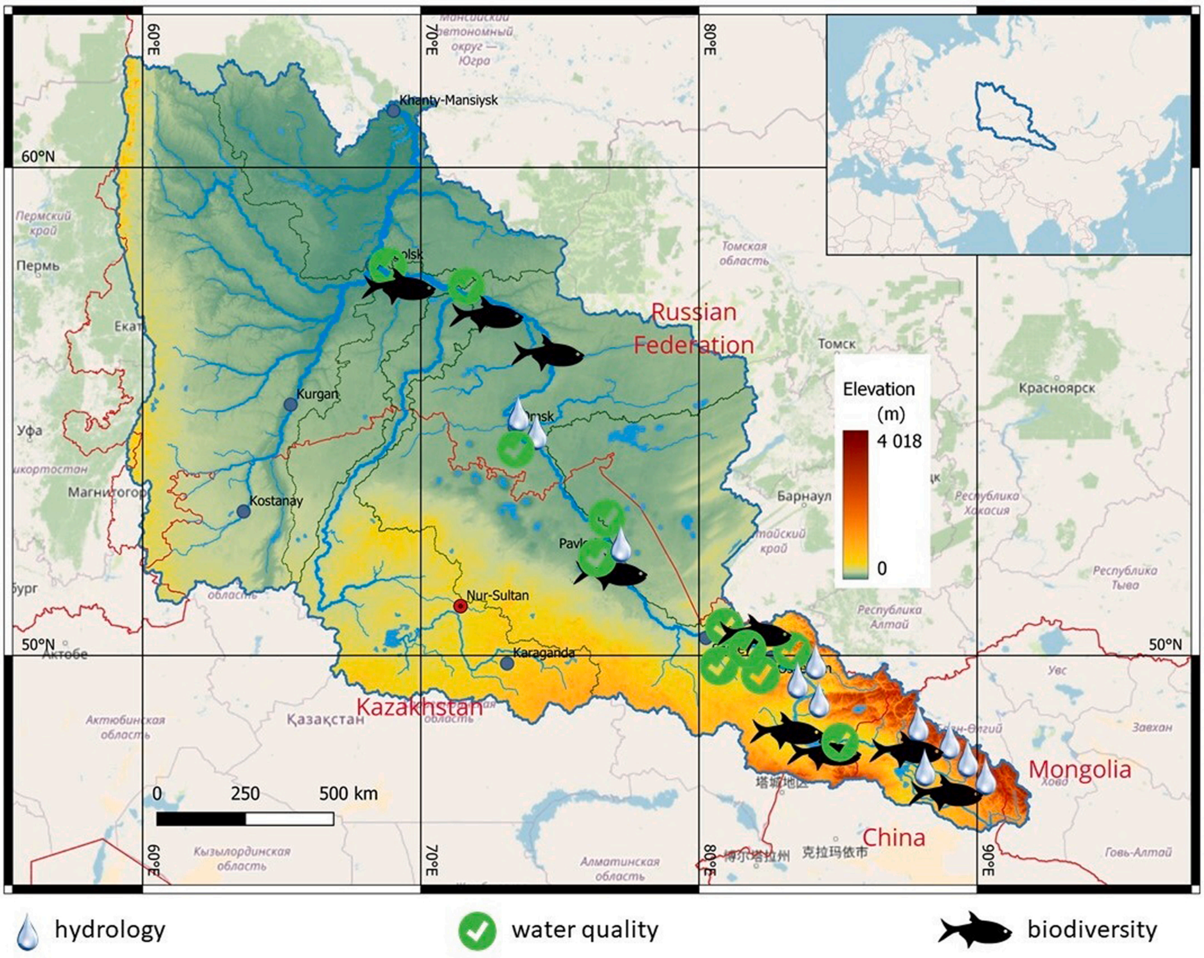

Fig. 2. The spatial distribution of studies carried out in particular sectors of the Basin by related issues.

assessment of potential impact from existing and future sources of contamination; and (iii) assessment of already affected areas by the River and respective response. The section on Biodiversity reviews the topics of (i) value of biodiversity systems of the River and belonged ecosystems; (ii) fish assemblage and influencing factors; (iii) studies about the potential for fisheries development; (iv) emerging issue of opisthorchiasis; and (v) insights about rare species in the River. Studies of the Policy issues discuss (i) the status of the cooperation between China and Kazakhstan; (ii) the water relations between Kazakhstan and Russian Federation; and (iii) the absence of tripartite agreements regarding the River. Spatial distribution of the investigations from the reviewed studies is presented in Fig. 2.

3. Study area

The headwater part of the IRB is mostly located in China characterized by high mountainous areas (top peak 4374 m.a.s.l.) with permafrost and glaciers but also with forest and grassland. Although the long term precipitation trend in the upper reach is almost constant, indicating a relatively stable rainfall distribution (300–320 mm/year for the headwater), it has been considered as the runoff generating area for the middle reach located in Kazakhstan since the middle reach is an arid and semi-arid region (Jiang et al., 2016). The research has also concluded that the long-term monthly temperature distribution follows a nice normal distribution with the highest temperature in July (22 ℃) and lowest in January (−20 ℃) while the monthly precipitation distribution showed a double-peak pattern for July and November.

Climate within the Basin on the Kazakhstani territory varies between mountain area on the south-east to flat plain towards the north-west direction in terms of temperature regime and in the amount of precipitation. The sharp continentality of the desert and semi-desert areas of the region is significantly smoothed out in the mountainous and foothill areas. January is the coldest month, when the average temperature varies between − 12 °C and − 19 °C, with a minimum of − 45 and − 49 °C, respectively. The average monthly temperature of the warmest month (July) is 20–22 °C. While the annual air temperature shows an increasing trend (Fig. 3), there is a tendency to a slight decrease of the temperature during the winter seasons (Kazhydromet, 2020a).

The annual amount of precipitation is distributed unevenly (Fig. 4). 400–650 mm falls in the north-east of the Basin (mountainous and foothill areas), and the least amount of precipitation falls in the areas of intermontane depressions - less than 200 mm per year. Precipitation of the warmest period (March-October) is greater than the precipitation experienced during the colder periods (December-March).

On the territory of Kazakhstan, Irtysh comes from China, and is also fed by tributaries of Ishim, Ulba, Tobol, and other small rivers (Burlibayeva et al., 2016). Precipitation, including in the form of snow, and groundwater, originated in Altay mountains, also contribute to the River significantly (Radelyuk et al., 2021a). Trends of the River flow on the Kazakhstani territory can be seen in Fig. 5. All gauge measurements indicate a slight, but constant decrease of water flow during the peak seasons (when snowmelt occurs) since 2016. The peak values of the flow for the stations Ulba and Semiyarka occur in April due to their locations regarding the cascade of reservoirs, which reflects storing water during this month. In May, water is disposed from the reservoirs, which is reflected in the peak values of the flow for the stations Pavlodar, Zhanabet, and Priirtyshskoe. The peak value for the station Kara Ertis in June can be explained by the receiving of the snowmelt from the Chinese part of the Basin by this month. The difference in the values of average annual flow between the stations of Kara Ertis and Ulba (280 and 94 m^3/s, respectively) and the next observation point (Semiyarka, 967 m^3/s) can also be explained firstly, by the location up-, and downstream, relatively to the cascade of reservoirs; and secondly, by the delivery of water from Ulba River. After that observation point, the average flow shows a slight decrease with relatively steady values for the last observation points on Kazakhstani territory (891 and 886 m^3/s for Zhanabet and Priirtyshskoe, respectively).

