The Handbook of Environmental Chemistry 105
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Water Resources Management in Central Asia

Springer

The Handbook of Environmental Chemistry

Volume 105

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Water Resources Management in Central Asia

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ISSN 1867-979X ISSN 1616-864X (electronic)
The Handbook of Environmental Chemistry
ISBN 978-3-030-57985-2 ISBN 978-3-030-57986-9 (eBook)
https://doi.org/10.1007/978-3-030-57986-9

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Series Preface

With remarkable vision, Prof. Otto Hutzinger initiated *The Handbook of Environmental Chemistry* in 1980 and became the founding Editor-in-Chief. At that time, environmental chemistry was an emerging field, aiming at a complete description of the Earth's environment, encompassing the physical, chemical, biological, and geological transformations of chemical substances occurring on a local as well as a global scale. Environmental chemistry was intended to provide an account of the impact of man's activities on the natural environment by describing observed changes.

While a considerable amount of knowledge has been accumulated over the last four decades, as reflected in the more than 150 volumes of *The Handbook of Environmental Chemistry*, there are still many scientific and policy challenges ahead due to the complexity and interdisciplinary nature of the field. The series will therefore continue to provide compilations of current knowledge. Contributions are written by leading experts with practical experience in their fields. *The Handbook of Environmental Chemistry* grows with the increases in our scientific understanding, and provides a valuable source not only for scientists but also for environmental managers and decision-makers. Today, the series covers a broad range of environmental topics from a chemical perspective, including methodological advances in environmental analytical chemistry.

In recent years, there has been a growing tendency to include subject matter of societal relevance in the broad view of environmental chemistry. Topics include life cycle analysis, environmental management, sustainable development, and socio-economic, legal and even political problems, among others. While these topics are of great importance for the development and acceptance of *The Handbook of Environmental Chemistry*, the publisher and Editors-in-Chief have decided to keep the handbook essentially a source of information on "hard sciences" with a particular emphasis on chemistry, but also covering biology, geology, hydrology and engineering as applied to environmental sciences.

The volumes of the series are written at an advanced level, addressing the needs of both researchers and graduate students, as well as of people outside the field of "pure" chemistry, including those in industry, business, government, research establishments, and public interest groups. It would be very satisfying to see these volumes used as a basis for graduate courses in environmental chemistry. With its high standards of scientific quality and clarity, *The Handbook of Environmental Chemistry* provides a solid basis from which scientists can share their knowledge on the different aspects of environmental problems, presenting a wide spectrum of viewpoints and approaches.

The Handbook of Environmental Chemistry is available both in print and online via www.springerlink.com/content/110354/. Articles are published online as soon as they have been approved for publication. Authors, Volume Editors and Editors-in-Chief are rewarded by the broad acceptance of *The Handbook of Environmental Chemistry* by the scientific community, from whom suggestions for new topics to the Editors-in-Chief are always very welcome.

Damià Barceló
Andrey G. Kostianoy
Series Editors

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Introduction

Sergey S. Zhiltsov, Igor S. Zonn, Andrey G. Kostianoy, and Aleksandr V. Semenov

Contents

Abstract The present book on water resources management in Central Asia is a follow-on issue of the book *Water Resources in Central Asia: International Context* edited by Sergey S. Zhiltsov, Igor S. Zonn, Andrey G. Kostianoy, and Aleksandr V. Semenov and published by Springer in 2018. The problem of water resources management in Central Asia has a long history. For many millennia in the conditions of the arid climate, the water had been used here only for irrigation of agricultural

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© Springer Nature Switzerland AG 2020, Published online: 8 July 2020

lands and for satisfying the needs of the people. In view of the low development of industry, it did not claim much water. From the mid-twentieth century, the problem of the use, distribution, and reproduction of water resources had become most crucial for Central Asia. In the times of the Soviet Union, among the negative factors, there were the high rate of the population growth in this region, intensive development of industry, and expansion of agricultural lands. This had led to exhaustion of water resources and, accordingly, to their deficit which had been growing with every year. This led to complete intake of water resources which deficit in the 1970s brought about the aggravation of the situation in the region. After the Soviet Union disintegration in 1991, the issues of water resources use and management acquired the interstate dimensions and moved to the political sphere giving rise to conflicts between Central Asia countries. The relationships in the water area of the Central Asian countries have changed basically. The territorial unevenness of water resources, their limitation, and permanently growing use influence greatly the water resources management. This leads to the boosting of the water demand in individual countries and in the region in general. The situation is aggravated by the regional climate change, water deficit, and the water quality deterioration. As a result, all Central Asian countries have to adapt to such changes correcting their relationships with each other and changing the benchmarks of national development.

Keywords Central Asia, Transboundary rivers, Water diplomacy, Water resources, Water resources management

1 Introduction

This book continues investigation of the problems that were studied in detail in the previously published book *Water Resources in Central Asia: International Context* by Sergey S. Zhiltsov, Igor S. Zonn, Andrey G. Kostianoy, and Aleksandr V. Semenov (Springer, 2018). The team of authors from the Central Asian countries, Russia, Europe, and the USA conducted the in-depth investigation of international relationships of the Central Asian countries in the water and energy area. They devoted much attention to the policy of EU, the USA, and China in respect of the water resources in Central Asia, identifiying their role in creation of the mechanisms for interaction among the Central Asian countries in the water and energy sphere (Fig. 1).

The growing interest to the water resources of Central Asia, the region surrounded by Europe, Near East, and Southern and Eastern Asia, may become a bridge between East and West. It is based on the increasing importance of water for the future development of the countries located here.

Central Asia consists of five states: Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, and Uzbekistan. This region is situated in the center of the European

Fig. 1 Central Asia countries (https://yandex.ru/images/search?pos=1&from=tabbar&img_url=https%3A%2F%2Fupload.wikimedia.org%2Fwikipedia%2Fcommons%2Fthumb%2F6%2F66%2FCentral_Asia_-_political_map_2008.svg%2F800px-Central_Asia_-_political_map_2008.svg.png&text=Central%20Asia%20countries&rpt=simage)

continent and covers an area of 3,882,000 km^2. Dozens of millions of people live in the Central Asian countries. This region borders on Afghanistan and Iran in the south, on China in the east, and on Russia in the west and north. There are also notions that Central Asia includes not only the former Soviet republics but also Afghanistan. However, in this book Central Asia is assumed to consist of five states that prior to 1991 had entered the USSR.

From the mid-twentieth century, the problem of the use, distribution, and reproduction of water resources had become most crucial for Central Asia. Water economy was adapting to the new economic conditions. In the time of the Soviet Union, the direction of their development was identified by the central powers. Among the negative factors, there were the high rate of the population growth in this region, intensive development of industry, and expansion of agricultural lands. This had led to exhaustion of water resources and, accordingly, to their deficit which had been growing with every year. The requirements in water outpaced the population growth. Simultaneously, the demand for water required for permanently growing industrial production and increasing agricultural lands also augmented. This led to complete intake of water resources which deficit in the 1970s brought about the aggravation of the situation in the region [1].

The Soviet system of water relations among the republics was based on water quotas apportioned to each and on the balance of obligations between the republics and the union center. The breakdown of the USSR entailed the disappearance of the "common pot" principle. And the most sensitive issue here remains the water sharing. The system functioning for many decades had collapsed leaving many unsettled claims which were primarily connected with determination of the water use volumes in the conditions of the market economy, the decreased investments into the water use sector, and the changed operating regimes of large water bodies (changeover from irrigation to power generation) (Fig. 2).

After the Soviet Union disintegration in 1991, the issues of water resources use and management acquired the interstate dimensions and moved to the political sphere giving rise to conflicts. The relationships in the water area of the Central Asian countries have changed basically. They were developing in the new conditions. Many factors influenced the water problem, but the most important was that these countries located in the harsh natural and climatic conditions where water was the vital natural resource. This required taking permanent efforts to save water and to look for the possibilities to augment water reserves [2].

2 Water Resources Management in Central Asia

The problem of water resources management in Central Asia has a long history. For many millennia in the conditions of the arid climate, the water had been used here only for irrigation of agricultural lands and for satisfying the needs of the people. Rather simple methods of water management permitted to meet the needs of the

Fig. 2 The Naryn River, Kyrgyzstan (https://yandex.uz/collections/card/58998790d7f77d96081c7a00/)

people living here. Water resources were used mostly for growing agricultural crops. In view of the low development of industry, it did not claim much water.

A negative factor for water management is the population growth rate which is one of the highest in the world – to 2.0%. In 2018 the number of population in Central Asia (without Afghanistan) was 72.7 million [3], while adding here the population of Afghanistan, it would be close to 105 million. The growing population urged to think about more effective water use in the region and introduction of the new management methods. While addressing this issue, the new approaches to the water use appeared, and the more up-to-date technologies of hydraulic construction were developed which provided for accumulation of water resources and their subsequent conveyance to considerable distances (Fig. 3).

The territorial unevenness of water resources, their limitation, and permanently growing use influence greatly the water resources management. This leads to the boosting of the water demand in individual countries and in the region in general. The situation is aggravated by regional climate change, the water deficit, and the water quality deterioration. As a result, all Central Asian countries have to adapt to such changes correcting their relationships with each other and changing the benchmarks of national development.

After becoming independent the problem of water and energy resources management in the Central Asian countries has become most acute due to breakup of the unified centralized model of their management. Moreover, the water resources in

Fig. 3 Central Asia (https://yandex.ru/images/search?pos=352&p=6&img_url=https%3A%2F%2Fgeohistory.today%2Fwp-content%2Fuploads%2F2017%2F10%2FCentral-Asian-Core.jpg&text=Population%20in%20Central%20Asia&rpt=simage)

Central Asia are the crucial factor of stability of all sectors of the economy, hence, such great attention to water management issues [4].

The attempts to substitute the outdated water management systems for the new ones based on regional integration slowed down the appearance of water conflicts but failed to provide the positive general result in addressing this problem. The Central Asian countries were unable to develop and accomplish in practice the multilateral mechanism of water management. This was true, first of all, of transboundary rivers of Central Asia. The policies of the countries on this issue have proved ineffective because of the national egoism, on the one hand, and the lack of money for water infrastructure modernization, on the other.

Therefore, the water resources were cut by state borders of the new Central Asian states. The times of the USSR when water was supplied free-of-charge have come to an end. This forced the Central Asian countries to initiate negotiations and the water diplomacy. However, the countries failed to arrange about direct pay for water and adopted the barter relations: gas for water (Uzbekistan – Kyrgyzstan and Tajikistan) or water for electricity (Tajikistan – Kazakhstan), etc.

In spite of numerous attempts of various international organizations and individual states, little progress has been attained in development of the proposals capable to address successfully the water management issue. In the recent decade, this has led to a growing number of interstate contradictions some of which were very sharp. But the acuteness of this issue is so high that the conflicting parties cannot find compromise but simply postpone the solution of the water problems. This only confirms the conclusion that the lack of an effective mechanism for water management in Central Asia may not only provoke interstate conflicts but also intensify the internal political stress in some countries of this region.

Such factors as the population growth, desertification processes, and climate warming have produced their negative effect too. Accordingly, the Central Asian countries pursue the policy targeted to unilateral assertion of their national interests in the water sphere. For instance, Tajikistan focuses much attention on the formation, use, and management of water resources which stresses special acuteness of the water management problem in this country.

Much attention is paid to the water management issues in Kyrgyzstan. The geographical position of this country is very advantageous. In the recent decade, the water use problem has been in the focus of attention in Kyrgyzstan as it is directly connected with the socioeconomic development. In addition, it is very important for Kyrgyzstan to establish interaction on the use of transboundary waters in the Central Asian region.

The strategy of Kazakhstan concentrates on water resources management that assumes application of water saving technologies and more efficient water use. Here Kazakhstan faces the problem of water scarcity which is typical of all Central Asian countries located in the downstream of transboundary rivers.

China is a very influential factor in development of the regional water management mechanism because in the Chinese territory the river runoff of the Irtysh and Ily rivers and also of more than 20 smaller rivers flowing to Kazakhstan and Russia is formed. Accordingly, the greatest concern of Kazakhstan is the water resources of the Ob and Irtysh rivers as well as the extreme hydrological events affecting the water bodies of the Ob-Irtysh basin.

The plans of China to increase water intake from the upper reaches of the waterways shared with Kazakhstan stir great anxiety mostly of the Kazakh side. Kazakhstan already faces the water deficit. The persisting tendency to the increase of water intake from transboundary rivers will result in reduction of power generation by the HPP cascade on the Irtysh River in Kazakhstan. The growing water intake from the Ily River by China will entail shallowing of the Balkhash Lake as this river accounts for 70–80% of the water inflow into the lake.

The spatial unevenness in distribution of water resources in Central Asia provoked tough rivalry for their control and the conflict of interests among water abundant and water deficit countries. The upstream countries of transboundary rivers are in a better position. Thus, Tajikistan and Kyrgyzstan control around 90% of water resources of the region, while Uzbekistan, Kazakhstan, and Turkmenistan are the water consumers. For upstream countries the power generation is the dominating task. It permits them to resolve not only economic but also the social problems ensuring additional heat generation in winter. The downstream countries are mostly agrarian ones and need water for cultivation of agricultural crops. Therefore, the former require energy to address their socioeconomic issues, while the latter need water to develop irrigated farming.

The potential participant of water use and management in this region is Afghanistan which so far has not been involved in discussing the water management issues. But in the nearest time, Afghanistan may claim essential adjustments in water sharing of the Pyanj and Amu Darya rivers.

Keeping the above in mind, the issues of water management in Central Asia become most crucial for the region development. The solution of this problem influences directly the economic development of the Central Asian countries and, in particular, the social aspects. Moreover, the interstate relationships of the regional countries and their internal political stability depend on the development of the effective mechanism for water resources management in Central Asia [5].

Remembering that the Central Asian countries locate in the water deficit zone ("zone of thirst") with its arid climate and growing population, the main water user here remains the irrigated farming. This predetermines the growing demand for water which resources are limited. With time on the local water resources get depleted, first, in the conditions of the natural regime of water bodies and later in the conditions of flow regulation [6].

The countries of Central Asia suffer from the water deficit which has more than once provoked the interstate conflicts [7]. The water deficit in many countries of Asia threatens the economy modernization forcing to build hydraulic structures in the upper reaches of rivers which waters are shared by several states. If the water geopolitics continues provoking tension among states due to decreasing water flows in neighbor countries, the Asian renaissance will be curbed essentially. Water becomes the key issue that will help to determine whether Asia is driven by the endeavors of mutually beneficial cooperation or the dangerous interstate rivalry [8].

The issues of water resources come to the fore as the unprecedented worldwide growth of economy will go on pressing on some vital strategic resources, including energy, food, and water. The Program of the Development, Concepts and Doctrine Center (DCDC) for Global Strategic Tendencies in 2007–2036 at the British Ministry of Defense predicts that in this period "the water deficit will grow as well as the risk of aggravating the already complex situation in the regions which may lead to military actions and population migration. The main zones of risk are North Africa, Near East and Central Asia with China where the water deficit and problems with irrigation may provoke the attempts to redirect the flows of rivers. . ." [9].

In March 2018 the International Decade for Action (2018–2028) "Water for Sustainable Development" was launched. The scientists and experts from the Central Asian countries express great concern over future challenges to be faced by the countries in the nearest decade. This process may be influenced by the issues of water division and water use in this region which include the population growth and changes in water demand, climate changes causing changes of river flow, irrigation development in Afghanistan, and its growing needs, likely changes connected with hydraulic power construction [10].

