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ORIGINAL ARTICLE

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Will the river Irtysh survive the year 2030? Impact of long-term unsuitable land use and water management of the upper stretch of the river catchment (North Kazakhstan)

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Abstract The Irtysh river basin all the way from river spring in China across Kazakhstan as far as the Russian part of Siberia is among the most ecologically endangered and affected regions on our planet. The study provides a summary of the historical reasons for anthropological interventions in this area, which began with the construction of plants of the military—industrial complexes in the forties of the last century during World War II. These plants have a major share in extreme high concentrations of heavy metals in surface as well in groundwaters locally. The Semipalatinsk nuclear polygon plays a specific role as a source of contamination of local waters. The release of top secret data enabled us to gain knowledge about serious problems related to high radioactivity of groundwaters, which should spread uncontrollably through a system of secondary fissures activated by nuclear blasts. Another serious problem in this region is the quantitative aspect of contamination. Model simulations of water balance indicate that large industrial development in the spring area in China and continuously increasing water consumption in Kazakhstan may lead to desiccation of the lower stretch of this large river in Siberia during the summer months of 2030.

Keywords Irtysh basin · Water quality · Radioactive contamination · Heavy metals contamination · Water balance

Introduction: a summary of major ecological issues

The catchment of the river Irtysh is one of the largest in the world. The river rises in the Altai mountain range of China and flows through the northern Kazakhstan; it crosses the border with Russia south of the city of Omsk. Its waters continue to the north and empty into the Arctic Ocean. The extent of the basin up to the Russian border is 596,000 km^2, of which 55,900 km^2 cover the spring area in China (Fig. 1). Of late, this 1,906 km-long stretch of the Irtysh river up to the Russian border has emerged as a serious ecological threat which may become a hot political issue.

The biggest and long prevailing problem is the quality of water. The area in northern Kazakhstan is world famous because of the Semipalatinsk nuclear polygon where at first nuclear blasts occurred on the surface and later underground in the period 1946–1969 when the region was an integral part of the former Soviet Union. Of a similar reach and importance is the Chinese polygon Lob Nor whose impact strongly affected the environment of the spring area of the river Irtysh. However, nowadays, the high concentrations of heavy metals coming from the local industry paradoxically pose a greater danger than the radioactivity of local waters. During the World War II, a substantial volume of armament produced by the former Soviet Union was transferred to the area of the upper Irtysh to the cities Leninogorsk, Ust Kamenogorsk and Semipalatinsk—the impact from these pose a terrible ecological burden.

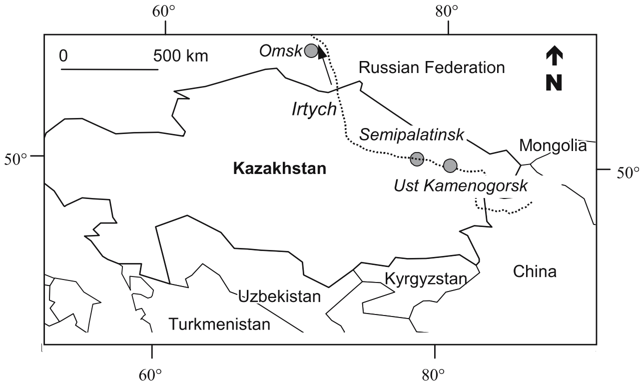

Fig. 1 Situation of upper Irtysh river

The second issue is the quantitative aspect since Irtysh is among the largest rivers in the world and its average water discharge at the border with Russia is equal to about 500 m^3 per second. Nevertheless, the hydrological regime of the river Irtysh had begun to change dramatically after World War II. A cascade of large dams was constructed mostly in its upper stretch. Already, by 1960, the largest dam Buchtarma had been put into operation. The capacity of this reservoir is able to retain water twice as much water as the annual water discharge of the Irtysh river. Another serious intervention in the river regime was the construction of a canal to the city of Karaganda. This watercourse was completed in 1974, draining water away from the river Irtysh about 15 m^3/s on a distance of 468 km. However, increasing demands on water consumption in Astana (formerly Alma-Ata), the new capital of Kazakhstan, need reconstruction and extension of the canal to the south and increase in the tapping of water. The absolute fundamental impact on the river Irtysh regime is the gradual construction and expansion of industrial complexes in the spring area in China. There are also rising new settlements, which should accommodate roughly 1 mn people in the year 2030 when they are scheduled for completion. These activities impose extreme demands on water resources as the water that will be consumed in the upper stretch will obviously be missing in the lower stretch and this will have a negative impact on the water quality.