The Irtysh River Basin contributes 30% of the total water runoff to the overall water availability in Kazakhstan, which is the highest rate among the country (Anon, 2017). Specific surface water availability is equal to 15.4 thousand m^3 per person in the Basin. The research by Karatayev et al. (2017) has shown that 9.9% of total available water in the Basin has been used in electricity generation in Kazakhstan. Official statistics (Bureau of National Statistics, 2020, 2021a; 2021b) have shown that trends of water abstraction and water use for industrial and domestic purposes in general remains steady with a slight decrease (Fig. 6a-c), while there is a sharp jump

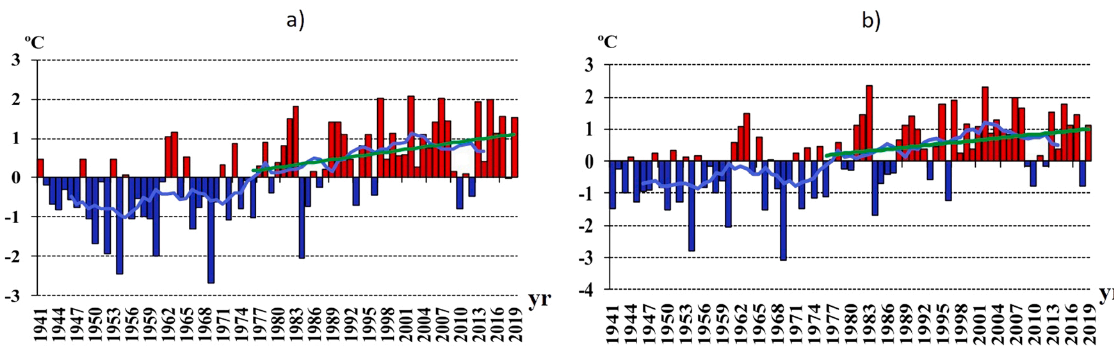

Fig. 3. Time series of annual air temperature anomalies for the period 1941–2019, averaged over a) East-Kazakhstani (primarily foothill) and b) Pavlodar (primarily arid) regions. Anomalies have been calculated relative to the period 1961–1990. Green color indicates a linear trend for the period 1976–2019 (Kazhydromet, 2020a).

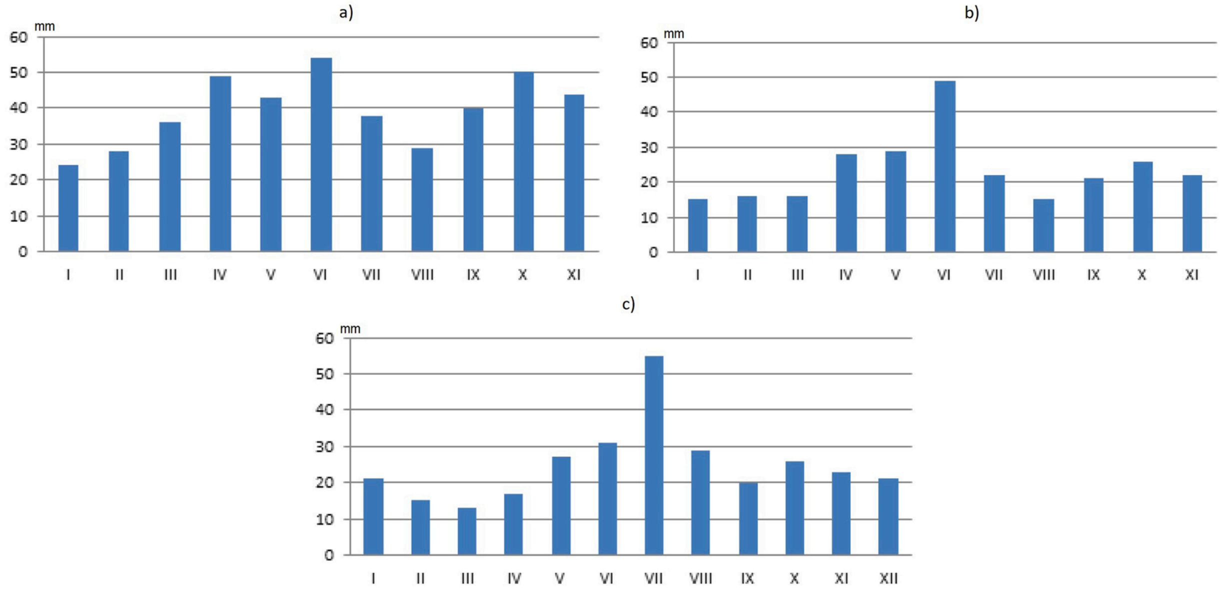

Fig. 4. Average monthly precipitation (in mm) for stations of a) Ust-Kamenogorsk (or Oskemen, depending on the origin of the name of the city in different languages), b) Semey, and c) Pavlodar (Kazhydromet, 2020a).

in the Pavlodar region for water use for agricultural needs in 2017 (Fig. 6d).

Data from Anon (2021) have shown that despite the growth of population in two out of three regions situated within the Basin in Russia, and related growth of water intake and disposal, implementation of rational water use strategy has led to a decline in water use since 2018 (Figs. 7a and 7b, respectively).

4. Hydrological status

The most recent research from Huang et al. (2021) has used remote sensing techniques to quantify dynamics of water bodies along the whole Irtysh River Basin and to estimate influence of the major factors, such as temperature, precipitation, evapotranspiration, and snow water equivalent. It has been identified that the total surface water area has shown an increasing trend since 1990 at a rate of 2922 km^2/year. The same growth has been identified for Middle Irtysh River Basin (MIRB), which mainly characterizes the sub-basin of the main stream. Coefficients of variation of the MIRB for permanent and seasonal water areas have shown relatively small values, which indicates that water is distributed uniformly. The factor of evapotranspiration has had the highest impact on total surface water area in MIRB among others leading to increased water consumption, while temperature has had the smallest contribution rate. Therefore, an interaction between different factors for MIRB has shown a relatively slight tendency. Relationship between surface water body area (SWA) and terrestrial water storage (TWS) showed an abrupt change in 2007. SWA showed growth, while TWS started to descend significantly with the lowest value in 2012. The same results of a little effect of precipitation, as well as of the amount of runoff, on TWS have been obtained by Yang et al. (2020a).

Decline in TWS of the Basin could be explained as caused by diminishing of glaciers and snow in the upstream area of MIRB in the Altay Mountains in northern Xinjiang during previous years. According to Wu et al. (2021), snowmelt runoff at the headwaters of the Irtysh River of the Chinese Altai Mountains in northern Xinjiang constituted 29.3% of total runoff in the river basin for the period 2000–2016. A study of snow hydrological processes in Chinese Altai Mountains during 1961–2015 has shown that the period from April to June contributes up to 58.1% of annual runoff by meltwater in the southern slope of the middle Altai Mountains (Zhang et al., 2017a). Yang et al. (2019) have investigated this issue in detail for the whole Basin in northern Xinjiang of China and concluded that firstly, snow cover mass declines at a rate of 10.2 Mt per year, or 0.3% per year; and secondly, the related loss of freshwater service contributes about 19%, implying that there would be a significant underestimation of service loss if only water supply is considered. While Gao et al. (2021) have reported no significant changes in the snow depth, snow water equivalent, snow days, and the start time of snow accumulation in the basin from 2001 to 2017; the trend of a shift to earlier snow cover melting in the upper Irtysh basin coupled with a decrease in late spring snow depth and snow cover duration had been identified (Dai and Che, 2014).