The solutions suggested for coping with these challenges are similar and repeated in all scientific publications: water saving, more efficient water use and storage, closer cooperation and joint management of water resources among neighboring countries, conditions of water division, and river regimes in various hydrological

Fig. 4 The Syr Darya River, Tajikistan (https://yandex.ru/collections/card/5af96ca8722214bb4c455feb/)

conditions. It should be noted that the mentioned solutions are proposed every year, but the water challenges in Central Asian countries remain (Fig. 4).

In the recent decade, the problem of water supply has become much worse. The water deficit and the water quality deterioration are the most serious challenges faced by many countries in this region. The key issue determining the internal stability of Central Asia is implementation of actions to increase the available water resources. The uneven distribution of water resources over territories and their limitation and the permanently growing water consumption result in the rivalry for water both at the national and regional levels.

In some regional countries, the possibilities for interbasin transfer of river flow and rational water management are nearly exhausted which urges to initiate investigation and development of the projects on joint water use based on inter-zonal (interstate) river flow transfer [11].

The analysis of the dynamics and forecasts of water use proves vividly that in this century the mankind will continue seeking solutions for the water problems. It will also be the time when the world community will find ways for the mutually beneficial joint use of water resources by the states on the basis of large-scale projects on inter-zonal transfers of water from full-flowing rivers to the water deficit regions.

The effective management of water resources is one of the crucial components of the national security and reliable food supply. The uneven spreading of surface runoff and impossibility to implement the water resources management on a long-

Fig. 5 Mountains in Tajikistan (https://yandex.ru/collections/card/5af065ee2b64823081e14046/)

term basis to satisfy the economic needs are typical of many world countries. Accordingly, there is a need in such water resources management that will include water redistribution by its transfer from water abundant regions. The interbasin river water transfer is not something new in this respect. The volumes of natural water resources fail to match the identified goals of state social and economic programs [12].

Climate changes observed in Central Asia influence significantly the water resources and their use. The consequences of these changes will affect most likely all regions of the planet, including Central Asia (Fig. 5).

3 Conclusions

The Central Asian countries focus much attention on the legal regulation of water use developing legal mechanisms at the national and interstate levels for water resources management trying in this way to attain their rational use. The focus on this issue is connected with the role of water resources in development of the Central Asian countries. However, the countries of this region have not so far succeeded in developing the legal basis for management of transboundary rivers. The Central Asian countries rely mostly on their national legislations regulating the management of water resources and their joint use. In addition, the addressing of this issue is obstructed by diverging interests of the regional countries which are governed only by their national interests disregarding the interests of their neighbors.

The ineffective management of water resources leads to reduction of the river flow in Central Asia which impedes the socioeconomic development of all regional countries and aggravates the environmental issues. In addition, the water deficit in Central Asia makes more acute the interstate contradictions among the Central Asian countries, thus, holding up their economic development [13].

Summing up it should be stressed that nearly all publications on water management contain solutions that do not take into consideration in full measure the national egoism of the Central Asian countries. Regardless of the necessity to address the water issues by the upstream and downstream countries, these states are not ready so far to change their approaches to the water policy, including in water resources management, thus, putting off the addressing of water problems to the future. Such approach creates the critical mass of problems that may entail the political, economic, and social disruptions and will require decisive actions from all Central Asian countries.

Acknowledgments A.G. Kostianoy was partially supported in the framework of the P.P. Shirshov Institute of Oceanology RAS budgetary financing (Project N 149-2019-0004).

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Role of Water Resources in the Modern World

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Igor S. Zonn, Sergey S. Zhiltsov, Andrey G. Kostianoy, and Aleksandr V. Semenov (eds.), *Water Resources Management in Central Asia*, Hdb Env Chem (2020) 105: 13–30, DOI 10.1007/698_2020_598,

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Abstract The problems of water use and water availability have a long history. For thousands of years, the people had used water in agriculture and for satisfying their own needs, while in the recent centuries the water supply of industry has been added here. However, beginning from the mid-twentieth century, the use, distribution, and reproduction of water resources have acquired special relevance. The quickly growing world population, industry development, and expanding agricultural lands have led to the water deficit which is increasing with every passing year. The water demand runs ahead of the population growth rate.

Many international organizations and individual states exerted enormous efforts to find the way to cope with this issue but so far without success. In the recent decades this has led to the growth of interstate contradictions of interests which gave rise to international instability and even to conflicts. This issue is so acute that the conflicting parties fail to find compromise. It means that in the nearest decades, we may witness the revival of “water wars” which will affect enormously the political map of the world.

Keywords Conflicts, Ecology, Struggle for water, Water resources, World politics

1 Introduction

For many centuries the water resources determined the places where people choose to live. The water resources and the geography of their distribution over the planet and their volumes available to a man have also governed the industrial and agricultural development. However, in the recent century, the role of water availability in the life of individual states and in interstate relations has been growing. The increase of water use has enhanced competition for this strategic resource. This factor has become crucial for international relations in different world regions, in particular those with transboundary rivers. They turned from purely geographical objects into the factor of the world politics. The political importance of water resources has gradually urged to address not only hydrological and environmental issues but also their management, protection, and regulation. As a result, the access to water has acquired political dimensions, and the water resources use and distribution – the international scale (Fig. 1).

In the recent decade, the water resources have become a key factor in development of agriculture, power engineering, industry, and meeting the household needs. But with every passing year, the attainment of this goal becomes more difficult as a considerable part of the world population has a limited access to water resources. As a result of the population growth global-wise, increase of resources use, and destruction of natural ecosystems, by the beginning of the twenty-first century, the water of the drinking and technical quality has become one of the most essential resources required not only for globalizing economy, but even for mankind survival. If in the

Fig. 1 A limited water resources (https://proprights.org/blog/phony-water-crisis-continues-legislative-style-hirst-heist-rolls)

recent decade each inhabitant of the planet is apportioned around 750 m^3 of freshwater per year, then by 2050 this figure will drop to 450 m^3 of water [1]. It should be remembered that the permanent population growth entails the increasing water demand and extension of economic activities as well as additional energy requirement [2].

The main source of water supply is rivers where the process of water renewal goes on most actively. Surface waters account for up to 70% of the total water use. At the same time, still more attention has been focused on groundwaters which are better protected against pollution and are often the most reliable and pure source of drinking water. According to different estimates, groundwaters are of crucial significance for the life and food security for around 10% of the population living mostly in Asia and Africa.

The interest to these resources is constantly growing which has already led to the increase of their use. However, the growing rate of groundwater intake is threatening with their depletion. The formation of groundwaters went on for a long time and their intake growing with each passing year may be disastrous.

2 Water Deficit

The aggravating freshwater deficit has become one of the key global challenges for the mankind in the twenty-first century. Resolution 70/1 "Transforming Our World: The 2030 Agenda for Sustainable Development" [3] says the following: "We recognize that social and economic development depends on the sustainable management of our planet's natural resources. <. . .>We are therefore determined to conserve and sustainably use oceans and seas, fresh water resources. <. . .>We are also determined <. . .>to tackle water scarcity and water pollution <. . .>" [3]. The

Fig. 2 Water resources deficit (https://econet.ua/articles/7599-ogromnye-zapasy-podzemnyh-vod-obnaruzheny-v-stradayuschey-ot-vechnoy-zasuhi-kenii)

wider access to freshwater resource and improvement of sanitary conditions are included into 17 main UN Sustainable Development Goals (Fig. 2).

According to initial assessments of the World Bank, by 2030 it will be required over $1.7 trillion to ensure the overall access to drinking water without damaging the sources. The Report of the World Bank published in May 2016 confirms that the water deficit aggravated by climate changes may cost individual regions to 6% of their GDP, stir up migration, and cause conflicts [4].

On the other hand, the countries have failed to develop the optimal "form" of the water problem solution. By the early twenty-first century, over 3,600 agreements were signed on various aspects of international water use and nearly 150 of them in the late twentieth to early twenty-first centuries. This demonstrates the availability of a critical approach to addressing the issues of joint water use [5].

Water scarcity directly affects the social and economic development of the countries and individual regions resulting in worsening of the sanitary-epidemiological situation. Lack of water resources or their permanent insufficiency may provoke the spread of diseases and epidemic. Pollution of drinking water sources, unsatisfactory living conditions of the people, rather frequent and long-time droughts, and insufficiency of water resources for agriculture may stir up social strain. These factors contribute to formation of a conflict potential in water supply and water use. Two decades ago in 1999 at the G8 Summit in Schwerin (Germany) (Russia became the member of G8 in 1997) at the environment ministerial meeting, it was stressed that the deteriorating ecological condition of natural resources and their scarcity may give rise to conflicts among states.

3 Demographic Dimension

In the past century, the population on the planet was permanently growing. In the twentieth century, the world's population has increased 3.7-fold [6]. The world's freshwater consumption reached 10 km^3 per day which is equal to the annual extraction of all kinds of mineral resources. Freshwater is the main and essential component of the natural environment and ecological equilibrium; it is used in all spheres of life activities of a man and society.

The pace of the world population growth is expected to be 0.9% per year on the average. It will increase from 7.6 billion in 2018 to 9 billion by 2040–2050. The population growth on the Earth entails the growing food consumption and, accordingly, the development of agriculture. The energy demand also requires ever-growing volumes of water resources [7].

The greatest population growth is expected in Latin America, Africa, and South-east Asia. These are the regions where in the recent decade the increase of freshwater deficit was witnessed (Fig. 3). By 2050 only a part of the world population will have access to water without any limitations, while the rest will have restricted access to water or will face practically unresolved problems due to water scarcity.

4 Struggle for Water

The whole history of mankind was fraught with struggle for resources. It was the main driving force determining the world order. In different periods of the society, development such resources as land, gold, forest, etc. played different roles. In the past century, these are energy resources – oil and natural gas. The main feature about

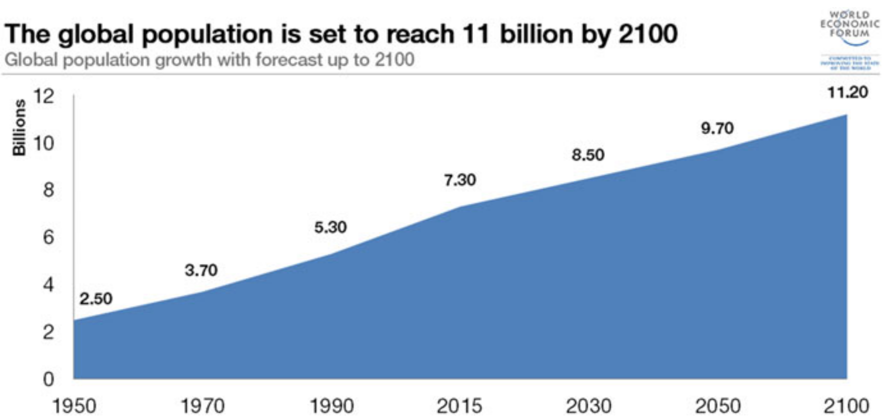

Fig. 3 The global population growth (https://www.weforum.org/agenda/2015/10/countries-growing-fastest-11-billion/). Source: United Nations

these resources is that they are not renewable. Not far is the time when they will be exhausted, the so-called pipe-end strategy. The tough and, at times, even bloody struggle (like in Iraq) is conducted not for where the oil reserves are greater but for where they will last longer.

During the long history of mankind, water was the cause of many conflicts. In the past 500 years “water weapon” was used on five continents from direct destruction of large waterworks to imposing a water diktat as a radical means to press on the opposite party [8]. In other words, water is not only the source of life but also a trump card in political games.

The second half of the twentieth century was distinguished by aggravation of the water supply issues. The water deficit is formed mainly due to the enhanced discrepancy between a quick growth of water use and the available water resources that have remained practically unchanged through the year. The accelerated growth of water use is connected with the unprecedented boost of the world economy and, quite recently, with the escalating food crisis witnessed in many world countries. It may be said that the ratio between the available water resources and the constantly growing water demand has become critical. That is why in April 2000, Kofi Annan, that time UN General Secretary, said that the “water issue” became one of the priority problems for the mankind to face in the twenty-first century [9]. Preserving the available water resources and searching for new water sources are among the most burning issues in the twenty-first century [10]. For this reason many in the West have named the new century the “century of water,” while the hardened pessimists even the “century of water wars.” As Sandra Postel, the US expert, wrote “Forget about oil. The just division of freshwater creates the no less explosive and far-going political puzzle than the global climate change” [11].

5 Regional Water Geopolitics

The problem of water supply bears the imprint of the past historical development of individual countries and whole regions. About half of the world population lives on the banks of ten major rivers which, according to assessments of the World Wide Fund for Nature, are in a critical state [12]. These are La Plata, Danube, Rio Grande, Ganges, Murray-Darling, Indus, Nile, Yangtze, Mekong, and Euphrates. Around 41% of the population living in the basins of these rivers suffer from water scarcity caused mainly by large-scale dam construction, excessive water intake, climate changes, aggressive intrusion of alien plants and animals into river basins, and excessive fishing. According to the US estimates [12], out of 227 major world rivers, 60% have too many dams and canals which lead to degradation of ecological systems. And, finally, the water availability has acquired in many countries the national security dimensions.

Limited water resources of river basins give rise to rivalry in the strategy of economic development of different countries. Taking into consideration the lawful economic interests of individual countries, it is quite possible that conflicts concerning water sharing may arise among them. At the same time the conflicts related to access to quality water between the upstream and downstream countries in river basins are also highly probable. In some cases, the water may be required for such alternative uses as irrigation and hydropower engineering.

In many countries the water deficit and the negative impact of economic activities on the natural environment may provoke conflicts, too. It is meant here that many water issues have clear-cut international dimensions.

At joint water use, the difficulties with managing river basins lead to the conflicts at various hierarchic levels, both interstate and interregional. It should be remembered here that the technology upgrade and the growing water deficit contribute in a large measure to stirring such conflicts. In addition, the traditional water use and water management practices and other factors impede cooperation development on such rivers.

According to different estimates, currently over one billion people in the world have no adequate access to water resources, and in 15–20 years, up to 50% of the world population may suffer from water scarcity. By 2025 around three billion people will live in the countries with water deficit. According to UN estimates [13], by 2050 two-thirds of the population on our planet will face water deficit. It should be remembered here that the global climate changes may swing the arrow of "balances" to aggravating the situation.

Already now the strenuous situation with water reserves and their use is observed in many world regions. Only in the recent half century there were more than 500 disputes over water in the world. Nearly 40 countries located in the arid zones face water deficit, and they depend greatly on water coming from outside.

The water resources are becoming more and more often the internationally traded commodity which cost may exceed already in the twenty-first century the cost of hydrocarbons – oil and natural gas. And this may happen already in the nearest decades having intensified rivalry among individual states for access to and control of water resources.

Still back in the 1980s, the US secret services identified at least ten regions in the world where wars could have been detonated due to depletion of water resources. These are, first of all, Near East and Arabian Peninsula. Former US President adviser on water resources J. Starr said that "soon water security will go abreast with military security in the corridors of military departments" [10]. Such events were presented most vividly in the BBC TV serial "Water Wars" showing most "hot" water points on the planet: US West, Near East, and Aral and Circum-Aral area in Central Asia. This film created the impression that Near East would be the first world region to face in the next decades the "water crisis."

We can soon witness the toughening struggle for water between China and India, between Egypt and Ethiopia, and between Angola and Namibia. And it is not accidental that the book "Resource Wars" of Michael T. Klare published in 2001 in the USA has a subtitle "The New Landscape of Global Conflict" [9]. Covering the oil and gas conflicts from the Persian Gulf to the Caspian, the author also considers the water conflicts in the basins of the Nile, Tigris, Euphrates, Jordan, and Indus rivers.