The above-mentioned problems led to the implementation of the IRBIS project financed in the years 2001–2003 by the French government. The objective of the project was to create a uniform information database of the Irtysh catchment in the territory of Kazakhstan and Russia needed for optimization of water management. The activities were carried out by local organizations, universities and the private sector under the technical supervision and assistance of experts from the French companies, OIE, SAFEGE and ANTEA. This paper is aimed at providing the first interim results of data processing obtained as a result of monitoring as well as giving a prognosis of development of the hydrological regime.

Natural conditions of the Irtysh river basin

The above-mentioned huge extent of the Irtysh catchment is reflected in very varying natural conditions. From the viewpoint of morphology, the basin can be divided into two completely different parts. The spring area lies in the Altai mountain range with elevations exceeding 4,000 m a.s.l. (Belucha 4,506 m a.s.l.). Local rocks are crystalline Paleozoic complex metamorphic rocks with some magmatic intrusions. Then the river valley, roughly below the city of Ust Kamenogorsk, merges completely into a flat country belonging to the southern tip of the Siberian sedimentary basin.

The area of the middle Irtysh in flat Siberian basin shows characteristic signs of continental climate with extreme temperature values between the winter and summer seasons. The difference between the maximum +42°C measured at Pavlodar and the minimum –56°C observed in the Orlov valley gives an extraordinary 98°C. The prevailing air circulation from the west and south makes the climate rather dry. The driest region is the country between the city of Pavlodar and the river Shagan where the annual average precipitation does not exceed 250 mm, of which the maximum falls during the summer months characterized by extremely high evaporation. Different types of climate can be observed in the spring area in the Altai region. This region is to be considered the major source of water for the whole catchment since long-term annual totals vary between 1,500 and 2,000 mm. This rainfall is distributed much evenly in contrast with climatic conditions of the Siberian platform. The evaporation is also lower due to prevailing lower temperatures.

The morphology mostly reflects the local geology. The Altai mountain range is constituted of Paleozoic volcanic and metamorphic rocks. Larger depressions are filled with Neogene sediments. East of the city of Semipalatinsk, the crystalline complex merges into the huge sedimentary complex of the Siberian Basin whose thickness increases northward to a few kilometres. The river Irtysh in this completely smooth relief forms terraces that are a few tens of meters thick, which are closely hydraulically connected with the river.

The combination of changing morphological, climatic and geological conditions actually results in the division of the Irtysh catchment into two completely different sections. The upper mountainous part built of crystalline rocks is the area where surface and groundwaters originate. In the lower flat section of the catchment, which is built of sediments of the Siberian Basin, the river Irtysh has no important tributary; so the area represents a rather deficient environment from the viewpoint of water management.

Characterization of the monitoring

The present Russia as well as Kazakhstan inherited the system of environmental monitoring from the era of the former Soviet Union. The monitoring of all elements of the environment was in the past financed by the government having been subject to stringent secrecy. Political and economic changes in both countries brought both positive and negative effects. In effect, all data on the state of the local environment have been declassified including until quite recently top secret information from the vicinity of the Semipalatinsk polygon and the city of Ust Kamenogorsk. On the other hand, the disruption of central management and control and funding of monitoring in particular became a major problem in the region. The lack of funds in some areas resulted in considerable reduction in water quality monitoring or at worst even its complete stoppage so that long-term series of observations were interrupted. The specific problem in today's Russia and Kazakhstan is their fast transformation into free market economy. A large number of institutions or companies involved in monitoring were privatised so that the data in their possession are again difficult to obtain because of the lack of money needed for their acquisition.