Zhang et al. (2021) have focused their research on the impact of a cascade of hydropower plants located in the northern Xinjiang on environment and society. The analysis has been based on data of streamflow between 1959 and 2012 and considering data of water demand for the same period. These hydropower plants were estimated to guarantee 95% of water supply for domestic and industrial purposes, 90% for ecological baseflow and for northern Xinjiang, and 75% for agricultural irrigation. It has been found that the designed water supply guarantee rates can be met on the sufficient level for socio-economic benefits, and also for restoration of the ecological diversity in the region. There is a large cascade of reservoirs on the territory of Kazakhstan on the river. Huang et al. (2014)

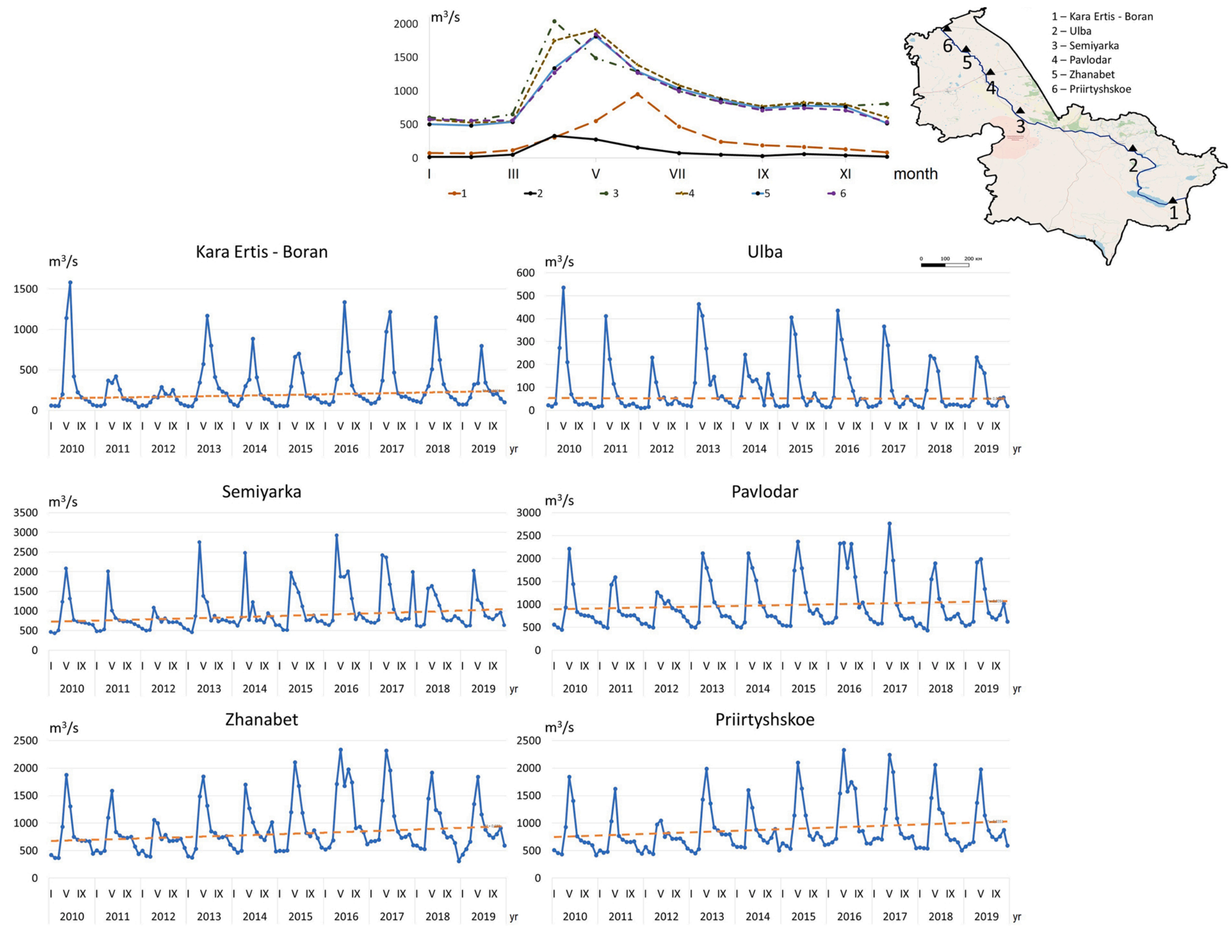

Fig. 5. Hydrographs of water flow (in m^3/s) based on six observation stations along the main course of Irtysh river in Kazakhstan. The upper most graph shows monthly-averaged flow within the stations.

have tested difference between the pre-dam and post-dam seasonal discharge on the Kazakhstani territory using the Lepage test. It has been found that precipitation over the Irtysh River Basin changed little before and after the operation of the reservoir, which means that changes along the streamflow mainly depend on a control of water storage in the reservoirs in the middle reaches of the river. Beysembaeva et al. (2016) have studied flow characteristics after the start of operation of the Upper Irtysh River cascade of reservoirs and found that summer flow decreased by 38% for the period 1935–2010, while winter flow increased by 70% for the same period. The research by Smagulov et al. (2019) has calculated scenarios for water balance in the Kazakhstani site of Irtysh based on retrospective data and assumptions, if water consumption remains on the current level ("positive scenario") or increases intensively ("negative scenario") (Fig. 8). The results have shown that annual flow would decrease in both scenarios. A slight deficit (approx. 2 km^3) has been forecasted for the zones between a Kazakhstani-Chinese border and Bukhtarma reservoir (zone I), between Bukhtarma and Schulba reservoirs (zone II), and between Schulba reservoir and a border between East-Kazakhstan and Pavlodar regions (zone III) in the positive scenario. If a situation with water consumption follows the negative scenario, the deficit increases significantly for the zone I (more than 7 km^3 in 2050) with a serious decrease of annual flow (from 29.2 to 16.1 km^3). Nevertheless, tributaries of Irtysh in zone IV (between the Pavlodar region and a Russian-Kazakhstani border) would supply enough water to avoid a deficit in future if the situation remains unchanged.

Russian site of Irtysh River is highly concerned about both quantity and quality of the water in the river, as it receives them after two countries. Zonn et al. (2018) noted that compared to the 1990 s, the Irtysh flow in Russia has fallen on three occasions. The Omsk hydrological station has been used to determine the impact of upstream cascade reservoirs on instream ecological flow in the study from Li et al. (2018). The results have shown that at the start of operations of two out of three reservoirs upstream Omsk hydrological station (built in 1959) led to uneven distribution of annual flow volumes after 1959. The study emphasizes the same conclusion about efficient operation of the reservoirs on mutual agreement. Gusev et al. (2019) assessed possible scenarios of variations in water balance in the basin. The results have shown that areas of relatively small runoff of the Irtysh can be found in the southern Russian part of the Irtysh basin and northern Kazakhstan. These areas risk to increase and extend southward by 2045–2070. Also, there are studies about water loss in water supply from the River due to poor conditions of water supply networks in Russia (Kondratyeva et al., 2021). Therefore, there are attempts to implement water-saving techniques and to better manage the river. For example, an updated