The impending threat of war over sharing water resources of the Euphrates, Tigris, Jordan, and Nile rivers has occurred more than once in the recent decades. The last event was in early 2008 when Syria and Turkey, not for the first time, came into clash over freshwater sources. According to the Arab daily *Asharq al-Awsat*, Damask claimed the increase of water intake for its needs from the Euphrates River. Ankara denied this claim in view of its own dependence on the Euphrates which is one of the main sources providing water to its arid territories.

As UN General Secretary Ban Ki-moon noted, the military actions burst out in the Darfur Province of Sudan during drought when "food and water ceased to be available to all for the first time." Here is another example. In 2006 in Sri Lanka, the armed conflict arose over the access to a reservoir supplying water to over 60,000 Singhalese people. The leadership of the movement Liberation Tigers of Tamil Eelam accused the government of unequal access to water and seized the reservoir. The bloody battle lasting for several days took a toll of over 1,000 people. This event with the reservoir gave rise to initiating the wide-scale military actions.

The examples of struggle for water resources are many. Much was spoken about the need of developing the mutually beneficial cooperation in this sphere that would not only cool the conflict relations among the countries, but would help working out the effective mechanism of water sharing. But this issue remains unsolved so far.

6 Near East Water Dominoes

The water deficit situation is most strenuous in such world region as Near East (Fig. 4). All countries of this region locate in harshly arid conditions where water reserves are very scarce. Deserts cover about 60% of the territory of Israel, 70% of Syria, 85% of Jordan, and 90% of Egypt. And the areas with the highest water intake and the highest population density locate along rivers.

The largest river systems in this region are transboundary rivers of Tigris and Euphrates with their tributaries. Running across three countries – Turkey, Syria and Iraq – they make the key economic and geostrategic resources for development of these countries, being, at the same time, the "apple of discord."

Water deficit in Near East has been felt most acutely in the recent decades. In fact, not only history, but the present time abounds in cases showing vividly that the struggle for water, for access to water causes if not armed conflicts, but, at least, the tension in interstate relations. Of special importance now is not availability of water as it is, but more on the control of its sources as the main rivers of this region – the Nile, the Tigris, the Euphrates, and the Jordan are transboundary. The conflicts between Israel and Arabian states; between Israel, Syria and Jordan over water intake from the Jordan and Yarmuk rivers; between Egypt and Sudan; between Turkey, Syria and Iraq may be also listed as examples.

The other example is Saudi Arabia, Kuwait, and UAE where the only source of water is the waters from the Persian Gulf after their desalination at special plants. As Foreign Minister of Kuwait Sheikh Muhammad al-Sabakh said in one of his

Fig. 4 The Near East (https://www.gtreview.com/news/mena/taylor-dejongh-appointed-as-advisor-on-saudi-projects/)

interviews: "The Gulf is the only source of water. If there is a nuclear disaster in the Persian Gulf (meaning accidents on nuclear facilities in Iran) we will have no water to drink. We will be left without water" [12].

Water issues urge to look differently on some conflicts, for example, the Arab-Israeli wars. The Golan Heights in Syria occupied by Israel is where the Jordan River, the main source of water for Israel, originates. By occupying the Palestine territories, Israel is seeking to control groundwaters available in significant quantity within ancient Palestine. And this is quite understandable as 95% of the Israeli territory locates in arid regions and more than 60% of its territory is covered by the Negev Desert. Water resources in the country are very scarce and are formed mainly by atmospheric precipitations. In the period from 1989 through 2005 the average precipitations accounted for 6 billion m^3, of which 60–70% were lost to evaporation soon after rainfalls and at least 5% ran along river channels to the Mediterranean (mostly in winter). Of the remaining 25% of water that seeps into soil the great quantity also gets into the sea with groundwater flow. Accordingly, the access to water is critical for development of this state [14].

It should be noted that the religious issues are often used as a disguise of struggle for water, including with the use of military forces. The same picture becomes visible if we compare the religious and interethnic conflicts with rivalry for hydrocarbons that occurred in the past century.

The Euphrates is the historical river on the banks of which one of the oldest civilizations had appeared. The watershed area of the Euphrates is about 580,000 km^2, which is shared by Iraq (49% of the area), Turkey (21%), Syria

Fig. 5 Tigris and Euphrates rivers (https://www.pinterest.fr/pin/611715561863566996/)

(17%), and Saudi Arabia (13%). Originating in Turkey, this river crosses Syria and Iraq and after confluence with the Tigris brings its waters further to the Persian Gulf. The Euphrates has different significance for each of these countries. Until recently Turkey that is rich in water resources has used the Euphrates water insignificantly. For Syria the Euphrates is practically the only source of drinking and agricultural water supply. Iraq, apart from the Euphrates, has the Tigris River which compensates to a certain extent the importance of the Euphrates.

In the recent decades, the problem connected with enhanced development of the Euphrates energy potential in Turkey has appeared (Fig. 5). The acute rivalry for the Euphrates waters started more than two decades ago. In 1983 Turkey prepared the master plan for development of the most backward provinces in southeastern Anatolia where 40% of all cultivable lands locate. This plan assumed the integrated use of upstream water of the Tigris and Euphrates rivers for development of irrigation and hydropower engineering. It included 13 major projects on construction of 22 dams (7 dams on the Euphrates), 19 large hydropower plants, and irrigation of 1.7 million ha of semiarid lands. In the future the implementation of these projects will help increasing electricity generation to 27 billion kWh per year. At the beginning of construction, this project cost was US $32 billion. This plan which goal was to control water resources was considered by Turkey as the main element of future security and might of the state. By controlling the water flow to the downstream countries (Syria and Iraq), Turkey could acquire levers to influence the policy of these countries. The Turkish government also expected to sell the additionally received agricultural produce to the countries of Europe and Near East and obtain dozen billion dollar worth profits. Regulation of the river flow in the Turkish territory resulted in a sharp reduction of runoff going to Syria and Syria constructed the As-Saura Dam and Assad Reservoir on the Euphrates to create water reserves for supply of its agriculture.

Syria and Iraq expressed their concern that the construction of dams in Turkey would "rob" them of 40–90% of the Euphrates flow. In 1987 Syria and Turkey reached an agreement about the use of the Euphrates river flow according to which Turkey had to ensure the passage of 500–850 m^3/s of water per year to the Syrian territory. But the Arab press had criticized sharply Turkey accusing it of cutting the water supply to neighbor countries for exerting political pressure on them. The Turkish officials refuted such statements.

The relationships among the countries of this region were aggravated in 1989 when the severe drought occurred as a result of which the water level in the Euphrates had dropped significantly. This drought affected the economics of Turkey, but it was still more disastrous for Syria where the water and electricity supply in Damask, Aleppo, and some other cities had reduced significantly.

In the early 1990s, Syria and Iraq had new concerns this time about construction of the Ataturk Dam in Turkey which would take the greater part of the Euphrates flow for irrigation of lands in the Urfa Plain. The apprehensions appeared after in January 1990 Turkey blocked the Euphrates for filling the reservoir. The Ataturk dam which construction was started in 1984 is 179 m high and 15 m wide. This is the largest dam built on the Euphrates and its tributaries in their upper reaches. It will provide irrigation of 874 thou ha of lands and generate 8.1 billion kWh of electricity.

For many decades the countries of this region had made attempts to arrange about sharing of water resources and to develop the mechanisms for settling the arising disputes. However, there were only declarations. As a result, Turkey demonstrates its "water muscles" by implementing its most ambitious water engineering project, thus, controlling water flow to the downstream Arab states.

In order to mitigate somehow the contradictions among states, Turkey proposed the Peace Pipeline Project envisaging construction of a large water conduit to deliver waters of the Ceyhan and Seyhan rivers to arid countries of Near East – Syria, Jordan, Israel, and Persian Gulf countries. There were also negotiations about signing an agreement with Israel for 20 years for selling to this country 50 million m^3 of freshwater per year. And despite very long negotiations, the agreement on water export had been attained.

The principle of "water dominos" has affected also the plans of Iraq which locating in the lower reaches had suffered the water deficit to a much greater extent. During the USSR times, the Russian specialists invited by the Iraqi government took part in construction of the large hydraulic complex Tartar on the Tigris River with the reservoir accumulating 69% (105 km^3) of the total water flow received in the country.

Prior to the Kuwait crisis, there were plans in Iraq to invest over US $300 million into projects on construction of flood control structures, power-generating facilities, reservoirs, and irrigation systems on this river for control of the Tigris flow.

The Nile water sharing has been for long the subject of disputes between Egypt and Sudan to which other countries located in the Nile basin may join in the future, such as Ethiopia, Tanzania, Kenya, and Uganda [15, 16]. The bilateral and multilateral arrangements and agreements existing among the countries in this region envisage mainly the actions on transfer of water from water-rich to water-deficit regions and its desalination. In the early 1990s, the water issue sparked the conflict on the Nile River. The growing population in Egypt, Sudan, and Ethiopia that depend on water supply from this river sharpened the rivalry for water.

Egypt is one of the most densely populated Arab states. It locates in the Nile delta and practically has no levers to influence the actions of eight upstream countries. Former UN Secretary General B. Gali noted still in the 1950s that “the national security of Egypt is connected with water resources” [12]. That time it was decided to concentrate efforts on year-round irrigation, and these efforts were crowned with construction of the Aswan High Dam that ensured guaranteed water supply for irrigation of agricultural lands. As it was arranged with Sudan, Egypt could take 7.5 km^3 of Nile water in addition to the right to water intake of 48 km^3 of water. Accordingly, Egypt was entitled to the guaranteed water intake of around 55.5 km^3 per year from the Nile.

There are several factors that may trigger the water crisis in Near East. First, this is an arid zone with high temperatures and precipitation deficit. Surface waters are represented by small rivers many of which dry out in summer and some large rivers (the Nile, Euphrates, Tigris, and Jordan) crossing vast deserts which do not receive tributaries in many parts and the water from which is intensively taken mostly for agricultural and water supply needs. Second, the thriving population in this region. By the population growth rate, this region takes one of the first lines in the world. Overpopulation is observed mostly in river valleys, for instance, 55% of Egyptian people live on 3% of the country’s territory. There are also states in this region which are in conflict to each other due to historical and socioeconomic factors.

Therefore, Near East is one of the most vulnerable world regions. The struggle for water may lead not only to interstate conflicts but entail general destabilization here.

7 Virtual Water

The sharp rise of water consumption in the twentieth century was connected not only with the growth of the population and increase of its incomes but also with the changed habits of consumption. In many world countries, the growing incomes of the population stimulate the use of meat, poultry, milk, and butter, i.e., the foods which manufacture requires much water. The process called today “the protein revolution” means the changes in habits of whole states and a drastic increase of protein food in a daily ration of people [17]. Such process started in most developed countries of Asia, Japan and Korea. However, with the economic development of the region it covered still greater number of countries. In 1985 the per capita consumption of meat in China was 20 kg per a year, and in 2011 it was already 53.5 kg [18]. It means that the people of China had wider possibilities to increase food consumption. At the same time, the meat consumption in India did not change due to traditions and religion, although the meat production for export to the Near East countries had increased enormously.

In many world countries, the consumption boom had led to a many-fold increase of water use. The higher living standards proclaimed in many countries had also affected the situation with water resources which had been already apportioned completely.

8 Growing Rivalry

The world is facing the growing rivalry for water resources between agriculture and industry: the latter uses water with much higher value-added cost of the final products. In China such internal rivalry for water resources is most obvious: agriculture accounts for 12% of GDP, while industry for nearly 46.5%. But the agricultural producers prefer not to cut the water consumption but to increase the added value of their products. This explains, in particular, the drastic growth of fruit and vegetable production in China in the recent decade as they have higher value than grain crops. At the same time, it is the industry that is mainly responsible for deterioration of water quality through pollution making water unfit for further use in agriculture. This is the main scourge for the developing countries.

Consequently, high water consumption in agriculture (when water is not returned into a natural cycle) and water intake (when water is returned in a cycle after passing through industrial production or power facilities, but its quality is heavily deteriorated) should be considered in a complex. For sustainable development of territories both indicators should be taken into account: the co-existence of agriculture and industry with high water intake demands the allocation of quotas for water intake and requirements to water treatment. Otherwise the situation may be established which China has to address today: regardless of physical availability of water the level of industrial water pollution is so high that this water cannot be used in agriculture and less so for household needs [19].

Such form of water crisis is rather specific and was incidental of Europe in late nineteenth to mid-twentieth centuries. The international political result of the crisis was signing of bilateral and multilateral agreements dividing the water flow of international rivers, establishment of special ecological commissions and supranational managing bodies. The increase of water intake for industrial needs was not critical by itself. However, the environmental implications threatened the existence of traditional agricultural branches (e.g., fishery in the Rhine) [20].

Currently, due to movement of some industrial productions to Asia, a high level of development, considerable investments into new technologies, and improved supranational regulation within the European Union, this crisis was overcome to a great extent. It can be said that the crisis had the least effect on international relations as it occurred largely in water abundant regions and the most grave implication of this crisis was heavy deterioration of water quality. The European integration enabled its member-countries to address effectively such contradictions and to develop the most advanced system of international cooperation in the water sphere – the European Water Initiative.

9 Water Security

The hopes for development of water saving technologies and effective water use confronted not only economic issues but also long-term social problems one of which is slow change of mentality of simple water users, mostly rural people, for whom the efficient use of water resources is not the priority issue. This process will require many years. The economic development of the Central Asian region by leading global players is impossible without appropriate legal regulation of the water issue and the more so in case of some large-scale regional conflicts over access to water resources.

Pollution is a transboundary phenomenon. Pollutants get into water sources with surface runoff from the territories of settlements, enterprises, and agricultural lands. The existing water treatment facilities fail to meet the requirements of the formulated goals.

The regional cooperation in water use is held up by the lack of the effective mechanisms for water distribution, water use management, and settlement of conflicts, by the low level of information exchange on water quality and its use. Moreover, the littoral countries make attempts to share the benefits from access to water and not the water proper which complicates the joint use of transboundary rivers. This may be largely attributed to the fact that in conditions of the growing water deficit in the transboundary river basins the countries of the region have to address the problem of satisfying their own needs. As a result, the interests of neighbor countries are ignored. In the absence of the laws regulating this area of relations, the regional countries become free to take unilateral actions and the more so as the water legislation of the Central Asian countries does not contain norms that regulate water saving.

The water resources differ greatly from hydrocarbons. They have some specific features, such as their interrelation in space, lack of borders capable to influence their distribution, and variability of water flow in time depending on the season. As a result, we have practically identical situation when the upstream countries acquire effective levers to press on downstream countries.

10 Conclusions

In many world countries, the available water resources have been already developed. At least this is true of the easily accessible resources. The possibility in the future of obtaining the water resources in some alternative ways is not visible. In any case we do not see the economically feasible ways in the foreseeable future, while the water demand is growing with every passing year.

Technological progress has not decreased the probability of conflicts for water resources. On the contrary, it made their potentially still higher. Water similar to hydrocarbons make the basis of the national security of each state as generation of electricity by thermal, nuclear, and hydropower plants depends on availability of water.

The active use of water to meet the industrial, agricultural, and household-utility needs depletes gradually the world resources and makes countries, both developed and developing, dependent on water resources. According to US estimates, by 2025 the water demand will grow by 22% compared to the present level [21]. In the economic sectors where production is impossible without water, the production growth may slow down.

The main causes of water resources depletion are environment pollution, irrational water use, low-effective land reclamation, and population growth in the countries suffering from water deficit.