The issue of exploitation of the Irtysh waters

The river Irtysh has been characterized in the introduction as a large river, which is the most important source of water for huge areas from the Altai, across Siberia as far as the Arctic Ocean (Table 1).

However, human activities and interventions have strongly disturbed the natural regime of the Irtysh catchment. Under regular conditions, some thousands of square kilometres of smooth relief of the middle Irtysh were flooded during the spring snow thawing. The ecosystem adapted to these periodical floods was to a large extent disturbed by a cascade of dams in the upper reaches of the river Irtysh.

Table 1 Flow rate of the Irtysh River (m^3/s)

Station	Flood discharge (1 day)	Flood discharge (183 days)	Low water discharge (347 days)	Comment
Chinese border	597	321	215	
Cemiyaskoïe	1,660	917	614	
Pavlodar	1,600	880	590	Influence of Karaganda channel
Russian border	1,580	844	557	

On the other hand, a much more dangerous trend is the permanently increasing water consumption, a tendency which will reach its climax in 2030, the year when the construction of industrial complex and housing development will be completed in China (as mentioned earlier). There in no doubt that the region of Central Asia is very vulnerable to human interventions into water regime, which can be demonstrated in the case of Aral Sea. Inappropriate regulation and extreme water consumption for irrigation caused an ecological disaster of global character connected with disiccation of the Aral Sea, soil salinization and other classic manifestations of desertification. In order to prevent the occurrence of such a situation in the Irtysh catchment, the IRBIS project, using a hydrological model, tried to establish scenarios of development of water regime under various simulated conditions.

The requirements for carrying out hydrological simulations were extremely high. The basin of the Irtysh covers a surface of 596,000 km^2 up to the border with Russia, including 55,900 km^2 in Chinese territory. The length of the river in Kazakhstan is 1,904 km, and this area is extremely varying in terms of the morphology and climate. Moreover, the hydrological regime of this major river is strongly disturbed by a cascade of reservoirs. No wonder the first conventional precipitation-discharge simulations (e.g., the SACRAMENTO model, Burnash 1995) have failed. Therefore, a variant of development of a new model was selected and designed in the Visual Basic language. The Irtysh river catchment was segmented into 15 blocks, of which each represented a more or less homogeneous area as far as hydrology and climate were concerned. The simulation of hydrology covering the whole region then consisted of a series of 15 partial precipitation-discharge models which were mutually interconnected. Each partial simulation took over input data from a block lying above and also provided input data to the subsequent block. Data from 36 rainfall stations of the Kazakh Hydrometeorological Institute relatively evenly distributed over the entire catchment provided basic and entry information. Simulations and subsequent calibration of the whole set of models were based on data from the river Irtysh discharge measured on 12 profiles. The oldest collections of measurements came from the region of Ust Kamenogorsk from the end of the 19th century, so that even periods with undisturbed hydrological regime could have been used in hydrological simulations.

The results of a calibrated model enabled us to forecast the development of runoff conditions. Provided all pessimistic hypotheses are fulfilled and the tapping of water reaches the expected volumes, then the Irtysh water regime in the year 2030 will have a character demonstrated in the following figure. It is to be noted that this simulation is based only on long-term climatic observations and data but does not take into consideration possible negative impacts of global warming. As follows from the diagram, the intervention into the water regime of the Irtysh river would be so fierce that in July 2030, this large river at the city of Omsk would be completely dry! It is to be stressed that the ecosystem of the large surroundings is completely dependent on the Irtysh water. As follows from the next chapter, the gradual decrease in water discharge would result in another negative phenomenon—gradual worsening of surface water quality, which even now is not very good.

The issue of water quality in the Irtysh catchment

One of the major ecological problems of Northern Kazakhstan and subsequently even the adjacent part of Siberia is the high degree of contamination of both the surface and groundwaters. Long-term monitoring of water quality unambiguously showed two major sources of pollution. The first one is represented by extremely high concentrations of a variety of heavy elements from industrial complexes, whereas the second specific kind of pollution is the radioactivity.