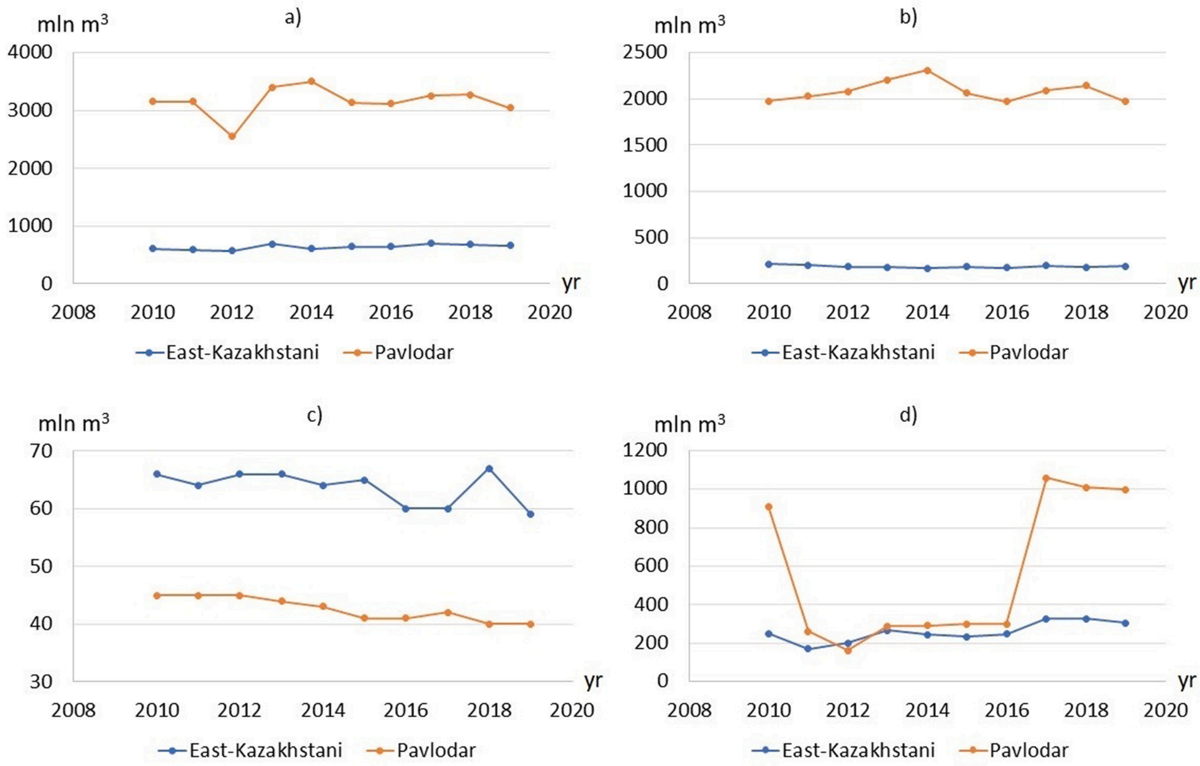

Fig. 6. Statistics on Kazakhstani regions situated within the Basin for a) water abstraction (in million m^3), b) water used for industrial purposes (in million m^3), c) water used for domestic purposes (in million m^3), d) water used for agriculture (in million m^3).

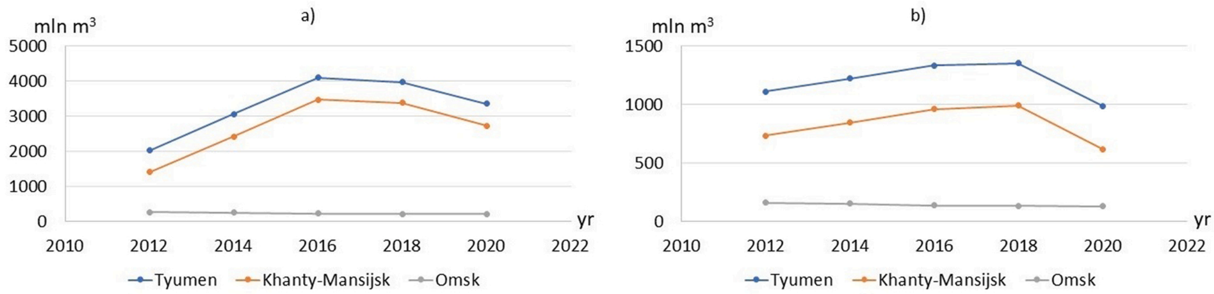

Fig. 7. Statistics on Russian regions situated within the IRB for a) water abstraction (in million m^3), b) water disposal into surface waters (in million m^3).

wastewater treatment unit has been successfully launched in Omsk city, that has led to a reduction of the intake of water from the river as well as eliminating the discharge of the contaminated wastewater into the River (Alekseev, 2018).

5. Water quality

Scientific literature gives poor information about water quality in the upper reaches of the Basin. While China is well aware of the challenges of increased water use, the pollution problem has been ignored. In a recent study, Deng (2014) has identified a top-ten list of strategically important challenges to tackle for the future, including ecosystem protection and eco-environmental protection together with traditional issues involved in Integrated Water Resources Management (IWRM), where the key issue is the general water use efficiency.

According to the classification of water bodies, Irtysh has been rated differently in two regions of Kazakhstan, where the River flows (Kazhydromet, 2020b). The water quality in the Pavlodar region has been considered suitable for all purposes, including fishery, domestic, recreation, irrigation, etc (class 1). The water in the East-Kazakhstani region has been ranked on class 4, which means that

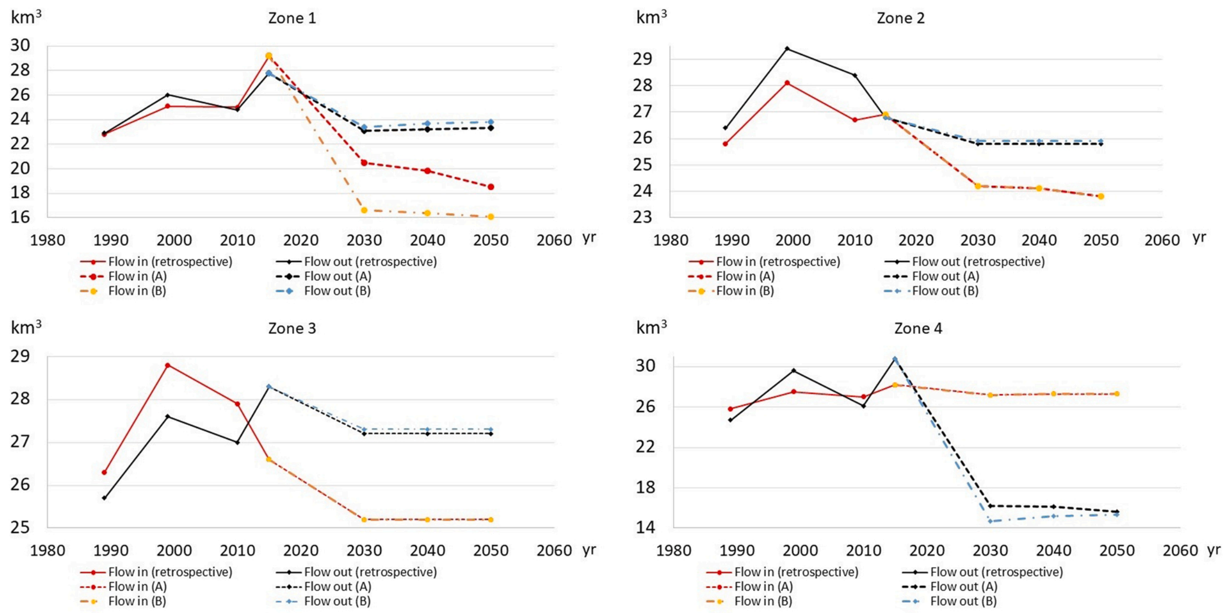

Fig. 8. Scenarios for water balance in case of (A) rational ("positive scenario"), and (B) intensive ("negative scenario") water use by China and Kazakhstan, adapted from (Smagulov et al., 2019).

the water body can not be recommended for fisheries, domestic purposes (it is possible to use only in case of intensive treatment), and recreation. Mainly, suspended matters have exceeded permissible levels at the monitoring points. These exceedances have been observed downstream at the point of wastewater discharged by industrial enterprises, or after the Ust-Kamenogorsk reservoir. Also, severe pollution has been detected downstream at the cross-section with the Ulba River tributary with the exceeding of concentrations of suspended matters and manganese. It can also be pointed out that toxicity tests have shown a high level of toxicity in tributaries, for example, the death rate of indicators (*Daphnia magna*) in samples from Ulba varied between 13.3% and 100% with an average of 60% between winter and summer 2020.