Ineffective water use technologies and scales of their application contribute significantly to water pollution and reduce the volumes of water fit for drinking, domestic, agricultural, and industrial use. This is aggravated by the intensive population growth, mostly, in the regions which have always suffered from the scarcity of renewable freshwater resources required for sustainable social and economic development.

There is an opinion that fears about insufficiency of water resources in the future are groundless. As an argument they speak about huge water reserves of Arctic and Antarctic glaciers and also enormous groundwater reserves. However, they do not always consider the economic aspect – the cost of using such water resources and the long-term perspective – the effect of the global climate warming and likely irreversible negative consequences. As is known, the oil reserves in the world are quite sufficient. However, the cost of not easily extracted resources may lead in the future to further growth of their cost for users.

The conflicts in water resource management are stirred often by striving of some water-abundant countries to impose complete national sovereignty over these resources. Water, likewise oil and natural gas, becomes already now the serious factor of interstate relations, the mechanism of influence. In the future, the role of this factor will be growing.

For the countries possessing sufficient water resources the sharing of water among users – neighbor countries – acquires political dimensions. Many water-abundant countries announce that water is a commodity and require certain pay for water from neighboring states.

The uneven distribution of water among countries makes it imperative to deepen integration in water management by diversification of the whole water management complex ensuring sustainable economic growth. The issue of joint use and protection of water resources has become more complicated in view of the demographic, social, and economic pressure on natural resources. Currently, the countries are trying to find the mutually acceptable ways to manage water resources, but so far the results are not impressive. Today we have no effective mechanisms that would regulate the interstate relations concerning water resource use.

The retrospect of failures to control oil prices in the world suggests that the conflicts between producers and users of hydrocarbons being strongly influenced by data on reserves may escalate. The situation with water is much more complicated as water resources are more strongly affected by short-term climate variations.

There is no need to prove that structural imbalance in water resource distribution typical of many countries impede the attainment of political stability and sustainable social and economic development. By the mid-twenty-first century, many countries will have to import water. The struggle for water will be a source of tension and conflicts on the planet. In this context it is necessary to develop the water-saving technologies, both in agriculture and domestic and utility sphere. Facing such challenges, the world community has developed the integrated approach to water resource management. It is quite appropriate that one of the targets of the UN Sustainable Development Goals is to ensure access of people to clear and safe drinking water. This goal states clearly that "water quality is an important component of integrated management of water resources that has not been properly considered until recently" [22].

Water conflicts have become recently a part of the world geopolitical system as they control the essential resource required for viability of the modern industrial and technological society. Water becomes increasingly the crucial factor of modern geopolitics. It is quite possible that with time on the politicians and experts will use such term as "water conduit architecture" similar to natural gas and oil lines [23]. The struggle for water reminds somewhat the history of rivalry for oil and natural gas dividing countries into those who possess this resource and those who import it. The only difference is that in case of oil and natural gas, we can speak about alternative delivery routes or alternative sources, but in case of water, it will be much more complicated and costly. So, in this century, the cost of water which has become the "international commodity" may be compared with or even exceed the cost of hydrocarbons – oil, in particular.

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Evolution of Water Resources Management in Central Asia

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Contents

Abstract Since time immemorial, the water and all water-related components of life had been one of the key factors determining the development of civilizations. Water basins have no political boundaries. Water is the vital common wealth of all people on the Earth. Any attempts to divide it by force had led the society to wars and disasters. In Central Asia, water is the main uniting and dissociating factor. The causes of conflicts and rivalry for water among water users were water deficit, deterioration of water quality, and unbalanced system of water management for power generation.

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Igor S. Zonn, Sergey S. Zhiltsov, Andrey G. Kostianoy, and Aleksandr V. Semenov (eds.), *Water Resources Management in Central Asia*, Hdb Env Chem (2020) 105: 31–46, DOI 10.1007/698_2020_599,
© Springer Nature Switzerland AG 2020, Published online: 20 July 2020

In five Central Asian states located in the basins of the major rivers – Syr Darya and Amu Darya, the water dependence among them is so strong that it simply dooms these countries to joint management of all waters formed here and used by all peoples inhabiting this area to ensure regional security. Apart from difficulties faced with water distribution regulation across the territory, there are also complexities with regulation of water supply in time as various water users have their own specific time-related demand for water. This also requires the well-balanced actions. For the last five decades, the countries have been looking for the best form of water resource management.

Keywords Central Asia, Hydropower generation, Institutional arrangements, Irrigation, Water resources

1 Introduction

In the Central Asian region, the water that for many millennia had been the key attribute of vital activities played the crucial role in the development and collapse of civilizations. Here the philosophical notion “Obi Hayot” (Water – Life) appeared. It is the water and energy balance that determines the inner stability of the region.

In the Soviet Union times, the water management system was established. In the unified state, the mechanism of administrative and command control of water management was developed, improved, applied, and permanently optimized. It harmonized the opposing interests of energy and agriculture, industry, communal facilities, and fishery. The decisions were taken to minimize the damage to the whole state in the low-water periods, to improve the natural environment and to find resources for overcoming the critical situations. The most serious problems were resolved by the highest economic and even political leadership of the country. However, in the late 1980s, the existing form of water management had exhausted its potential, and its malfunction was observed. As a result, the changeover to the basin principle of management was adopted.

Breakup of the USSR in 1991 and formation of new independent states entailed division of water basins and appearance of serious and complicated problems in water resources management due to destruction of the old system of command management, the changed structure of water users, water suppliers, and other “stakeholders” as well as the processes of globalization, change of prices, etc. This resulted in a sharp increase of the number of water users, impairment of financial capabilities of water organizations and “stakeholders,” complication and divergence of the processes of development, maintenance, monitoring, management, and improvement of water economy. Such consequences were most painful for the water deficit states. And in this period, the rivalry for depleting water resources that had become the marketable product was started.

The Central Asian states rather quickly understood the need for restoration of the common system of water resource management. In the 1990s, the water management started changing with the progress of the social and economic reforms already in independent states. This required some institutional measures for cooperation and coordination of interstate water management taking into consideration the interests of all regional countries. At the same time, considering the geographical position of these states, their water resources make and will make in a certain historical perspective the natural basis for economic development and improvement of the life of people and society. Water and its sharing remain at present one of the basic means to develop relations among the regional states. Water availability and water sufficiency are the key factors guiding the population distribution and economic activities in the region.

2 Water and Energy Resources of Central Asia

The Central Asian region locates in the center of the Eurasian continent. It includes the former republics of the Soviet Union – Kyrgyzstan, Uzbekistan, Tajikistan, Turkmenistan, and Kazakhstan. The inland location of the region determines its natural and climatic conditions. The region covers over four million km^2 (the greatest area is taken by Kazakhstan (68%) (the greatest population is in Uzbekistan (43%) without Afghanistan (2019). The climate in this region is continental characterized by inadequate water supply of the territory, except mountain areas. The deserts, semideserts, and dry steppes extend over 70% of the territory. The sources of water here are in the mountains locating partially or fully in the territory of the Central Asian countries and nearby regions. The mountain systems Tian Shan, Altai, and Pamir, more precisely their glaciers (total area of 17,950 km^2), are the main water sources which help maintaining the balance of water resources in the region.

The water resources of Central Asia include surface (rivers, lakes) and groundwaters. They are distributed unevenly, thus, posing a very serious water supply problem in economic and political terms. The Central Asian countries are closely connected via river systems of Amu Darya and Syr Darya, Tarim, and Irtysh. The Amu Darya River formed from confluence of the Vakhsh River originating in the mountains of Kyrgyzstan and the Panj River originating in Afghanistan is the major water course crossing the territories of Kyrgyzstan, Tajikistan, Afghanistan, Uzbekistan, Turkmenistan, and Iran. Its length is 2,620 km; the watershed area is 227,000 km^2. Its long-time average annual flow is 78.5 km^3 per year with the annual values varying from 47 to 108 km^3. The second largest river in this region is Syr Darya that is formed from confluence of the Naryn and Kara Darya rivers in Kyrgyzstan. It takes in the waters of rivers running from the southwestern slopes of the Fergana Ridge and the northern slopes of the Altai and Turkestan Ridges. Its length is 2,860 km; the watershed area is 136,000 km^3, and its long-time average annual flow is 37 km^3 per year. The annual water flow varies from 21 to 54 km^3. This river crosses the territories of Kyrgyzstan, Uzbekistan, Tajikistan, and Kazakhstan.

The third largest hydrographic system is formed by the tributaries of the Tarim River flowing to China from the mountains in Kyrgyzstan (Saryzhaz, Uzengyukuush, Aksai, Kyzyl Suu Rivers with the total flow of over 7.1 km^3) and in Tajikistan (Makansuu River with the flow of about 0.5 km^3). Kazakhstan is connected with China by Black Irtysh (about 10 km^3), Ily (about 10 km^3), and two dozens of smaller rivers inflowing from the Chinese territory. The rivers of Chu (3.6 km^3), Talas (1.6 km^3), and Karkyra (about 0.3 km^3) flow from Kyrgyzstan to Kazakhstan. The runoff of the Amu Darya and Syr Darya Rivers is regulated by the Toktogul water reservoir 19.5 km^3 in capacity on the Naryn River (Kyrgyzstan) and the Nurek water reservoir 10.5 km^3 in capacity on the Vakhsh River (Tajikistan) in the many-year water-energy regime that is also ensured by the parallel operation of energy systems entering the united energy system of Central Asia [1]. The downstream countries (Kazakhstan, Turkmenistan, and Uzbekistan) are water-deficit countries, while the upstream countries (Kyrgyzstan and Tajikistan) are the water abundant countries. A very important peculiarity of Central Asia is that two of its countries (Tajikistan and Kyrgyzstan) are located in the zone where 80% of freshwater flow is formed, while other republics are located in the zone of its spreading. It should be stressed here that Kyrgyzstan is the only state in Central Asia which water resources are fully formed within its own territory. The hydrological distinguishing feature of this country gives it certain advantages. The countries in this region are interconnected by transboundary rivers forming the single system of water resources. Any changes of water use in one of the countries affect invariably the interests of other countries. The upstream and downstream states have competing interests in the use of water resources, in particular the use of water for irrigation and power generation. For Tajikistan and Kyrgyzstan where the main flow of the Aral Sea basin is formed (over 80%), the dominating economic interest is the development of hydropower engineering (to avoid energy deficit) in the absence of other internal sources of power supply, while for Kazakhstan, Turkmenistan, and Uzbekistan, this is irrigated farming. Therefore, the upstream countries are interested in maximum releases of water in the energy-deficit winter time, while the downstream countries need maximum water in summer for land irrigation.

Breakup of water resources by Central Asian countries is illustrated in Table 1 below.

The above table shows that in the territory of Central Asia, the surface water resources in the amount of 151 km^3 are formed as follows: 42.5% in the Republic of Tajikistan, 31.1% in the Republic of Kyrgyzstan, 18.7% in the Republic of Kazakhstan, 5.9% in the Republic of Uzbekistan, and 1.8% in Turkmenistan. The coefficient of transboundary water dependence (the fraction of river runoff coming from outside) is 4.2% in Kazakhstan, 77% in Uzbekistan, and 82% in Turkmenistan which proves that the states of Central Asia are in need of the harmonized policy on rational management of water resources. From the Syr Darya River, Uzbekistan receives 50.5%, Tajikistan 7%, and Kyrgyzstan 0.5%. The Amu Darya flow is distributed as follows: Uzbekistan 42.2%, Turkmenistan 42.3%, Tajikistan 15.2%, and Kyrgyzstan 0.3% (Fig. 1).

Table 1 Water resources of Central Asian rivers by countries (km^3 per year)

State	Amu Darya basin	Syr Darya basin	Balkhash Lake basin	Issyk-Kul Lake basin	Tarima River basin	Total	%
Kazakhstan	–	4.5	23.8	–	–	28.3	18.7
Kyrgyzstan	2.0	34.0	0.3	3.7	7.1	47.1	31.1
Tajikistan	62.9	1.1	–	–	0.3	64.3	42.5
Turkmenistan + Iran	2.8	–	–	–	–	2.8	1.8
Uzbekistan	4.7	4.1	–	–	–	8.8	5.9
Total	72.4	43.7	24.1	3.7	7.4	151.3	100
%	49.9	24.3	18.6	2.4	4.8	–	100

The distribution of energy resources in Central Asia is also uneven by countries: hydrocarbon resources are the greatest in Kazakhstan, 77.4%; Uzbekistan, 12.7%; and Turkmenistan, 6.7%. So, these countries are energy abundant. Kyrgyzstan and Tajikistan are energy-deficit countries, and they import 40–50% of hydrocarbons at world prices. The hydropower potential is the highest in Tajikistan generating over 300 billion KWH and Kyrgyzstan over 142 billion KWh. The thermal power generation using coal and natural gas: in Kazakhstan 87.5%, Uzbekistan 85.9%, and Turkmenistan 99.9%. The hydropower generation in Kyrgyzstan accounts for 83.5% and in Tajikistan 92.7%. The share of hydropower in the total energy generation of the region reaches 27.3%; in Tajikistan and Kyrgyzstan, it is 75–90% (Fig. 2).

According to some publications, in the recent 100 years (1900–2002), the temperature in the countries of this region had risen, while the precipitations diminished. These climatic changes stir serious concern. If this tendency persists, it should be acknowledged that climatic conditions in the Central Asian region become worse tending to further aridization. According to forecasts, the water resources will reduce significantly due to climate changes having serious consequences for the glaciers of the Tian Shan and Pamir for decades ahead which will make more urgent to reassess the water use issues. The glaciers of Central Asia are the most important source of replenishing river flow in the warm season, but their distribution across the territories of the regional countries is very uneven. In Kyrgyzstan, there are 8,200 glaciers with a total area of 8169.4 km^2, covering 4.2% of the country's territory; their water reserve is assessed at 650 km^3. In Tajikistan, there are 8,492 glaciers with a total area of 8,476.2 km^2 or about 6% of the republic's territory, storing around 500 km^3 of water. Other glaciers are found in Kazakhstan on the ranges of the Zailiysky Alatau, Dzungarian, Kungei, and Terskey Ala-Too. For Uzbekistan, the glaciation is not typical. Beginning from 1960, the glaciers of Tian Shan lose on the average 5.4 billion tons of ice every year making in total 3,000 km^3 [2]. The intensive climate warming is witnessed in all Central Asian countries. The perspective assessments of water resources in this region with regard to climate changes show that none of the considered climatic scenarios taking into account

Fig. 1 River network in Central Asia. https://zoinet.org/wp-content/uploads/2018/01/02_water_network_metrostyle_central_asia.jpg

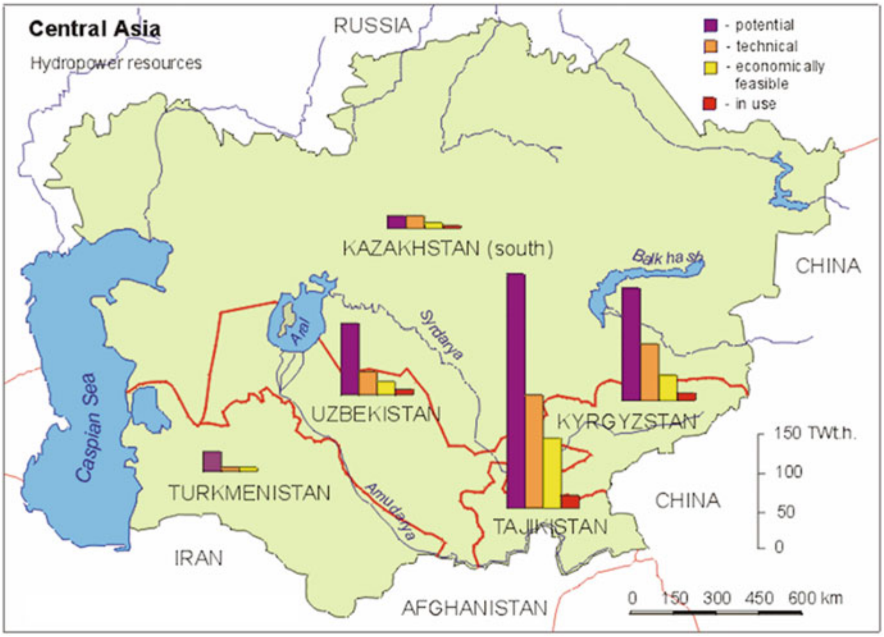

Fig. 2 Hydropower resources in Central Asia. https://dnd.com.pk/tajikistan-will-export-electricity-to-uzbekistan-and-kazakhstan/139346/amp. Source: Tashhydroproject (UZB)

climate warming predict the growth of available water resources. According to the most recent estimates conducted by the US World Resources Institute based on climatic models and social and economic scenarios, the Central Asian countries – Kyrgyzstan (4.93), Kazakhstan (4.66), Turkmenistan (4.30), and Uzbekistan (4.19) are included into 33 world countries which by 2040 will suffer the extremely high stress due to water deficit (the maximum coefficient is 5) [3]. Other mathematical modeling estimates have proved that by 2050, the river runoff in the Amu Darya River basin will decrease by 20–30% and Syr Darya by 15–20% [4].