Radioactive contamination: the Semipalatinsk nuclear polygon

The Semipalatinsk nuclear polygon began to be used by the former Soviet Union in 1949 when the first nuclear blast was carried out. Surface nuclear blasts continued until 1969 when were then moved underground. These activities have strongly affected the local environment in broad surroundings of the polygon. It is paradoxical that the transfer of surface to underground blasts is the major cause of the present ecological problems. Altogether 295 underground explosions in galleries were carried out in the years 1961–1990. These galleries were driven in crystalline rocks of the Deguelen Massif, which is situated SW of the city of Semipalatinsk. This mountain range is maximum around 1,000 m a.s.l. high with semiarid climate (ca 250 mm of annual rainfall). Regardless of this type of climate, several permanent rivers flow through the region such as the Ouzynboulak river and the Shagan river in particular, which drains the whole region and empties into the Irtysh river. Completely specific phenomenon represents the lake ‘‘Atomic’’, which is an artificial lake filling a cavern that originated by a nuclear blast. A breakthrough of the ceiling of one the galleries gave rise to the major source of surface contamination.

Underground nuclear blasts strongly disturbed the local hydrogeological regime. The Deguelen Massif was already initially disturbed by two systems of fractures and fissures trending NE–SW and NW–SE. The most important fault played a role in the structural control of the Ouzounboulak river valley, which is 10 km long. The nuclear blasts gave rise to a secondary network of open fissures that considerably increased the ability of infiltration of atmospheric precipitation and particularly enabled the connection of radioactive waters with hydrogeological circulation in broader surroundings. Although all galleries are nowadays sealed with concrete barriers, a number of them are only partly functioning. Contaminated water flows out from at least 30 galleries.

Consequently, the quality of Irtysh water is nowadays endangered by two sources of pollution surface wash from contaminated areas and percolation of groundwaters. Highly radioactive waters in galleries pose a higher danger actually because the routes of their circulation are difficult to detect. Moreover, the volume of water flowing out of galleries indicates relatively fast circulation. Nine galleries lead into the Ouzynboulak river so that total yield of the emptying waters amounts to 3,000 l/min. The monitoring of radiation is particularly focused on Pu^{239}, of which half-time decay is 2.4×10^4 years and the isotopes of Cs^{137} and Sr^{90}. The radiation level of waters flowing out from local galleries is demonstrated in Table 2.

Although the level of radiation of surface waters can easily be monitored and the results show gradual improvement, the quality of groundwater becomes a major problem as far as the radiation is concerned. The principal issue in the Semipalatinsk area is the lack of information about the level of radiation of groundwaters in galleries and particularly data on the flow rate and direction of contamination. Great differences in radiation of waters in galleries of the same localities argue, besides other factors, for complex routes of groundwater circulation in heterogeneously disturbed rocks of the Degelen Massif. Therefore, there is no chance of forecasting when and where highly contaminated waters would appear on the surface and subsequently rapidly flow into the Irtysh river.

Contamination by heavy metals

The major sources of pollution are the industrial complexes in the cities of Pavlodar, Semipalatinsk and Ust Kamenogorsk. All these cities lie on the banks of the river Irtysh, which is the major source for potable water. The local heavy industry began to develop over 60 years ago and since then, the technologies, that are absolutely substandard from an ecological point of view, produced a huge volume of pollutants. This can be demonstrated in the industrial waste at Ust Kamenogorsk where the total volume of toxic waste exceeds 30 mn tons (Table 3). With regard to poorly protected dumps, there is no wonder that observation boreholes drilled in Quaternary aquifer in the neighborhood of the Kazzink

Table 2 Radiation level of waters flowing out from some adits in 2002 (Iskakov and Touleoubaiev 2003)

Gallery No.	Contents (Bq/l)			Admissible radiation in water according to Kazakh norm NRB-96		
	Pu-239/240	Sr-90	Cs-137	Pu-239/240	Sr-90	Cs-137
504	0.019	520	622	5 Bq/l	45 Bq/l	96 Bq/l
511	0.039	160	144			
104			230			
165			354			
609			313			
A-1			296			
503	2.12		188			
506		100				
177	113					
173			380			
196			108			

industrial complex in 1999 detected the following pollutants:

SO_4 9,750 mg/l; Cl 1,295 mg/l; F 3.24 mg/l; Zn 2,725 mg/l; Hg 0.02 mg/l ; NH_4 45 mg/l; Li 0.63 mg/l; Pb 0.14 mg/l; Be 0.038 mg/l; As 0.72 mg/l; Cd 22.5 mg/l; Mn 276 mg/l ; Se 0.4 mg/l; Fe 60 mg/l; Cu 11 mg/l; V 0.22 mg/l; NO_3 72 mg/l.

These concentrations are not isolated but rather characteristic of the area. Another ecological threat is the contamination by kerosene at the southern border of the city of Semipalatinsk, which endangers sources of potable water for this city having a population of 290,000 inhabitants.

Since all sources of pollution are mostly very close to the river Irtysh, the pollutants quickly reach the watercourse so that each large settlement leaves its characteristic imprint upon the chemical composition of the Irtysh water. Nevertheless, regardless of the above-mentioned problems, the lower stretch of the river Irtysh is of a relatively reasonable quality for two reasons. The first positive phenomenon is the system of dams which functions as settling basins because the large volume of heavy metals settles and is absorbed by mud covering the bottom of the basins. However, this process does not resolve the problem because the basins then become a secondary source of pollution. On the other hand, the water flowing out of the dam is of better quality than that flowing in. Another positive phenomenon improving the quality of the Irtysh water is its high dissolving capacity due to the extreme high rate of flow (Figs. 2, 3). The dilution of contamination can be demonstrated on the following graph documenting the development of Cr concentration along the Itrysh watercourse in the territory of Kazakhstan. The chemical composition of water clearly shows and reflects the sources of contamination by Cr in Ust Kamenogorsk and Semipalatinsk and gradual decrease in its concentrations in the lower stretch of the river. However, it is to be pointed out that this situation characterizes the state at the current rate of flow. In the case of implementation of model scenarios of water tapping in a horizon for the next 30 years (see previous section) the concentrations of all toxic elements will increase even in lower stretches of the Irtysh river.

Conclusion

Data collected during the execution of the IRBIS project provided us with evidence on the strong anthropogenic interference in the entire Irtysh river basin. The amount and quality of data as well as the frequency of measurements in the system of monitoring of all elements of the hydrosphere are of fair quality. Although the IRBIS information system has not yet been loaded with all accessible data, it enabled us to outline a regional view

Table 3 Characteristics of Ust Kamenogorsk dumps

Industrial plant	Quantity of waste produced in 1998 (tons)	Total accumulated wastes by the end of 1999 (tons)	Surface area of the dumps (hectares)
Lead–zinc smelter	275,157	13,100,622	16
Ulba metallurgical smelter	30,769	8,959,988	200
Ti and Mg smelter (lagoons and stockpile)	50,038	1,664,722	11
Power plant	142,528	4,409,152	60
Total Ust Kamenogorsk	549,181	30,125,378	332