High density of industrial capacity along the River generates historical and current contamination in Kazakhstan. Both regions East-Kazakhstani and Pavlodar highly contribute to the industrial development of the country. As a sound example, Burlibayeva et al. (2016) have analyzed a connection between recent characteristics of the hydrochemical regime and toxicological indicators near the city of Ust-Kamenogorsk. The authors have assessed, firstly, an ecological status regarding the maximum permissible concentrations (MPC) of the major pollutants such as salt content, biochemical oxygen demand (BOD_5), phosphate, Si, Fe, Cu, Zn, Ni, Cr^{6+}, Pb, V, Hg, Cd, Mn, As, volatile phenols, petroleum products, fluorides, oxidizability and nitrogen, using data from Republican State Enterprise "Kazhydromet"; and secondly, toxicological tests have been applied to selected water samples. Phytoplankton and Daphnia have been used as bioindicators. The water quality has been recognized as relatively clean on the sampling point near the China-Kazakhstani boundary (Boran village), exceptionally rare exceedings of heavy metals and organic compounds during the flooding seasons. The slight increase in concentrations, but still below or around MPC, of potentially toxic metals (such as copper, iron, and manganese), phosphorus, and nitrogen have been detected on the following sampling points, located near the cascade of reservoirs and big cities. This fact most probably can be explained by runoff from the territory of large settlements and industrial enterprises. However, severe contamination has been investigated in one of the tributaries near mine discharge, where concentrations for copper reached 37-fold and 51-fold MPC, for zinc 215-fold MPC, and manganese to 19.6-fold MPC. Also, biotesting results have shown a high level of acute toxicity of water samples in tributaries, where the survival rate of most water samples was lower than 46.7%. Combination of those results says about a necessity to pay more attention to the methods and programs of the assessment of the water quality in the River, as there is a high risk of severe pollution.

Historical experiments of explosions of a nuclear weapon on a former Semipalatinsk (Semey) Test Site have also been considered as a potential threat for Irtysh. Solodukhin et al. (2015) have carried out laboratory studies of radiation near the segment of Irtysh River and its tributary (Shagan River), which belonged to the Test Site. Results of radionuclide and elemental compositions of water objects (water, bottom sediment) have shown a safe status. However, it has been found that the content of some elements (Li, Be, B, V, Cu, Sr, Mo) slightly increases downstream, which requires extra investigations. The same situation remains for potential mercury contamination by former mercury–cell chlor-alkali plant operated in Pavlodar, Northern Kazakhstan. Many research have proved (e.g., Ullrich et al., 2007, Guney et al., 2021) that there is no transport towards the River, however there is still public concern about a potential threat. Also, some potential sources of pollution make concern about a potential impact on water quality. For example, Issakhov and Zhandaulet (2021) have developed a numerical model to analyze the impact of thermal pollution from a future nuclear power plant. In result, there is a recommendation to keep the temperature value below 3 °C at a discharge rate of 1.0 m/s to avoid a negative effect on aquatic life.

Complaints come from the territory of Russia about water quality in Irtysh after it flows from Kazakhstan. Kondratyeva et al. (2021) with the reference to The Annual Bulletin of the Omsk Region Government and the Ministry of Agriculture and Food of the Omsk Region have reported that the content of chemical oxygen demand (COD), iron, copper, and aluminium slightly, but permanently, exceed threshold limit values (TLV) near Omsk city. Russia experiences the same issues with current and historical water contamination like Kazakhstan. Chemagin (2020) has carried out a chemical analysis of bottom sediments along 179 km of the River and found a periodic excess of oil products in there. The author has linked this fact with activities of river piers and ship-repair sections of the river fleet, releases of sewage treatment facilities from big cities, and industry. Also, first-order tributaries contribute to mineralization processes of the River, where related parameters exceeded the parameters in Irtysh two-fold (Mihailova et al., 2019). Gulchenko and Bazhenova (2016) have used phytoplankton as indicators of water pollution near Omsk city. It has been found that the most influential factors were flowrate, temperature, and chemical and biochemical oxygen demand (COD and BOD). Most of the phytoplankton species have been indicators of severe pollution, what reflexed the respective polluted status of the River in the investigated area. Evaluation of flora and fauna of the floodplain in the right-bank of the lower reaches of the River has shown that plant communities of the Irtysh River are stressed by anthropogenic invasion from the deteriorated quality of water supplied, which lead to the disruption of natural ecosystems, including a decrease in species diversity, density and biological productivity at the test sites (Popova, 2019).

6. Biodiversity

There is a general increasing concern of environmental protection and biodiversity consideration in China among decision-makers. In a recent large-scale campaign, an integrated investigation was carried out on areas of the upper Irtysh which is classified as the national natural reserve where the basin-wide biodiversity, the flora and fauna, community structure as well as socio-economic characteristics have been analyzed (Wang et al., 2017). In a recent attempt, Sun and Zhou (2020) used a quantification method based on a Chinese standard to calculate and quantify the economic values of various ecosystem services in the upper reaches of Irtysh. The results of this study have shown that Fuyun and Altai farms have the largest total value and the most dominant contribution for all the farms come from water conservation (Fig. 9). Besides the water and soil conservation, the value of ecosystem services also includes,