It is stressed that "the climate warming will distort the traditional forms of water sharing" [5]. This urges to change the paradigm of water management.

Water resources are also very important for industrial development although the existing industrial facilities were inherited from the Soviet time. But the regional countries make efforts to create the new and to reform the existing industrial potential, so, the water needs will grow accordingly.

3 Basin Principle of Water Resource Management

The main programs that survived to the present outlining the principles of water sharing among the Central Asian countries had been developed as far back as in 1975–1980 on the basis of the Schemes of Integrated Use and Protection of Water Resources prepared for all river basins in the USSR.

In 1981–1983, the USSR Ministry of Water Economy in union republics approved the water quotas calculated on the basis of the available land stock with regard to prospects of development and application of scientifically validated regimes of irrigation of agricultural crops. The water quota due to each republic was calculated as percentage of the estimated reserves, while the volume of supplied water was regularly revised with regard to the actual water availability. The water and energy contradictions were alleviated rather effectively owing to the centralized planning of the economy development of the whole country.

In the Soviet Union, they proceeded from the fact that in Central Asia, the majority of the population had been practicing agriculture since old times; thus, the use of river waters for irrigation was in priority. At the same time, in autumn and winter, the upstream republics compensated their energy needs by supplying heat and energy resources, so the barter principle "water – for energy" was applied. At such scheme, the upstream republics received the missing energy resources and the downstream republics – water. Here the compensation mechanism was well developed in every detail, and the scale of supplies was not confined to Central Asia but was supported by the potential of the whole country. After breakup of the USSR in 1991, this conflict became more acute and complicated. It concerned mostly the operating regime of the Toktogul headworks and reservoir (Kyrgyzstan) being the largest not only in the Syr Darya basin but in whole Central Asia, as well as the Karakum reservoir (Tajikistan) directing waters to the Syr Darya middle reaches.

In order to alleviate contradictions in ensuring the sustainable water use, efficient water sharing and safe water passage through the whole length of rivers the Central Asian countries adopted the Basin Principle of Water Resources Management. It assumed management of a water body and related waterworks within the whole basin of a river or lake in order to pursue the single, balanced, taking into account specific features of a water body and population, engineering, economic, social, and environment protection policy for the whole watershed area. River basins were considered as a basis for establishing the bodies of state management of water resources.

The basin principle of water resources management was called to ensure the rational regulation and settlement of conflicts among different industries. It assumed that the financial mechanism should guarantee the direct dependence between the water pay and financing of the priority water conservation actions within a basin.

In the early 1990s, the Basin Water Management Associations (BWMA) "Syr Darya" and "Amu Darya" were established. Having in its structure the central dispatch points of control and communication, the observation stations on structures in the regional countries, this organization coordinated the operating regimes of reservoirs, water apportioning among the countries, and safe water passage. According to the special resolution of the USSR government, all large reservoirs and head water intakes with a capacity over 10 m^3/s along channels of both rivers and their tributaries were included into authority of BWMA. They were allowed to change the water quotas within 10% for each republic depending on the current situation but could not interfere in the processes of water use within republics and control water quality. BWMA were also authorized to prepare the operational plans of water allocations for the coming 6 months and the schedules of water intakes and water releases from reservoirs based on forecasts of water reserves prepared by the republican hydrometeorological services.

It should be stressed that delegation by the USSR Ministry of Water Economy and Ministries of Water Economy of Central Asian states of certain functions on water resources management to BWMA and changeover to the basin principle of management proved efficient. First, the accounting and control of water use were simply set to order; second, the accounting of unproductive water losses in rivers and in inter-republican main canals was improved; and third, a particular organization responsible for the results of water use and distribution was established. The management system became more flexible and satisfying all parties. A certain level of understanding and trust was attained in relationships among the states in this region.

At joint use of water resources that requires more intricate management of river basins, the disagreements (conflicts) at different hierarchical levels – intrastate, interstate, and interregional may appear. It should be remembered here that improvement of water use technologies and the growing deficit of water resources increase the probability of intrastate and interstate discordances. The Soviet mechanism of water resources allocation in the Central Asian countries had become morally outdated and did not already match the modern interests of the states in this region. The development of successful cooperation in joint use of the Central Asian rivers is hindered by the differences in traditions of water use, managerial structures, and national interests of the countries concerning the water use principle.

Many disputes concerning the system of hydropower generation in Central Asia created tension among the countries regardless of their mutual complementarity – three downstream countries produce oil and gas and two upstream countries generate hydropower.

After disintegration of the Soviet Union and disappearance of the common economic and political space when all union ministries ceased to exist quite naturally, the following problem came to the fore: how to manage the common water resources in the Central Asian region. Understanding the need of the well-coordinated and organized solution of the issue, including the joint management of water resources of the Amu Darya and Syr Darya rivers which had become interstate water sources after breakup of the USSR, and in order to pursue in the future the agreed policy for economic development and improvement of the living standard of the local population in the Central Asian region, in February 1992, the ministers of water economy of the Central Asian republics signed in Alma-Ata the Agreement on Cooperation in Joint Management and Use and Protection of Water Resources of

Interstate Sources. They also established the Interstate Coordination Water Commission (ICWC) that included two existing basin water associations – BWMA "Amu Darya" and BWMA "Syr Darya" as executive bodies of ICWC.

Regardless of the fact that after the USSR breakup BWMA continued demonstrating its viability, the legal status of these organizations as authorized decision-makers on issues involving interests of the new formed sovereign states required immediate revision.

Currently the basin system of management is most effective. It provides for better organization of the management of water supply and the mechanism of accounting and collection of pay for water supply and control of rational water use. The legal basis of basin management is the Water Code containing one of the fundamental principles – the basin-based management of water resources. This code was legally enforced in all countries of Central Asia.

The Agreement of 1992 formalized structurally the joint management of transboundary water resources, retained the state of affairs in interstate water sharing, and water use established historically in the basin of each particular river and excluded the loss of manageability of transboundary water resources in the Aral Sea basin.

One of the most important consequences of the Alma-Ata Agreement is the decision of the heads of the Central Asian states to approve the Regulations on the International Fund for Saving the Aral Sea (IFAS) and the Agreement on the Status of IFAS and its organizations adopted on April 9, 1999, in Ashkhabad. These documents consolidated the BWMA status. In this way, the creation of the legislative and institutional base of regional water cooperation in Central Asia is completed.

The system of management of the use and protection of water resources in the Central Asian countries included many ministries, departments, and organizations. The extremely complex and centralized structure of water economy that existed that time was a hindrance for systems formation and development of water management. Its excessive complexity was revealed in the too cumbersome hierarchy of water management that enhanced such traditional drawbacks as duplication or incomplete implementation of the functions by ministries and departments.

The existing regulatory and legal support of water use is far from being perfect and requires serious improvement. The available legal instruments are either too formalized or declarative or simply become obsolete or not abided by in full or in part and do not contain the effective mechanisms to ensure their fulfillment [6].

In view of the shortage of budget finance for water development activities and considerable wear-out of water facilities, it is necessary to attract the non-state (private) sector to water activities, primarily, to water supply, repair, and maintenance of water facilities. The basin water management bodies will play an important role in formation of such market in water economy. They should formulate clearly the targets of denationalization in the water sector, determine its practicability limits, and identify the need of the legal support. The functions of water management (issuance of licenses and permits to special water use or licensing of water development activities) are performed by the basin management body.

Table 2 Existing organizational structures of water management at the national level in the Central Asian countries

Kazakhstan	Kyrgyzstan	Tajikistan	Turkmenistan	Uzbekistan
Ministry of Ecology, geology and natural resources Committee for Water Resources 8 Basin Water Departments (BWD) State Body for Water Economy (SBWE)	Ministry of Agriculture, food industry and land reclamation Department of Water Economy 7 Basin Water Departments (BWD) 40 regional BWD	Ministry of Land Reclamation and Water Resources 2 Regional State Water Departments (SWD) 42 Regional and Interregional SWD	Ministry of Agriculture and water economy 5 Regional (Velajat) Water Associations (RWA) District (Etrap) Water Departments (DWD) Daikhan Unions, farmers – Water users Department for Karakum Canal (Karakum-Darya)	Ministry of Agriculture and water economy Chief Department of Water Economy 10 Basin Departments for Irrigation Systems (BDIS) Department for Main Canal System (DMCS) in Fergana Valley
Principle of administration				
Basin	Industrial	Administrative-territorial	Territorial	Basin

Denationalization of agricultural facilities and establishment of non-state farms create, in fact, the alternatives of the state-owned water operations – the water user associations (WUA). But the task of the state here is to create equal conditions of water intake for water users regardless of from whom they get water: from state water organizations or WUA. Quite often the state water organizations and WUA duplicate each other in performing maintenance of irrigation systems. The effectively operating water user associations will permit to save irrigation water and to support farmers with available means.

Currently the vertically arranged water management organizations in Central Asia include state organizations established by the governments for state management, the national water management body (Ministry, Department) – Basin Water Management Department; Department for Irrigation System, Canal (DIS); and Water User Association (WUA) water users (Table 2).

4 Integrated Water Resources Management (IWRM)

The population growth, the increasing water deficit as a result of traditional wasteful use and pollution of water resources, and also the depletion of water reserves due to climatic changes are the factors that change essentially the functions, principles, and mechanisms of water management. Currently, the Central Asian countries started including the principles of sustainable development into their strategic documents and the practice of state administration. One of the instruments of transfer to sustainable development is the Integrated Water Resources Management (IWRM). The global water partnership that was formed in 1996 as an international network of organizations (public, private, regional, scientific, design, and others) involved in water management suggests the following definition of IWRM [7]: "IWRM is a process which promotes the coordinated development and management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems." They are speaking here about introduction of the principles of integrated water resources management (IWRM) being the new water paradigm. This idea combines "water resources management" and "management of water demand" through water saving and increased efficiency of water use. Traditionally, the Central Asian countries focused on water resources management. After becoming independent states in the conditions of water deficit, it becomes more and more evident that the pure technological approaches are unable to resolve the water use problems. The priorities in water use are shifting from industry to the socium and ecology. The environmental requirements of management are realized through satisfying the water needs of ecosystems and prevention of hazardous impact of water.

As Tarlok E. Dan notes "IWRM is not a new concept. There is a long history of management of river basins as a whole and attempts to plan and execute the strict management regimes. IWRM is based on this old tradition that traces its roots back in the USA and the former Soviet Union. However, it tries to correct the ecological and social short-sightedness of previous systems and to ensure wider involvement of the society and economy into the practice of water sharing. It focuses, to a great extent, on creating of a wider range of alternatives for finding the long-term environmentally and socially sustainable ways of water use compared to the previous planning models" [5].

And this is correct. As for the Soviet Union, in the past, the integrated approach to water resources management was taken in this country. In the new IWRM paradigm, the integration is complemented with attraction of water users in a wider meaning of this "class" to planning and management of water resources. In other words, the social development is added as a separate and equal principle.

Table 3 illustrates the evolution in water resources management in the recent 50 years.

As is well-known for implementation of water management, it is necessary to have the interrelated elements: engineering infrastructure of water supply (reservoirs, canals, regulating facilities, water diversion system) and organization infrastructure – water management organizations for servicing the first infrastructure.

For its functioning, the management instruments are required; they are legal base and regulations, methodological base (to assess water requirements, water distribution, water use analysis, etc.), and monitoring system (hydrometry and information base). In addition, the system of financing and initiatives (pay for services, for

Table 3 Evolution of water resources management

1970s–1980s	1990s	Twenty-first century
• Water is a renewable natural resource that is affected (in the form of pollution) by industry • Development of basin schemes of integrated use and protection of water resources • Basin principle of management – the management of a water body and related waterworks within the scale of the whole river basin. The basic structure of the governmental system for water resources management • Appearance of the concept of environmentally sustainable development (ESD) comprising three mutually supporting principles: environmental development, social development, and environment protection	• Water is considered the "exhaustible and vulnerable resource being simultaneously the commercial commodity and natural resource, having its cultural, social and environmental value." (Declaration of the Dublin Conference on Water and Environment, 1992) • Rivalry for water and energy resources due to their uneven distribution • Shifting of focuses in the environmental policy to institutional and economic approaches and instruments of management	• With the progress of national reforms, it becomes necessary to adjust the water management with regard to ESD targets by adherence to integrated water management – sustainable, just, and equal supply of water to meet the needs of water users and environment • Climate changes drastically enhanced the significance of the conditions of water resources and related facilities. Water became the key economic resource and the independent factor for addressing the development issues

pollution, and others) is required. Taken together this makes a complex process that currently referred to as IWRM [7]. The main purpose of IWRM is a sustainable, reliable, just, and equal supply of water to satisfy the needs of water users and nature.

IWRM is the process based on accounting of all available water sources (surface, ground, and return waters) within the hydrographic borders. It harmonizes the interests of various industries and hierarchical levels of water use, involves all interested parties into the decision-making process, and facilitates the effective use of water for attainment of sustainable welfare of the society and environmental security.

At the same time, IWRM is a political process seeking to settle conflicts, while the need in this process proper is dictated by the endeavor to achieve justice in joint use of water resources.

Currently, the IWRM process is the best technology in water management. It should be stressed here that this process is included into the list of priorities declared by the UN General Assembly within the framework of the International Year of Freshwater and the International Decade for Action "Water for Life" which "consolidated the understanding of the world community about the need to go from discussions, expression of intentions and declaration of commitments to taking practical steps in the water area."

It is quite obvious that the cumbersome institutional structure inherited by the Central Asian republics required soonest reforming. The institutional transformations should include the reasonable combination of the mechanisms of governmental, democratic, and market regulation. And IWRM which different modifications have been tested in some countries, such as France, Spain, and others, suits best this requirement.

IWRM pursues the aim that the new water requirements were recognized as potential limitations of the traditional, often inefficient kinds of water use.

In the Central Asian countries, the initial conditions for IWRM introduction are differing and require significant preparatory works and much time. In some countries, the IWRM notion for their leadership and society was something new although the basin principle of water management has been practiced by water organizations for long.