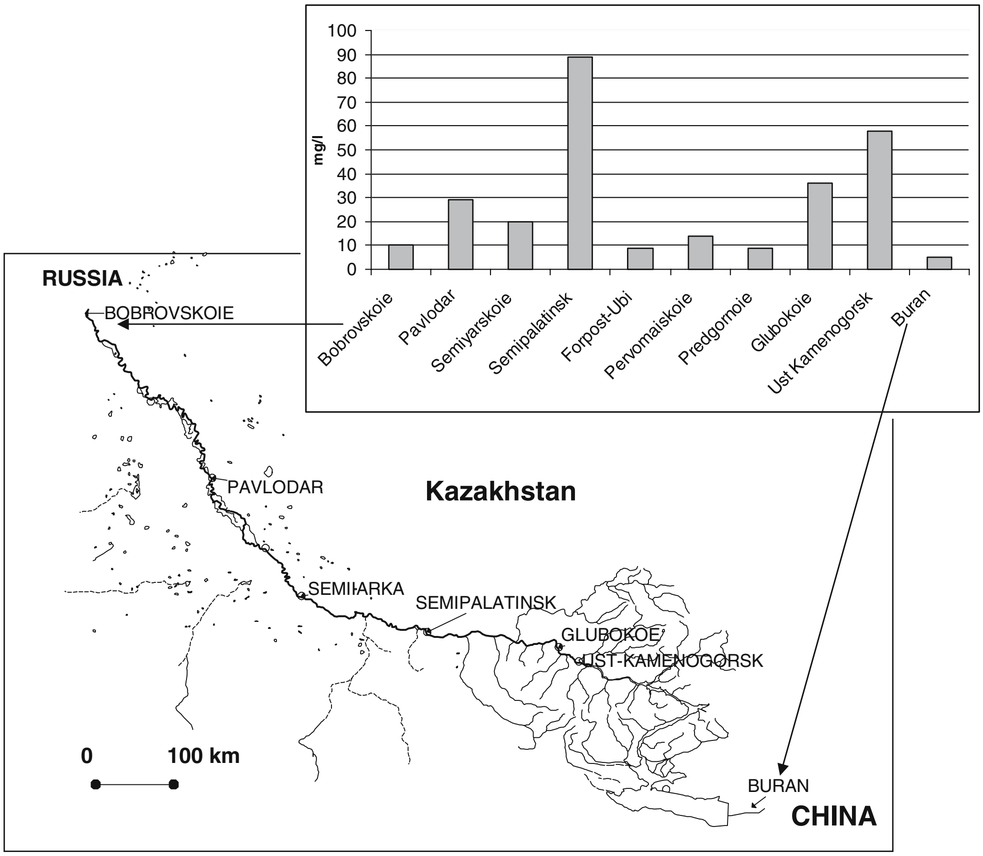

Fig. 2 Maximum Cr concentration in Irtysh water in the year 1999 (Panin S 2002 unpublished data)

on the state of the environment in the catchment and to define the major problems.

From the qualitative point of view the liquidation of sources of heavy metals pollution was given high priority. All these sources are well documented. The present remedial technologies enable us to resolve this problem but the volume of contamination and the extent of polluted area presents a huge financial burden, which is obviously beyond Kazakhstan's resources. Consequently, the first step should include a risk analysis of all the important sources of pollution so that the areas to be remedied at first can be outlined. Another delicate issue is the radioactive contamination. The present level of this kind of contamination is relatively low but it comes mostly from a sheet-wash. Much greater danger is presented by highly contaminated groundwaters, which may be spreading uncontrollably through a system of fissures. Therefore, the monitoring should be extended by a more detailed observation of groundwater flow and its quality.

The quantitative aspect includes the disproportion between the resources of water in the catchment and the gradually increasing demand and consumption. Model simulations of the water balance indicate that if

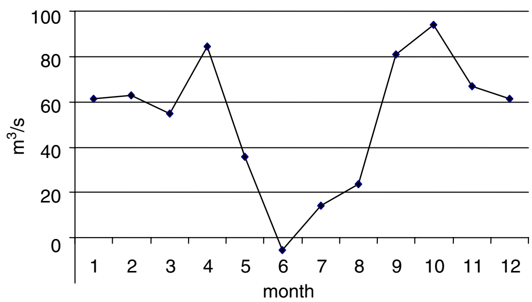

Fig. 3 Model simulation of Irtysh discharge in Omsk for the year 2030

this negative trend is to continue, a similar ecological disaster as in the case of Aral Sea may happen during a short period of time. However, this extreme effect of excessive exploitation of surface and groundwaters will be preceded again in a short period of time by a dramatic decrease in the quality of the waters. The current relatively satisfactory quality of local waters is due to the great ability of the system to thin the contamination down to acceptable concentrations. On the other hand, in order to quantify the scenario of the development of water quality in the river Irtysh, the hydrological model should be extended by a hydrochemical model.

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