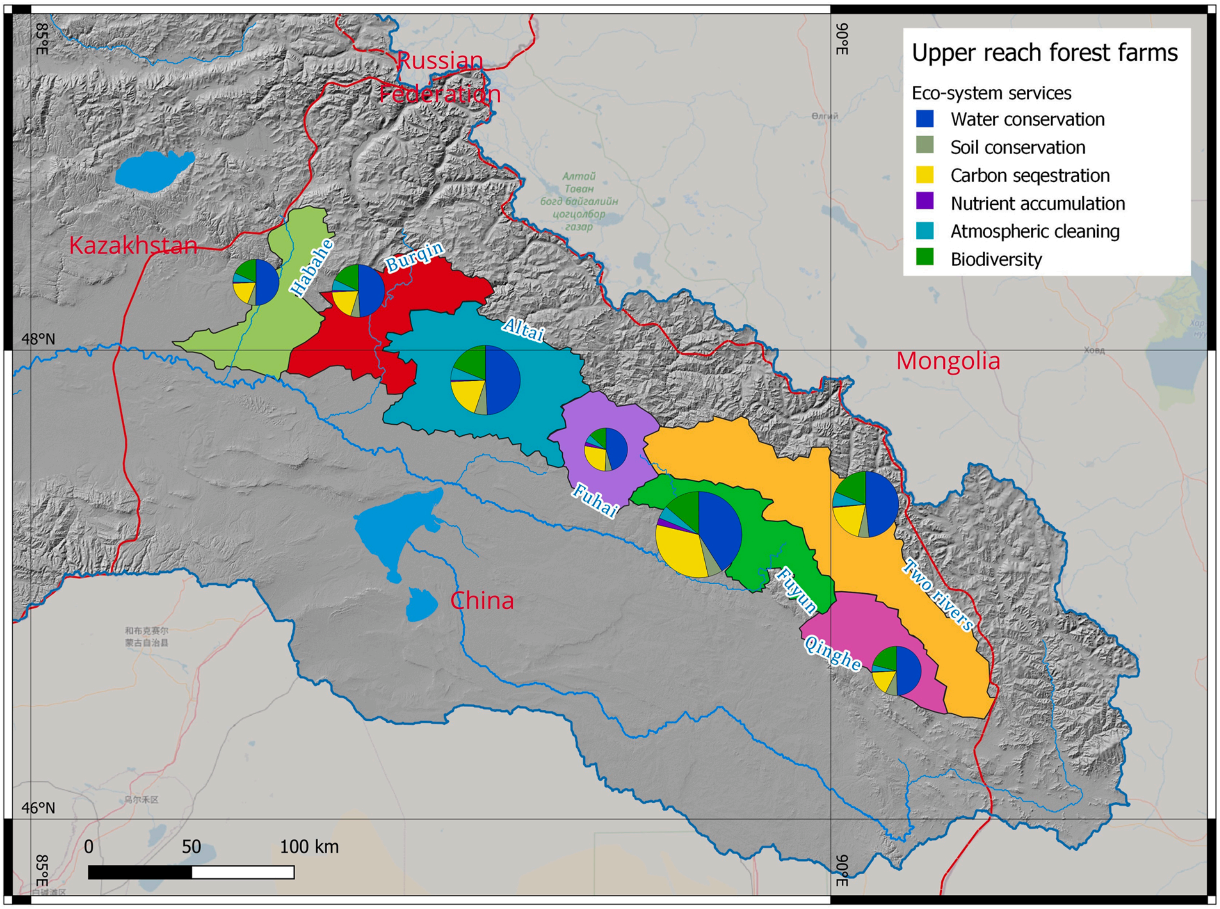

Fig. 9. Ecosystem service quantification of 7 forest farms in the upper Irtysh. The pie-chart size symbolized the 6 different services and relative total value for each farm.

carbon sequestration and oxygen release, nutrient accumulation, biodiversity and atmospheric cleaning.

The Chinese section of the Irtysh River is considered an area with a broader range of fish assemblages according to Zheng et al. (2018). That research has aimed to characterize the food web of the River on the Chinese site with a particular focus on potential effects of resource availability and flooding regime on food web trophodynamics. One of the main conclusion was that flooding scouring and dam construction plays an important role in trophic structure and impacted the hydrological regime, which regulates availability and distribution of primary and secondary food resources. Regions with higher trophic positions and food chain length at the upper reach were noted to have high availability of food resources and more fish species (insectivorous and piscivorous fish).

Borisenko et al. (2013) have attempted to carry out substantial work in identification of distribution of fish in the Lower Irtysh basin during summer periods. The following representatives were found: *Acipenser ruthenus* (sterlet), *Coregonus muksun* (muksun), *Rutilus rutilus* (roach), *Leuciscus idus* (ide), *L. leuciscus* (dace), *Abramis brama* (bream), *Car assius carassius* (crucian carp), *C. auratus* (golden carp), *Perca fluviatilis* (perch), *Gymnocephalus cernuus* (ruff), *Stizostedion lucioperca* (pikeperch), *Esox lucius* (pike), and *Lota lota* (burbot). The juveniles in a family of cyprinids (*Rutilus*, *Leuciscus*, *Abramis*, and *Carassius*) dominated and represented over 80% of fish abundance. Areas of a large floodplain complex and within limits of a riverbed depression seemed to be the most attractive places, as there were found the maximum density of the fish aggregation. Also, it has been found that the downstream migration of juveniles takes place at nights in narrow floodplain channels with no cloudiness or rapid streams. The intensity of brief movements of fish is also synchronized with the change of day and night in channels with turbid flow, though the relationship is reverse: maximum activity is observed during the day. Investigation of the effect of water level and temperature on the fish population has been carried out in the floodplain-channel complex of the Lower Irtysh during the spring flood season (Chemagin, 2019). The place is recognized as a good fit for feeding and a spawning place for various species of fish. Results showed that the density of fish decreased from 4 to 13 times due to their migration to the floodplain during the 30-days observation period. It can be concluded that low temperature serves as a signal there is a risk for reduction of the success of catching prey, which makes fish staying in the main channel. Also, the predominant migration of small fish from the mainstream to tributaries was observed during the period of water level increase, which could be explained by attempts to decrease the density of aggregation and to survive. Another study by Mochek et al. (2015) also has investigated factors of water level, local environmental conditions (such as depth, substrates, patterns), and diurnal cycle on fish distribution on the fish distribution in the same area. The level of illumination was rated as the most influential factor. Most migration with the significantly higher density was observed during nights. The largest proportion of these fish was represented by early juveniles not exceeding 2 cm in body length. Also, Chemagin (2018) has observed that in the zones of vortices along the River, the number of fish is on average 2 times higher compared with the "no vortices" zones at the same depth. There are also attempts to restore fauna of the River. For example, larvae and juveniles were artificially grown with the enriched nutrition to increase their growth and survival potential (Korentovich and Litvinenko, 2018).

There is a huge potential to develop fisheries. For example, research from Luan et al. (2021) has shown that the population of northern pike spreading from the mainstream of Irtysh to connected water bodies with a low risk of extinction. Xie et al. (2019) have investigated the influence of environmental factors on the population of Phoxinus ujmonesis. The results have shown that abiotic factors like dissolved oxygen, pH, total dissolved solids, and conductivity in water as well as biotic factors like plankton diversity and fish species diversity might contribute to genetic diversity and divergence in the population in the region. Analysis of growth, natural mortality and maturity for a fishery species European bream *Abramis brama* from the family *Cyprinidae* in the downstream section of the Irtysh River in China have been performed (Ding et al., 2019). The authors have proposed to increase the minimum age limits (by increasing mesh sizes of fishing nets) to conserve the *A. brama* stock in the region, as there is a higher risk of growth overfishing than that of recruitment overfishing. Also, the abundance of benthic organisms might be a more important influencing factor of growth rate compared to the latitude according to Zhang et al. (2016). Additionally, Zhang et al. (2017b) have highlighted that *A. brama* in the lower reaches of the Irtysh River is vulnerable to overexploitation due to relatively late reproductive maturity in their life span, maturity for a short period and spawns in aggregations. Fish-processing enterprises are also located in the Irtysh-Zaysan basin, with the largest in the Pavlodar, Karaganda, and Ust-Kamenogorsk regions (Park et al., 2020).

Studies of the characteristics of biodiversity in the Kazakhstani section of Irtysh indicate that opisthorchiasis is widespread. Home animals of the habitants in rural settlements of the region, especially cats and dogs are fed by unprepared fish from the River, which highly contribute to the existence of opisthorchiasis foci (Proskurina et al., 2020). Akhmetov and Maralbayeva (2020) have investigated the fish trematodes fauna in the Pavlodar region and found that the maximum intensity and prevalence of infection (7.9/94.4% respectively) was in stomach and esophagus of pikes. The infection rate of *B. luciopercae maritas* in fish of the region was estimated as 40%. The prevalence of invasion of *S. bramae* ranged from 6.7% to 26.09%. As a result, most human cases of opisthorchiidosis have been found in the north and northeast part of Kazakhstan in areas drained by the Irtysh River and its tributaries (Sultanov et al., 2014). The same problem related to the distribution of parasites in fish exists in Russia. Investigations of the invasion of the most widespread fish family in Lower Irtysh, Cyprinidae, have shown that 13 species of trematodes occupied all representatives of the family (Liberman, 2020). A significant infection of bream *Abramis brama* (Linnaeus, 1758) with opisthorchiasis has been revealed in the Lower Irtysh by Liberman and Voropaeva (2018).