The adoption of clear democratic procedures of discussion and taking financial decisions with participation of all interested parties, the wide awareness of the public about the basin water policy and environmental programs at all stages of their development and implementation, and also informing of the population about the condition and quality of water resources are mandatory for realization of the basin principle of water resource management.

At the same time, certain differences in the political and economic approaches to the development of the social and nature conservation spheres have been visible among Central Asian countries, and maintaining in such conditions of the unity of the interstate management is not an easy task.

The Central Asian countries understand that IWRM is a process directed to preparation and adoption of decisions at all levels – local, sub-basin, national, and regional for ensuring effective integration of the key factors related to the use of water and land resources into the processes of economic and social development to ensure welfare of the population on the principle of justice and least damage to ecosystems.

The Central Asian countries are eager to revise the established regimes of water sharing so as to adopt IWRM. The most effective way of changing the public opinion and obtaining the political support for implementation of the IWRM principles is an experiment on application of these principles on the example of pilot canals on three irrigation systems in Kyrgyzstan, Tajikistan, and Uzbekistan within the framework of the project on Integrated Water Management in the Fergana Valley outlining the possibilities for crucial increase of the use of water taken from sources. The people should see and assess the positive aspects of IWRM, including its economic efficiency in the specific conditions of a country, elaborate the sequence of interaction of different sectors involved in water management, and develop the common approaches to consolidation of the intersectoral actions at the regional level. However, the IWRM introduction is a complex task that requires addressing such issues as wide involvement of the public in discussing the rational use and management of water resources in the region – from attraction of nongovernmental organizations, movements and parties with different basic platforms for improving the environmental situation in the region to extending the authorities of the Water User Association [8].

It should be also remembered that the attainment of environmental sustainability poses new tasks, and the existing methods of management and organizational structures cannot always suggest the quick and correct solutions for them.

The joint water use supposes the precise identification of priorities and requirements of each state and also ways to compensate for the likely losses for each country.

Currently many specialists agree that the establishment of the Interstate Water-Energy Holding will be the most convenient mechanism for development and implementation of the mutually beneficial use of water and energy resources and taking into account the interests of each republic. This will permit not only to unite water and energy resources but also the agricultural resources for the benefit of economics, ecology, and socium.

5 Conclusions

It should be reminded here that while discussing the situation with water resources in the Central Asian countries, the attention is focused, voluntarily or not, on the issues of management.

In the book “Water Resources in Central Asia: International Context” published by Springer in 2018, this issue was reflected in publications of Barbara Janusz-Pawletta [9], Marton Krasznai [10], and Bo Libert [11] that is why we decided to touch in a concise form the issues that have not been discussed there.

In the recent time, we have observed that the Central Asian countries do their best to transfer water planning and management to a new paradigm of integrated management. And the main reason for such changes is that “complex development resulted in considerable environmental costs and increased social inequality in many world regions” [5]. In the Central Asian countries, the existing administrative and territorial system of management in the conditions of the market economy is losing its initial basis and, as a result, becomes less effective. In the present conditions, the basin system of management being a part of IWRM is most efficient. It provides for application of the best systems of management of water, accounting and mechanism of collection of pay for supplied water, and control of water rational use. This is most important as the efficiency of water use should be calculated as the required quantity of water per unit of produce. It should be noted that the injection of IWRM into the environment of politicians, specialists, organizations, and the public dealing with water issues is not deep as the IWRM principles have not been realized in full. The reforms in the water economy based on IWRM are supported by governments, governmental bodies, parliaments, and public institutions. The main IWRM requirements are fixed in water code; however, the dispersion of responsibility and reporting of the obtained results and indicators are far from the expected. Such issues such as omnipresent management of water demand, differentiation of pay for water and its delivery with regard to particular conditions, creation of the private, and collective and shareholding forms of water use in different conditions of water activities are coped with rather slowly and differently in different countries due to revision of the established water sharing regimes so as to be able to adopt the IWRM elements. The accelerated solution of many problems is at time hindered by the conflicts among various departments, first of all, among hydropower engineering, environment, and agriculture at the national level. And these conflicts are most intense in the low-water years.

We cannot exclude the interstate disagreements due to divergence of positions of different states in water sharing and the ineffective mechanisms of overcoming these discordances and also due to striving of neighbor countries to use their geographical position for obtaining the maximum economic and political benefits. And this is so regardless of bilateral and multilateral treaties and regional agreements. The creation of the respective political and legal frameworks for constructive dialog and enhanced awareness of the importance of joint effective use of water resources should be given due credit.

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Water Resource Transfer in Central Asia: Projects, Results, and Perspectives

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Contents

Abstract Nowadays water availability has become the crucial issue in many countries of Central Asia. The uneven territorial spreading of water resources and their insufficiency and permanently growing water consumption create rivalry in water demand at the national and regional levels. Water deficit and deteriorating water quality are the serious challenges that have been faced by many countries of this region. The key issue for stabilizing the situation inside Central Asia is to find ways to increase available resources.

In some countries the possibilities for inter-basin transfers of river flow and rational water management within a territory have been nearly exhausted which

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Igor S. Zonn, Sergey S. Zhiltsov, Andrey G. Kostianoy, and Aleksandr V. Semenov (eds.), *Water Resources Management in Central Asia*, Hdb Env Chem (2020) 105: 47–64, DOI 10.1007/698_2020_600,
© Springer Nature Switzerland AG 2020, Published online: 14 July 2020

forces to initiate studies and to launch projects on joint use of water resources based on inter-zonal (interstate) river flow transfers.

Analysis of the dynamics and forecasts of water consumption proves that in the coming millennium, mankind will be preoccupied with finding solutions to water resource problems. For the world community, this will be a period of mutually beneficial joint use of water resources by states on the basis of large-scale inter-zonal conveyance of water from water surplus rivers to water-deficit regions.

Keywords Central Asia, Ecology, Megaprojects, Water resources, Water transfer

1 Introduction

Water availability is one of the crucial components in the national security framework as it is connected with food supply reliability. Uneven spatial distribution of surface flow and its mismatching of the requirements of economic development are most typical of the water management situation in many world countries. The quantity of available natural water resources does not correspond to the objectives of state social and economic programs. Therefore, there is a need in large-scale redistribution of water resources within a territory – by flow transfer from water surplus areas. River water conveyance from donor to recipient basins is not quite new alternative to improve water availability in some areas.

In the Central Asian countries, the irrigated farming is the main user of water. Its development depends on natural conditions, i.e., whether or not it belongs to a zone of insufficient moistening or a “water hungry” zone with its arid conditions and thriving population. These very factors are responsible for the growing demand in water which resources are scarce. With time on the capacity of local water sources becomes depleted, first, under natural regimes of water bodies and, later, due to their regulation [1].

It is a known fact that the Central Asian countries face severe deficit of water resources which more than once has led to acute interstate conflicts [2]. “Water deficit in the greater part of Asia becomes a menace to accelerated economic improvement urging to build waterworks in the upstream parts of rivers which waters are shared by several states. If the ‘water geopolitics’ stirs further the tension among the countries due to depleting water flows in neighbor states, the Asian ‘renaissance’ will slow down significantly. Water becomes the crucial issue and it may help unveiling whether Asia is governed by mutually beneficial cooperation or dangerous interstate rivalry” [3].

The water issues come to fore as the unprecedented world-scale growth of economy will go on exerting pressure on some most vital strategic resources, including energy, food, and water. The forecasts of the Development, Concepts and Doctrine Centre’s (DCDC) Strategic Trends Program for 2007–2036 at the

British Ministry of Defense say that in this period the water deficit will grow along with the risks of aggravating conditions in the regions where the situation is already complicated and where the military actions and population migration are quite possible. The main risk zones are North Africa, the Near East, and Central Asia, including China, where water deficit and irrigation problems may lead to attempts to re-direct the river flows... [4].

It is not accidental that in March 2018 the International Decade for Action "Water for Sustainable Development" (2018–2028) was declared by UN. Scientists and experts from Central Asian countries are concerned about some future challenges that may affect water division and water use in the region. These include the population growth and, accordingly, growing demand for water, climate changes causing changes of river flow, the irrigated farming development in Afghanistan and its growing demand, and the likely changes related to the development of hydropower construction [5].

The solutions to cope with these challenges are unambiguous and formulated in all publications: water saving, water use efficiency and water storage, closer cooperation and joint management of water resources among neighbor countries, and conditions of water division and river regimes in various hydrological conditions. It should be noted that the above solutions have been suggested for many years as some mantra, while the challenges remain as they are.

2 First Water Transfer Projects

The projects of river water transfer or spatial redistribution of water resources and their implementation have a historical background. In 2500 B.C. in Ancient Babylon, the Tigris and Euphrates rivers were connected by a shipping channel. Ancient Egyptians supplied water to great distances for irrigation of their fields. In 428 B.C. in China, the canal connecting the Yangtze and Huai He rivers was constructed that later on became a part of the Grand Canal connecting Beijing with southern regions. Russian Tsar Peter I contemplated the idea how to connect the Volga and Don rivers. In the twentieth century, the inner-basin and inter-basin water transfers have become quite customary. But the volumes of diverted water in the largest transfer projects have grown enormously reaching 10 km^3 per year. Such projects were accomplished in the USA, India, Australia, Canada, and the former Soviet republics of Central Asia (Table 1).

From time to time, the ideas of megaprojects on territorial redistribution of water, i.e., river flow transfer from surplus river basins to water-deficit regions to meet the water needs of the latter, have been roaming in different world countries (Plan NAWAPA – USA, Canada). Further development of economics and technologies has created the real prerequisites for implementation in various world countries of some of these projects, e.g., South-North Nánshuǐ Běidiào Project supposing diversion of water from the Yangtze River in the south of China to the Huai and Hai river basins in the north, although it is quite unlikely that many of them will be

Table 1 Inter-basin water transfer schemes by continents

Continent/number of countries	Existing inter-basin water transfers		Planned inter-basin water transfers	
	Quantity of schemes	Transfer (bill m^3/year)	Quantity of schemes	Transfer (bill m^3/year)
Asia (10)	62	293	46	315
America (5)	78	164	11	700
Europe (11)	52	126	11	35
Africa (8)	21	9	9	37
Oceania (1)	6	5	2	2
Total (35)	219	597	79	1,089

Source: International Committee for Irrigation and Drainage (Presentation of I.A. Petrakov "World Experience in Development of Inter-Basin Redistribution of Water Resources," Almaty 2013)

accomplished in the near future. Many countries take rather cautious approach to practical implementation of large (accounting for diversion of several dozen cubic kilometers per year) water transfer projects as so far there is no experience of construction and operation of such major water management systems in the world.

In the late nineteenth century, the economic interests of Russia required the soonest development of natural resources of the Turkestan territory situated in the south of the Asian part of Russia (Central Asia). As a result, the governmental institutions and private businessmen-concessionaires organized many exploration expeditions. For five decades prior to the breakup of the Russian Empire, they had conducted detailed investigations that provided enormous data about its natural resources and their possible use in the Russian economy. Field surveys and laboratory analysis of the obtained data were carried out with high accuracy and reliability as for the most part they were conducted by military institutions. Many projects were developed based on these results, and some of them still amaze with their immensity and original engineering solutions. The ideas of that time concerning irrigation were used in the Soviet time as a basis for irrigation development in the Soviet Central Asian republics. In 1873 special the Urundarya expedition was established in St. Petersburg that investigated the old channel of Amu Darya-Kunya-Darya (Daryalyk) rivers as far as the Sarykamysh Depression. In 1874–1880 the expedition of the Russian Geographical Society investigated the Amu Darya lower reaches and conducted reconnaissance surveys of the Uzboy dry channel from the Caspian Sea to Sarykamysh Depression 693 km long. The hydrophysical map of the Amu Darya Delta was prepared. It was found that the water level in this depression was 13 m lower than the water horizon in the Caspian Sea. Based on investigation results, the project "Conveyance of Amu Darya water via its old channel to the Caspian Sea and creation of the continuous Amu Darya-Caspian waterway from the border of Afghanistan along the Amu Darya, Caspian, Volga and Mariinsky waterway to Petersburg and Baltic Sea" was prepared. It envisaged construction of the Trans-Caspian Canal 1,590 km long taking water from Amu Darya at confluence of the Vakhsh and Pyandj rivers with the head waterworks discharge of 2,796 m^3/s for irrigation of 2.5 million desyatinas (1 desyatina = 1.0925 ha), including 0.3 million desyatinas in Afghanistan and 2.2 million desyatinas in the Trans-Caspian Area. The canal route was designed to go in deep cut across the Southeastern Karakums and further on across the sand barkhans of the Karakum Desert. The project was given wide publicity; however, after construction of the Trans-Caspian Railroad, it had lost its significance. Several years later a new project was suggested for irrigation with the Amu Darya waters of the lands on the Caspian coast and turning the Trans-Caspian area into “Russian California and Russian Egypt” [6].

In 1868 the first project on partial transfer of the Ob’ and Irtysh river flow to the Aral Sea basin was developed by Russian engineer Yakov Demchenko, graduate of the Kiev University. The first alternative of the project he described in his work “About the Climate of Russia” when he studied at the 7th class of the First Kiev Gymnasium. In 1871 he published the book *About Watering of the Aral-Caspian Lowland to Improve Climate in Neighbor Countries* (the second edition of this book was published in 1900). He believed that the water level rise in the Aral and Caspian seas will help moistening the climate over a vast territory turning it into subtropics. The project of Yakov Demchenko envisaged the construction of a dam 75 m high on the Ob’ River downstream the Irtysh inflow, and the water from the formed Ob’-Irtysh reservoir would flow by gravity across the Turgai Lowland and reach the Aral Sea. However, this project had found no support either from Russia or Khiva and Bukhara rulers.

3 Large-Scale Projects of the Soviet Period

Much time has passed, and now we will try to penetrate the archive mist of the past and to resurrect some buried ideas and projects that addressed water management issues of the former Soviet republics of Central Asia that after disintegration of the Soviet Union acquired the status of independent Central Asian states.

Grand and large-scale plans and programs (not always effective) were typical of the Soviet power, and with their help, the USSR’s leadership expected to change the situation in the country within a short time period. The grand plan of the country’s electrification “GOELRO” (Russian abbreviation for “State Commission for Electrification of Russia”) was adopted on 21 December 1920 in Soviet Russia, the scheme of Volga reconstruction was prepared, and the construction of large shipping channels – Belomoro-Baltic (White Sea-Baltic Sea) Canal named after Moscow (Moscow-Volga) and others – was initiated. Further implementation of the plans was interfered with the Great Patriotic War (1941–1945). After the war the restoration of the USSR national economy required seeking for new areas where the grand ideas could be realized. And the nature proper made hints here – the draught and hunger of 1946–1947. I.V. Stalin made two “Stalin’s strikes at transformation of nature.” And one of them was the Decree of the USSR Council of Ministers and All-Union Communist Party (Bolsheviks) Central Committee “On the Plan for Planting of Shelterbelts, Introduction of Grassland Crop Rotation and Construction of Ponds and Reservoirs to Ensure High Crop Yields in Steppe and Forest-Steppe Areas of the

European USSR" that was adopted in late 1948. The Asian part of the country was not also neglected. Two years later at the end of 1950 on the initiative of I.V. Stalin, the USSR Council of Ministers passed the resolution "On Construction of the Main Turkmen Canal Amu Darya – Krasnovodsk for Irrigation and Water Supply of Lands in the Southern Circum-Caspian Plain in Western Turkmenia, the Lower Reaches of the Amu Darya and Western Karakum Desert."

Already that time it was clear that the successful coping with many national economy challenges in the USSR's Central Asian region could be possible if the ways to augment local water resources for increasing the food and cotton production were found. At the same time, the growing number of large irrigation canals that had transformed completely the hydrographic network at the exit of rivers from mountain regions became quite obvious.

The radical solution of the water problem in Turkmenistan required the conveyance of a part of the Amu Darya flow to the water-deficit southern oases of the Republic, to poorly developed desert territories suitable for farming and pasturing, to industrial centers in Western Turkmenistan. This goal was formulated still in 1925 at the First All-Turkmen Congress of Soviets that declared the formation of the Turkmen SSR as a part of the USSR.

The Congress tasked the government with finding solution to this problem. The leveling works near Kelif Uzboy confirmed that it could be used for conveyance of the Amu Darya waters. In spring 1927 during construction of the Bosaga-Kerkinsky Canal 100 km long, some Amu Darya flow was directed to Kelif Uzboy. The experiment was a success: water passed through a chain of Kelif depressions for 100 km having transformed the ordinary desert landscape in Western Turkmenia.

The issue on transfer of the Amu Darya waters came into focus again in April 1940 after the resolution "On Measures for Further Improvement of Agriculture and, in Particular, of the Soviet-Bred Long-Fiber Cotton in Turkmen SSR" was passed by the USSR Government and Central Committee of the Communist Party. However, the Great Patriotic War (1941–1945) held up implementation of these measures.

This project was returned once more when the issue on water transfer was posed anew. According to the project, the canal 1,100 km long should pass from the Amu Darya lower reaches (Takhiatash Cape) to the Caspian Sea (Krasnovodsk Bay) filling with water the dry channel of old river Western Uzboy. This canal opened new huge tracts of land (1.3 million ha) to agriculture, especially to cotton growing. In the Karakum Desert territory, this canal should provide water to 7 million ha of pasturelands in the zone of its command. The diversion irrigation and water supply canals with a total length of 1,200 km should be constructed to the irrigated fields and pastures. The pipelines should convey water to industrial enterprises, cities, settlements, and railway stations in Western Turkmenia which had satisfied their water demands with the transported fresh water. The project envisaged construction of a 100,000 KWt hydropower station. The design water intake of this canal from the Amu Darya was initially 350–400 m^3/s with its subsequent increase to 600 m^3/s. This canal should become a part of the waterway connecting the Amu Darya and Volga-Caspian basins. It would form a new shipping way of the same length as the whole navigable part of the Amu Darya (from Termez to the Aral Sea) [7].

Fig. 1 The Karakum Canal in Turkmenistan (http://web3.telecom.tm/photo/anons/1538397618.jpg) [8]

The construction of this canal was started in 1950. About 12,000 people worked there, and half of them were prisoners of Stalin's camps. In 1953 "wise architect" I.V. Stalin died, and the canal construction was abandoned. The same fate was shared by the "Stalin's plan of nature transformation," although some survived shelterbelts still "worked well" for economics. However, in 1954 the country returned to the Karakum Canal project, its southern alternative, having changed the water intake point that had been suggested still in 1920–1930. The construction of the Great Karakum Canal named after V.I. Lenin (till 1990) was initiated. After Turkmenistan became an independent state, this canal was named after S. Niyazov, the first President of the country, and in 2007 it was referred to as the Karakum River.

This is one of the world's largest and unique irrigation and water supply canals of the twentieth century. This artificial river over 1,380 km long crosses the Karakum Desert (Fig. 1). It was designed to cope with the grand problem of conveyance of 13.5 km^3 of Amu Darya flow to the water-deficit regions with vast fertile lands. It also supplied water to nearly all industrial centers of Turkmenistan, such as Ashkhabad, Mary, Balkanabat, and Turkmenbashi. This artificial river unites the Amu Darya, Murghab, and Tejen rivers into a single water management system. It also brings irrigation to around one million ha of lands. Four reservoirs 2.5 km^3 in capacity each were built on this canal mostly for accumulation of winter flow with its further use during the vegetation (simmer) period [8].

The canal construction was divided into six phases. By 1968 three phases were completed. This project stirred many disputes.

The main argument of opponents to this megaproject was its negative impact on the natural environment. In fact, in engineering terms, it was excellently designed, but the more in-depth understanding of its environmental implications posed many questions although the greater part of them could be answered only after the canal was constructed and put into operation.

It is a well-known fact that the economic effect of the project may be awaited quicker than the environmental implications. The changes in the natural situation are witnessed not at once. They become obvious after slow accumulation of their components and their aggregation, and this process in different physiographical conditions requires different time.

This canal constructed in earth cut without lining run across the Karakum sandy desert as a result the water losses for seepage were enormous. The expectations that natural clogging would resolve this problem failed, at least in the short time period. Its construction led to the formation of filtration lakes, waterlogging, overmoistening, salinization of soils, and quick growth of phreatophytes.

Later on, after 10 years of operation, the scientists of the Institute of Geography of the USSR Academy of Sciences analyzed changes that occurred in the natural environment that were caused mainly by water filtration from the canal bed through its whole run. It was noted that the impacts of the Amu Darya water transfer on the nature of Turkmenia that were assessed in the canal command area had to be taken into consideration in the development of the projects on the partial transfer of the Siberian rivers' flow to the plains of Kazakhstan and Central Asia [8, 9].

Limited water resources in Central Kazakhstan and the growing water demand for development of rich mineral resources required conveyance here of water from other river basins, first of all, from the Irtysh River, the left tributary of the Ob' River. The Irtysh basin is the main source of water in Southeastern and Eastern Kazakhstan, and it has strategic importance for water supply of the central and northern areas of the country. The total length of the Irtysh River is 3,712 km of which 405 km run in China. The main tributaries of the Irtysh are Ishim and Tobol rivers which mean annual flow within Kazakhstan is 1.4 and 1.5 km^3, respectively.

In the recent years, the sustainable water availability in Central Kazakhstan has been ensured by the Irtysh waters transferred via the Irtysh-Karaganda Canal which construction was started in 1962 and completed in 1974. This canal was the first stage of the largest water management system in Central Kazakhstan. The Irtysh-Karaganda Canal named after K.I. Satpayev 458 km long was the longest artificial river after the Karakum Canal (Karakum River). The canal was 20–50 m wide and 5–7 m deep. Its discharge varied from 76 m^3/s in the head to 13 m^3/s in its tail. In engineering terms, it was more complicated than the Karakum Canal. This canal is furnished with 22 pumping stations which raised Irtysh water to a height of 418 m to the Shiderty and Nura water divide. The water supply regime is regulated by a system of 14 reservoirs, inverted siphons, water spills, and water outlets. A total of 2.4 km^3 of water is taken from the Irtysh per year [6]. In 2002 a branch canal was constructed to the Ishim River and further on to the Vyacheslavovskoye Reservoir to

Fig. 2 Irtysh-Karaganda Canal (http://ekaraganda.kz/foto/796516cbb385d57cbb1ba254fef1e89a.jpg)

supply water to Astana, the capital of Kazakhstan (in 2019 it was renamed into Nur-Sultan) (Fig. 2).

In 1948, Soviet Academician V.A. Obruchev, the well-known geographer and novelist, wrote to I.V. Stalin about the idea of transfer of Siberian river flow to the south, but Stalin did not pay attention to this project. In the 1950s Kazakh Academician Shafik Chokin returned to this problem. In the 1960s the water use for irrigation in the Central Asian republics had grown immensely due to the population growth and extension of irrigated lands. In these years the first signs of the Aral Sea drying out and the water level drop in the Caspian Sea have been observed. Already that time various research institutes have developed several optional schemes of Siberian rivers water transfer to cope with these issues.

In 1968 the Plenum of Central Committee of the Communist Party of the Soviet Union (CC CPSU) ordered to the State Planning Committee, the USSR Academy of Sciences, and other organizations to develop the scheme of river flow redistribution. In May 1970 CC CPSU and the USSR Council of Ministers passed Resolution No. 612 “On Prospects of Development of Land Reclamation, Regulation and Redistribution of River Flow for 1971-1985” defining there the priority task of transfer of 25 km^3 of water per year by 1985 which would make 6–7% of the Ob’ River flow. More than 150 organizations were involved in the preparation of the feasibility report for the transfer project. That time the Irtysh-Karaganda irrigation and water supply canal was considered a part of the project on water conveyance to Central Kazakhstan.

In 1976 at the 25th CPSU Congress, the final design was chosen out of the four proposed alternatives. The decision on launching works for the project was approved. The West-Siberian (Turgai) alternative was given priority. It envisaged a head water intake from the Ob’ River, the world’s fourth river, with the flow of 400 km^3 to be constructed near Khanty-Mansiysk where the Irtysh River flows into it. It was considered feasible to convey water along the Lower Irtysh River as far as the head reservoir near Tobolsk City: (1) through the Irtysh channel in the anti-river regime by pumping water through the system of three low-lift waterworks; (2) through the left canal branching off downstream of the Irtysh mouth (from Belogorie village), or (3) by a combined method (anti-river-canal). In case the main waterworks at Tobolsk is constructed without a regulating reservoir, the water into the main transfer canal will be taken from the flow formed in the Upper and Middle Irtysh basin. The admissible water intake in this case depends largely on consumptive water use in the upstream river basin (Fig. 3).

The Siberian-Aral main canal for water redistribution goes from the Tobolsk Reservoir to the Turgai Depression via which in the past the waters impounded by the ancient glacier run from Western Siberia to the Aral Sea. The transferred water is lifted by five pumping stations to the water divide southward of the Kushmurun Lake after which it flows by gravity to the south. This canal that may be also used for navigation crosses the Syr Darya and goes to the Amu Darya. Its length is over 2,200 km, the average depth 12 m, width 200–300 m, the flow velocity 0.6–1.0 m/s, and the carrying capacity 1,150 m^3/s. The whole route of the canal goes mainly over a low-lying (to 200 m abs.) plain composed of thick loose sediments. Taking its origin in the forest waterlogged landscapes of the Tyumen Region, it crosses the forest-steppe, steppe, semi-desert, and desert natural zones. In the head part of the route, the Russian regions would receive 4.9 km^3 of water and Northern Kazakhstan

Fig. 3 General view of the Siberian-Aral Canal from the Ob’ River to the Aral Sea (http://cdn.mapme.club/images/2195/219513-peresyxanie-aralskogo-morya-odna-iz-uzhasnejshix-ekologicheskix-katastrof-sovremennosti.jpg)

3.4 km^3, and the Syr Darya and Amu Darya rivers would receive 16.3 km^3 for their recharge, including Uzbekistan 10 km^3. The design water losses for transportation should be 3 km^3 or 12% of the whole volume. The world practice has not known the examples of water transfer in such variegated and contrasting natural conditions.

For consideration of the Feasibility Report "Territorial Redistribution of a Part of Free Flow of the Ob' and Irtysh Rivers," the State Expert Commission consisting of the representatives of the USSR Academy of Sciences, the State Committee of the Council of Ministers for Science and Technology, and the USSR State Committee for Architecture and Construction was established at the USSR State Planning Committee which approved this Feasibility Report submitted by the USSR Ministry of Water Economy. However, in August 1986, the special meeting of the CC CPSU Political Bureau decided to abandon this project. Such decision was influenced by the numerous publications, the authors of which spoke against this project and asserted that it was too costly and disastrous for the natural environment. The project was put on the blacklist by the academic publishing "dictatorship" being not very learned in hydraulic construction and land reclamation issues who relied upon fake statistics and intellectual unscrupulousness.

Recently it has become popular the idea that the whole generation of people had grown criticizing these projects and that this negative attitude had been extended to the social and political system of the USSR which contributed to its breakdown [10].

In January 2002 Yury Luzhkov, Mayor of Moscow, made an attempt to revive "the project of the century." He sent a letter concerning this issue to Russian President Vladimir Putin in which he suggested "having revised the available developments resume consideration of the mutually beneficial use of flood and excessive waters of Siberian rivers for putting into exploitation the unused, but highly productive agricultural lands suitable for irrigation in Russia and Central Asia." In other words, he called to return to the megaproject on the partial water transfer of Siberian rivers to Central Asia that had been abandoned in 1986 by CC CPSU Political Bureau. He proposed "to return to this project at the lower cost level, but at the higher technological level on the basis of more reasonable policy and actual green thinking ..." [11]. There was no response to Luzhkov's proposal.

In September 2006 in Astana, Kazakhstan President Nursultan Nazarbayev spoke about the necessity to reconsider the redirection of the Siberian rivers to Central Asia. He repeated this idea in 2010 in Ust-Kamenogorsk at the cross border cooperation forum. "In the future this problem may acquire quite a grand scale in the face of the need to provide with drinking water the entire Central Asian region," said Nursultan Nazarbayev [12]. Earlier, in 2003 the Uzbek President Islam Karimov applied to the Russian leadership with the same proposals.

4 Megaprojects: The Dreams and Reality

The Central Asian countries have been always known for their bent for megaprojects to cope with both national and international issues concerning water management. This is connected with natural and climatic specific conditions as well as social and economic development of states suffering from high water, demographic, and ecological stress. The strategy of further development of these countries is targeted to the maximum possible mobilization of deficit water resources and search and utilization of outside water sources and all the more so, as the modern achievements in science and technology permit to address them.

At the end of the twentieth century, the prospects of the next century as the time of global civilization where such basic principles as harmony, equilibrium, and tolerance should be decisive in attaining the goals of sustainable development were outlined.

In 1977 one of the most active leaders of the Japan business, Chairman of Research Fund of Mitsubishi Corporation Masaki Nakajima, voiced the idea to establish the Global Infrastructure Fund (GIF). The fund concept is based on the globalization philosophy – promotion of global infrastructures within the frame of international cooperation through implementation of giant investment projects going out beyond the borders of national states [13]. In 1991 in his opening speech at the First GIF International Congress held in Atlanta, USA, M. Nakajima said that "we were quickly moving into the absolutely new era of construction of global peace. The GIP founders believe that this fund should become the alternative to superarmament" [14].

The Committee for Global Superproject Study of the International Association of Engineering Consultants has adopted the following criteria: non-realizable by one country; project cost exceeding 10 billion USD; their impact area should cover several countries or a vast territory; support of governmental bodies; and environmentally friendly projects. According to the US Global Development Council, the global projects are the projects of infrastructure or service facilities which implementation requires at least 1 billion dollars or the projects producing enormous global effect.

In view of stagnation of irrigation and drainage activities in Russia, all subsequent projects of the Central Asian countries cloned the Soviet project of transfer of Siberian rivers flow to the south. The first country that suggested the super-mega-futuristic project was Uzbekistan. In 1995 the Uzbek scientists from the Institute of Water Problems investigated the issue of long-time sustainability and reliability of water supply in Central Asia. They formulated the idea to construct the Single Asian Water Management System (SAWMS) that will connect the basins of Central Asian rivers: the Syr Darya in the north with the rivers of the Kara Sea and the Amu Darya in the south with basins of the rivers belonging to the Arabian Sea basin. SAWMS included the interstate mutually beneficial use of a part free flood flow of rivers of the Arabian Sea, in particular the flow from the Indus River basin [15–17].

It was envisaged to create the Arabian-Aral Water Transport Route (AAWTR) which would cross Pakistan, Iran, Afghanistan, Turkmenistan, and Uzbekistan. The water would be taken in the Indus lower reaches downstream Sukkur (Pakistan). A cascade of large pumping stations to lift water to a height of 750 m to the Iranian Plateau should be constructed in Baluchistan, Pakistan.