Despite ordinary habitats specific for the River, fauna is represented also by some rare species. For example, European freshwater mussels, including a unique *U. tumidus* haplotype of a relict origin, has been found in East Kazakhstan in samples from the Black Irtysh River and the Bukhtarma Reservoir (Bolotov et al., 2020; Babushkin et al., 2021). New species of Calanoida: *Diaptomus (Chaetodiaptomus) mirus* and *Gigantodiaptomus irtyshensis* have also been discovered in East Kazakhstani waters of Irtysh (Krupa and Aubakirova, 2021). The richness of biodiversity is still being investigated. For example, Bazhenova et al. (2019) has recently described plankton diatoms from the middle part of the River with the first appearance of 61 species in the studied sector. Chinese site is also a home of very rare aquatic species, such as freshwater sculpins *Cottus dzungaricus* belonging to order Osteichthyes, family

Scorpaeniformes and genus Cottidae (Yang et al., 2020b).

7. Policy

This section can be formally divided into two parts. First part can be dedicated to regional legislation, where the issues related to local management are described. Second part can be about transboundary relationships, relevant agreements and commitments, and related issues.

Kazakhstan and Russia have the same system of river management based on the Basin management (Ministry of Ecology, Geology and Natural Resources, 2019; Russian Federation, 2006). The Basin inspection regulates the use and protection of the River by establishing and control of water use limits, water balances by basins, control over the observance of the boundaries of water protection zones and strips, etc. Therefore, the Inspection does not rule the characteristics of discharge to the River and does not control water quality. This functional belongs to the Committee of Environmental Regulation and Control. The discharge characteristics are established based on the volume of effluents, while the content and a potential impact on the flora and fauna are barely considered (Radelyuk et al., 2021b). According to the Order from Ministries of Agriculture (Anon, 2015, 2020), Irtysh River belongs to the list of fishery water bodies of international significance. It means that the most stringent requirements are imposed for water quality of the respective water body (Ministry of National Economy, 2015; Anon, 2016). Tributaries of Irtysh also belong to this list; however, they are also recipients of discharges from mines and open pits.

The literature review reveals several important and interesting points in sense of multilateral agreements. Most researchers have admitted the *1997 UNECE Water Convention on the Protection and Use of Transboundary Watercourses and International Lakes* (*UNECE Water Convention*), as an unbiased guideline for the management of transboundary rivers. While China still has yet to ratify this Convention, there is a solid enough cooperation with neighbouring countries in a matter of shared rivers (Biba, 2014). Biba has analyzed the recent status of the cooperation between China and neighbourhoods aiming to approve or disregard a role of China as dangerous hegemon in controlling its upstream rivers, including Irtysh. In 2004, the Chinese government affirmed plans to use a max of 40% of the Irtysh to provide water to the Karamay oil fields and to construct a canal to divert water from the River to Lake Ulungur in Xinjiang. (Allouche, 2007). The major concern has been about dam building and river rerouting activities with possible negative ecological, economic, and political consequences. The outcomes of the study showed that even Beijing deals with a domestic water crisis, the principle of “peaceful development” has been promoted by authorities with consideration of the needs of downstream countries. In the context of Irtysh River, the author has highlighted that the Chinese government clearly agreed to institutional design to manage shared water resources between two countries: China and Kazakhstan, which resulted in two key agreements: *Agreement on Cooperation in the Use and Protection of Transboundary Rivers* (2001) and *Agreement on the Protection of the Water Quality of Transboundary Rivers* (2011). Moreover, these agreements were followed by respective joint commissions with the developed program for actions to solve all the addressed issues within the constant meetings (Zonn et al., 2018). Ziganshina and Janusz-Pawletta (2020) have investigated these agreements and concluded that following important issues are defined in mutual respect and with the pathway to dialogue: promotion of the exchange of hydrological and water chemical data, assurance of the optimal use of water resources, water quality control, and prevention of pollution of transboundary rivers (to reduce the impact on the environment and society “to the lowest possible level”), coupled with actions to avoid man-made accidents, to take obligation to take measures, and to respond in emergencies. Several authors (e.g., Zhiltsov et al., 2018; Stewart raf, 2014; Ho, 2017) have noted that China intensified the negotiation process with Kazakhstan and made incentives for cooperation. Park et al. (2020) also have highlighted that a potential failure in the mismanagement of water resources can not be explained by the concept of hydro-hegemonism only. The authors have clarified the importance of both institutionalizing cooperation and establishing communication at societal, governmental, and inter-governmental environmental levels. Effective implementation of an analysis of ecological risks aims to help stakeholders in decision-making and to avoid a passive state of the parties. Kukeyeva et al. (2015) have added to this idea a concept of sustainable development. The authors have proposed seeking for water-efficient technologies for all sectors, for example for farmers, to achieve environmental sustainability and greater social harmony.

Russia has long been concerned about upstream watercourse impact due to the reason that there are no tripartite agreements regarding Irtysh River (Krasnoyarova et al., 2019). Collaboration between Russia and Kazakhstan has been seeking for different forms to establish efficient and sustainable use of Irtysh, particularly in issues of runoff control, management of infrastructure, regulatory basement, and water quality (e.g., Vinokurov et al., 2018; Rybkina and Sivokhip, 2019). An ideal option to create a commonly ruled basin-wide joint inspection could probably fail due to lacking respective political will (Boklan and Janusz-Pawletta, 2017). The water relations between Kazakhstan and Russian Federation are regulated by the *Agreement on Joint Use and Protection of Transboundary Water Bodies* signed in October 2010 (Zhiltsov et al., 2018). This Agreement considers mutual efforts and information exchange in terms of quality and quantity of water supply. Therefore, there are still no enough data for researchers and stakeholders to effectively predict and propose patterns for sustainable River management (e.g., Vasilenko, 2015). The parties have emphasized the importance of cooperation programs for the conservation and restoration of ecosystems of the Basins within 2021–2024. The programs assume joint monitoring of the water quality of the River by respective scientific investigations with particular focus on identification of the sources of contamination; development of programs for recultivation, remediation, and modernization of existing treatment facilities to restore the River; the inclusion of representatives of the Russian Federation in the Interdepartmental Commission on the Use of the Cascade of Reservoirs in Kazakhstan; and permanent exchange of the relevant information (Anon, 2021).

8. Discussion

Padalko (2021) has identified a decreasing trend in water consumption in Russia and Kazakhstan, while China sees steady growth for the last decade. Specifically for the Irtysh River Basin, irrigation and agricultural water use went down by 18.6%, domestic and industrial water use fell by 15.8%. Special attention should be paid to the conditions of tributaries of the River in Kazakhstan, as currently they supply a sufficient amount of water and support to avoid a deficit of the mainstream. Observations of the increase of water supply by slightly increased precipitation and more intensive snowmelt potentially caused by Climate Change have been mainly confirmed by various researchers. For example, the results of the investigation of the processes of spring floods in the light of snowmelts in Eastern Kazakhstan indicated high influence of winter Arctic Oscillation on patterns of snow cover depletion over the region, which plays important role in the generation of annual runoff into the river (Fugazza et al., 2020). Melting of permafrost, glaciers, and snow in the upstream mountains of the River should be considered as one of the key processes in the hydrological budget. The amount of snow storage shows a relatively slight decrease, which causes higher water supply into the stream. However, the high impact of evapotranspiration rate could offset this effect. Spring season of the snowmelt along the whole Basin coupled with specific melting of snow and glaciers in the mountains during April-June can be considered as an advantage in the management of the reservoirs, used as hydroelectric power plants, located on the mainstream. However, there is a slight trend of a shift to earlier snow cover melting, which should be considered. The main point about reservoirs is not a fact of their existence in each country, but ways of operating them based on mutual collaboration. As changing water inflows is a function of energy system dynamics, the planning of future installations and operating already existing reservoirs deserves special attention. Previous plans aimed to assure water quantity on the respective level for restoration of the ecological diversity of the Basin. Therefore, some authors raise a significant concern about the development of the Xinjiang region and the building of the "Black Irtysh – Karamay - Urumqi" canal systems with the expected increase of water consumption for 50% of Irtysh volume in future (e.g., Krasnoyarova et al., 2019; Zonn et al., 2018; Biba, 2014). Hopefully, parties would follow the principles of Hydrosolidarity, Sustainable Development, and Circular Economy via implementation of water-saving techniques seeking for the no-harm principle.

Special attention must be paid to water quality issues, as these are followed by restoration of ecosystems and people health, e.g., water from Irtysh has been directly used by rural habitants (Tussupova et al., 2016). China is recognized as one of the most important countries that promoted a Circular Economy concept (Mathews and Tan, 2016). This concept has been recently introduced in the country and has led to more careful management of water resources, including the elimination of water pollution. Nowadays, the main focus on a Chinese site has to be on remediation programs of historical sources of contamination (e.g., Jia et al., 2019), while the Kazakhstani site still generates contamination. Main problems of water quality issues in Kazakhstan come mainly from two sources of the pollution. First, the high density of industrial capacity along the River, which generates historical and current contamination. Second, the run-off from the riparian surface. Industry in Kazakhstan takes advantage of loopholes in environmental legislation to pollute the River and its tributaries. According to the Entrepreneurial Code (Kazakhstan, 2015), industrial inspections are carried out once per six months with the preliminary notification at least thirty calendar days before the start of the inspection. Thus, businesses use the opportunity to prepare for the inspections in advance and to fix inconsistencies temporarily (Radelyuk et al., 2019). While the mainstream tends to self-purification and shows a good status of water quality, the water quality in tributaries, especially where risks of contamination are high, should be focused on. Methods of assessment and quality of monitoring of the River lacks efficiency, as they give a wrong picture of the current status of the River and should be revised. Standardization of monitoring and evaluation approaches across the Basin can allow for a more fair and objective assessment of the issues being experienced in the basin and thereby allowing for a more targeted approach to address these issues. Also, there is a critical lack of research about assessment and monitoring of persistent organic pollutants, pesticides, pharmaceuticals, microplastic, etc.

Review of biodiversity status has identified three major issues of the River: a status of living species and their interactions with conditions of the River; problems, related to parasites; and opportunities for fisheries. Biodiversity along the stream indicates the current good status of the River in general, including discovery and distribution of new exotic species. The following factors have been identified as comfort for fish distribution along the River: the large floodplain complexes; limited riverbed depression; appropriate water quality parameters; and biotic factors, like plankton diversity and fish species diversity to ensure a food chain. Therefore, redistribution of water flow appeared after construction of a cascade of reservoirs negatively affects conditions of the regional floodplain. For example, 90% of all the Kazakhstani floodplain of the River are located in the Pavlodar region. While the fluctuation of flow remained relatively unchanged (4–6%) for the period until 2010, a huge amount of warmed water after heat exchangers increased mineralization, which might affect soil and living species (Beysembayeva and Bazarbekov, 2015). Thus, these risks should be considered while planning the following ways of Irtysh use, including for fisheries. The main recommendation to provide sustainable fisheries is to consider vulnerability of the fish to overexploitation during the periods of maturity and spawns in aggregations. The third identified issue, parasites, cause inconvenience for their hosts, and first- and second-order consumers and demands proper outreach and communication to the people. Therefore, the behavior of parasites can be used for scientific monitoring of dynamic processes related to the River, such as the investigation of the impact of anthropogenic activities or Climate Change (Palm, 2011).

The section on Policy can be the hottest topic in a matter of the IRB. All involved countries consider the challenges listed above and implement respective legislation on a local scale, develop restoration programs, invest into minimization of water consumption, and seek alternative or recycling sources of water. The major point that has been raised by many researchers is lacking trilateral agreement for the River management based on searching for consensus (e.g., Ziganshina and Janusz-Pawletta, 2020; Zhiltsov et al., 2018; Boklan and Janusz-Pawletta, 2017). The reasons for it are underlying beyond the will of academic society. The main concern can be a denial from the Chinese side to ratify the UNECE Water Convention. However, researchers mainly evaluate actions of China as "peaceful development". Institutional cooperation and joint commissions seem to be the right response to support the common aim of a restoration of the River. This is also in line with the institutional capacity development in China as a general trend (Yang et al., 2016).

This research uses "ecosystem" or "water–energy–food–ecology nexus" approach to see the correlations between reviewed factors. For example, the issues with earlier snow cover melting time may positively impact energy generation in reservoirs, improve fisheries, and to supply enough water for consumption in the mid-term perspective. However, the tendency of the slight decrease in the amount of snow storage can be recognized as a problem itself and may cause negative consequences for the Basin in the long-term perspective. Another example is the interaction between water quality and biodiversity. While there are possibilities for fisheries, the current poor ecological status of the River causes risks of eliminating this opportunity or disseminating the contaminated fish to consumers, which affects the food chain of the River. The policy issues cover all the reviewed factors as they have power to restore the River on an appropriate level for use in the involved countries, and to assure the good status of the health of the River.

9. Conclusion

This research attempts to identify current challenges for Irtysh River considering the overview of scientific investigations of the Basin for the last decade. The challenges are supposed to be mitigated to ensure the good status of the Irtysh River in a matter of its sufficiency for ecological balance, domestic use, and living species. The state of the hydrological budget can be classified as stable, while contrary processes exist in the Basin: projected increase in water consumption in upstream and a higher rate of evapotranspiration from one site; and slowly, but permanently, increased snowmelt and precipitation rate from another. Thus, risks related to the impact of Climate Change and responsible water use should be considered and prevented. Involved countries should pay special attention to issues of water contamination both historical and permanent via respective remediation programs and implementation of restrictive legislation. These programs should be based on a unified and transparent monitoring system of the River, where all data will be available to all parties to make reasonable decisions on water management. Assurance of sufficient water quantity and water quality creates comfortable conditions for sustainable biodiversity management, which include stability of food chain and ecosystems and perspectives for fisheries development. One of the important actions to achieve the established aims is the building-up of a connection for efficient data exchange and information dissemination between governments involved. The latest investigations also present opportunities to manage the Basin more efficiently using the remote sensing techniques. Authors believe that international collaboration should start on an academia level at first. It will provide a more detailed and reliable assessment of the existing challenges of the River on the whole basin scale. Involvement of multidisciplinary researchers will let to evaluate the complex system of the River basin with the following best scientific-based suggestions for key stakeholders for the sustainable River management. Thus, this research can be used as a starting point for future investigations of issues described in the paper. Obviously, this research has a limitation in the lack of full access to all data available in three countries to obtain a better picture of the processes within the Basin. The proposal for future research is to close existing gaps and to provide a more detailed basis for investigations.

CRediT authorship contribution statement

Ivan Radelyuk: Conceptualisation, Methodology, Investigation, Formal analysis, Visualisation, Writing – original draft, Writing – review & editing. **Linus Zhang:** Conceptualisation, Methodology, Investigation, Formal analysis, Visualisation, Writing – original draft, Writing – review & editing. **Daulet Assanov:** Conceptualisation, Investigation, Data curation, Formal analysis, Writing – original draft, Writing – review & editing. **Gulira Maratova:** Investigation, Writing – review & editing. **Kamshat Tussupova:** Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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