After pump lift the first terminal for handling cargo ships is constructed after which the gravity canal goes on and joins the Harirud River (Afghanistan). Its length is 1,700 km, depth 8–10 m, bottom width 80–100 m, and water edge width 120–130 m. Here the water intake to direct water to the Pakistan national canal is to be constructed with a cascade of hydropower plants compensating electricity consumed for water lifting and a buffer reservoir. AAWTR will be navigable in a stretch as far as the second terminal located at Kushka on the border with Turkmenistan (Fig. 4). The canal carrying capacity is provisionally taken as 60 million tons of cargo per year or 100,000 tons per day on the average in one direction.

The construction of national canals with hydropower plants and buffer reservoirs is planned for irrigation and development of arid territories in Iran (Baluchistan, Sistan, and Horasan), in the Gilgit-Arghandab Valley in Afghanistan. Along the AAWTR route, the recharge of Atrek and Tejen rivers is also possible. The Iranian Plateau and the Turan Depression will be linked via the Murghab River on which a cascade of hydropower plants will be built. Some water of AAWTR from the lower pool of the terminal power plant will be directed to the Kerki area to replenish the Amu Darya flow and to convey water to the operating Karshi main canal.

The AAWTR route may be also directed to the Termez area to replenish the flow of the Amu Darya as well as the Murghab River. The transferred volume will be 30–35 km^3 per year. The pump water lift requiring much energy will be to a height of around 700 m.

The total length of the canal will be 2,665 km, of which 1,280 km is in Pakistan, 464 km in Iran, 464 km in Afghanistan, and 457 km in Turkmenistan (compare the canal for transfer of the Ob' water to the Syr Darya and Amu Darya basins in Central Asia which is 2,550 km long).

The total cost of construction is $30 billion (in the 1990s prices); the construction will take 25–30 years. The average annual costs may amount to $1.0–1.2 billion [16].

Still more global super-mega-project was proposed by D.I. Ryskulov, Doctor of Economics, close associate of Yu.M. Luzhkov, in his report "Transasian Corridor of Development" (TRASCOR) made in Tashkent in 2008. He proposed "to create the meridional geostrategic transport ridge in the Eurasian space poorly developed economically. In other words, this will be the magnificent integrated transport artery including the shipping canal, high-speed automobile highway and railroad connecting the Yamal Peninsular via the Caspian Sea with the Persian Gulf, in short "Arctic – Persian Gulf".

This project is conceived as "the weaving of the global transit network for "catching" benefits and advantages by transport networks" [18]. It relies on the unique experience of the Great Silk Road. The TRASCOR roadmap includes the navigation canal "Asia" connecting the Kara, Aral, Caspian, and Arabian seas. The project envisages the following canal route: port Igarka – The Kara Sea – Gulf of Ob' – Turgai Depression – crossing of the Syr Darya River to the west of Djusaly – crossing of the Amu Darya River nearby Takhiatash – along Uzboy to Port Turkmenbashi (formerly Krasnovodsk) on the Caspian Sea (Fig. 4).

From here the water route goes on over the Caspian Sea to the south as far as port Enzeli in Iran and then along the canal via Khorramshahr or across the Desht-e Kaevir Desert to the Persian Gulf (Port Bandar Abbas). The total length of this

Fig. 4 Water transfer area (http://karteplan.com/turkmenistan/physische-landkarte-von-turkmenistan.jpg)

waterway from the Kara Sea to Bandar Abbas will be around 6,000 km. The design depth of the canal “Asia” will be 15 m and the width over 100 m. The water losses for seepage and evaporation are estimated at not higher than 7%.

Two other components of TRASCOR are the high-speed automobile highway Salekhard-Kurgan-Arkalyk-Kzyl-Orda (with branches off to Tashkent and to China via Kyrgyzstan and also a branch to Afghanistan via Kabul or Chābahār and further on to Pakistan)-Dashoguz (with a branch leading to Serakhs and to the Persian Gulf across Iran)-Port Turkmenbashi and the high-speed railroad Salekhard-Kurgan-Arkalyk-Kzyl-Orda (with a branch off to Serakhs and Turkmenbashi). The project designs to create forest shelterbelts 4,000 km long on both sides of TRASCOR. The total construction cost of the waterway Kara Sea-Persian Gulf (including the canal Eurasia), the railroad, and automobile highway with attending facilities may amount to $ 100–150 billion, while the construction will take 15 years; the expected average annual profit is $7–10 billion. The payback period of TRASCOR is about 20–25 years after construction commencement.

If the foregoing projects may be considered as the developments of the future and are probably hardly realizable, the works in Eastern Turkmenistan are already underway on implementation of the grand hydraulic project – creation of the Turkmen Lake “Altyn-Asyr” [19]. It was decided to accumulate the collection and drainage waters (CDW) from irrigated farming that had been recently discharged into the Amu Darya River and the Sarykamysh Lake and to divert and store them in the natural depression of Karashor in the Central Karakums having an elevation of

−28 m abs. which roughly corresponds to the current level of the Caspian Sea. This depression locates eastward of the Kara-Bogaz-Gol Bay in the Caspian Sea. Its length is 120 km, width 20 km, and area 2000 km^2 (Fig. 5).

Irrigation of agricultural lands with the Amu Darya waters generates around 6 km^3 of CDW per year, and in addition to CDW formed in the territories in neighboring Uzbekistan on the right bank of the Amu Darya River, their total amount may exceed 10 km^3 per year [19]. Some CDW waters were discharged into the Amu Darya, thus deteriorating its water quality and increasing salinity from 0.9 to 1.5 g/L, while some other CDW waters were diverted into the depressions in the Karakum Desert where they flooded and increased salinity of pasturelands reducing their areas and productivity, and still some other waters were diverted into the Sarykamysh Lake being a drainless water body.

If CDW generated in the Khorezm Province of Uzbekistan and having been discharged until now into the Sarykamysh Lake is intercepted and conveyed into the Turkmen Lake, the Sarykamysh Lake inflow may annually lose to 3 km^3 of water which certainly will affect its water balance. In 2006 the water area of the Sarykamysh Lake was approximately 4,000 km^2.

According to the project, the Altyn Asyr Lake will be filled with drainage waters supplied by two routes – the Dashoguz (northern route) Collector and the Great Turkmen Collector (southern route) (Fig. 5). The northern route should carry CDW from irrigated lands in the Dashoguz Province and a part of CDW of the Khorezm Province in Uzbekistan by the Ozerny (150 m^3/s) and Daryalyk (60 m^3/s) collectors.

Fig. 5 The Altyn Asyr Lake (Turkmenistan) (https://turkmenportal.com/images/uploads/blogs/ICC_7128%20(28).JPG)

The Dashoguz route will go across three natural depressions: Zengi Baba 2.7 km^3 in capacity, the Uzyn Shor (0.76 km^3), and Atabai Shor (0.02 km^3). Before filling, the length of the Altyn Asyr Lake will be 103 km, the width 18.6 km, the average depth 69 m, the water area around 1915.8 km^2, and the volume 132 km^3. It is planned to convey in it annually up to 10 km^3 of CDW, including from Akhala, Mary, and Lebala 3–4 km^3 by the Great (Southern) Collector and 6–7 km^3 by the Dashoguz (Southern) Collector. To attain the planned CDW inflow into the Altyn Asyr Lake, it will be necessary to increase water supply from Dashoguz having redirected a part of flow from the Sarykamysh Lake into the Northern Collector, including CDW from Khorezm Province in Uzbekistan. However, this diversion currently amounts to 1–2 km^3. The lake filling will take 15 years.

Creation of this lake will make a vital input into addressing numerous environmental and economic issues of the country: improve the condition of agricultural lands, ensure water supply of 1.5 million ha of desert pastures, use drainage waters for irrigation of 800 thousand ha of desert lands, stop discharging drainage waters into the Amu Darya, develop fisheries, promote recreational and ecological tourism, and, in general, improve the environmental security of the population.

This project about $4 billion worth is one of the world's largest in desert development through land reclamation [19]. The future will show how much such engineering solution was well-considered and correct.

5 Conclusions

Great Soviet expert in water management S.L. Vendrov contemplating the reconstruction of rivers in the USSR noted that "in the future it would be necessary to use the flow of northern rivers being remote from places of consumption, but we believed that the objective need in this would arise . . . mostly in the 21st century" [20]. This was said in 1970.

In any case Russia as a country taking one of the world's leading positions by river flow will have to take part in addressing water problems of Central Asia. It is quite unlikely that water saving in the water-deficit countries of Central Asia will do much for harmonizing the population growth and distribution and the available natural water resources. Hence, the transformation of the natural regimes of the existing river network will be required.

One of the perspective ways to deal with water issues is the international maneuvering with river flow. This will require quite serious and long-time scientific and engineering analysis of the earlier abandoned projects or consideration of new projects.

The utterly new technologies and territorial redistribution of river flow are two ways that should be considered in the future. They may complement each other depending on the geography of a region. It should be noted that the principally new technologies appear quite seldom. This urges us to undertake more intensive and in-depth development of both ways to resolve the water supply problem. Here first should go the measures for improving the efficiency of water use in the existing water supply and irrigation systems and only after this the choice of schemes for territorial redistribution of river flow.

Today we can name only one not large country in the arid zone that quite successfully realized both ways. This is Israel. This country created a specific natural-technogenic construction on the basis of which the highly productive agrotechnologies are developing. For Israel water is a strategy, security, and independence. In this country the Central Asian slogan "Drop of water – grain of gold" is materialized not in words, but in deeds [21].

River water transfer projects represent in a sense a search of new model of international cooperation and general world management in the conditions of the newly emerging multipolar world.

As well-known American geographers P. James and J. Martin wrote: "we should move ahead not repeating the mistakes of the past, but always with bold pursuit to develop new hypothesis and, at the same time, not be afraid to criticize the already developed hypotheses and may be even abandon them" [22].

Acknowledgments A.G. Kostianoy was partially supported in the framework of the P.P. Shirshov Institute of Oceanology RAS budgetary financing (Project N 149-2019-0004).

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Legal Aspects of the Water Resources Management in Central Asian Countries

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Contents

Abstract The Central Asian countries keep in focus the issues of the legal regulation of water resources use. Such great attention stems from the role of water resources in development of the Central Asian states. The ineffective management

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Igor S. Zonn, Sergey S. Zhiltsov, Andrey G. Kostianoy, and Aleksandr V. Semenov (eds.), *Water Resources Management in Central Asia*, Hdb Env Chem (2020) 105: 65–76, DOI 10.1007/698_2020_618,
© Springer Nature Switzerland AG 2020, Published online: 16 July 2020

of water resources results in depletion of the flow of rivers in Central Asia which affects the socioeconomic development of all countries in this region and aggravates the environmental issues. Moreover, the deficit of water resources in Central Asia escalates the interstate contradictions among the regional countries, thus holding up their economic development. The Central Asian endeavors on the national and interstate levels to develop the mechanism of the legal regulation of water resources management, thus attaining their rational use. But the solution of this problem is impeded by diverging interests of the regional countries that are guided solely by their national interests neglecting the requirements of their neighbors in the region.

Keywords Central Asia, Conflicts, Legal issues, Water management, Water resources

1 Introduction

In the Soviet Union, the formation and pursuance by the Central Asian republics of their independent policy was not even considered [1]. All problems of water distribution and use were addressed in a centralized manner by the USSR Ministry of Water Resources based on the unified plan of development of the regional economy and agriculture. The Soviet system of inter-republican relations in the water sphere rested upon the quotas of water sharing among them and the balance of contractual obligations between the republics and the Union center. The transboundary river flow regulation was aimed at attaining the balanced economic development of all five Central Asian republics combining such targets as power generation and development of the agrarian sector [2]. The criterion for reservoirs operation was the maximum common benefit [3].

2 Water Deficit

Appearance of the new independent states in Central Asia puts forward the issue of ownership of water as water and many other natural resources were cut by the state borders and now belonged to different countries. The water deficit and claims of each state to use them most intensively in the interests of each aggravated the situation in the region. Regarding the high birth and unemployment rates in Central Asia, the water issue became a serious factor of destabilization in the region [4].

The USSR breakup resulted in disintegration of the system of water resources management. And the most serious challenge here was water sharing [5]. The overnight collapse of the Soviet system resulted in mutual unsettled claims of the republics. These mostly include the determination of water intake volumes in the

Fig. 1 Water deficit in Central Asia (http://kabar.kg/news/nedostatok-vody-mozhet-sokratit-ploshchadi-pod-ris-v-uzbekistane/)

conditions of market economy, decreasing of investments into the water use sector, changes in the operating regimes of major reservoirs (changeover from irrigation to power generation regimes), and many other issues. Accordingly, the endeavors of the upstream countries to increase power generation contradicted the interests of the downstream countries which irrigation targeted policy required other approaches to the water use. Such conflicts and divergence of interests in the use of water-energy resources staggered the situation, both in the region in general and among individual countries, and affected the interstate relations in the region (Fig. 1).

The main factor that strained the relations among the upstream (Tajikistan, Kyrgyzstan) and downstream (Kazakhstan, Turkmenistan, Uzbekistan) countries along the transboundary rivers was the water flow regime. Kazakhstan and Uzbekistan are most industrially developed countries possessing significant oil and natural gas reserves and other mineral resources [6]. These countries have the greatest population compared to other regional states. Locating in the lower reaches of the rivers, they depend strongly on the upstream countries (Kyrgyzstan and Tajikistan) having more ample water resources and, in fact, controlling the Amu Darya and Syr Darya flows, the main waterways of Central Asia.

Water resources became the source of potential sociopolitical, ethnonational and interstate conflicts because of diverging policies of the upstream and downstream countries along the transboundary river. Tajikistan and Kyrgyzstan which, by different estimates, control 80% of all fresh water reserves in Central Asia, having considerable water resources for power generation release water not only in summer but in winter as well. The reservoirs built still in the Soviet time in the upper reaches of the Amu-Darya and Syr-Darya permit to regulate the flow going to the downstream countries. As a result, these two countries have a very powerful lever for

Fig. 2 Climate change impact on Central Asia (http://www.toptj.com/News/2019/08/21/chem-grozit-globalnoe-poteplenie-tadzhikistanu)

exerting pressure on the neighbor countries – Kazakhstan, Uzbekistan and Turkmenistan.

In Central Asia all reserves of water supply are practically exhausted. By different estimates, the annual river flow here makes around 120 km^3, and the main contributors are the Amu-Darya and Syr-Darya rivers that take their origins in the glaciers and snow of the mountains in Kyrgyzstan and Tajikistan. Meanwhile the Amu-Darya flow is regulated for 96% and Syr-Darya for over 85%. And much of the waters of these rivers cover the irrigation needs.

Climate changes influence significantly the policy of the Central Asian countries (Fig. 2). The low-water years occur with growing frequency in Central Asia, and in the foreseeable future, they may become a norm. In recent 50 years, the area of glaciers where the Amu-Darya and Syr-Darya originate has shrank by nearly 40% which cut their flow significantly. According to forecasts, by 2025 the population in the Central Asian republics will increase, which will require additional water resources [7].

The factors connected with the economic development and social processes in these republics have enormous influence. The demography remains the key issue for Central Asia. The growing population combined with the water deficit provokes conflicts among the countries and enhances their rivalry [8].

Having declared independence and taken a course to development of the market economy, the Central Asian countries started pursuing the independent policy in control and distribution of water resources. Their policies focused on their own plans for the management of the water-energy resources. Each Central Asian state followed its national interests in water resources management having low concern for how they correlated with the interests of their neighbors and how they influenced the situation in the region, in general [9].

Water resources in the Central Asian countries are one of the key factors determining the situation in many branches of the economy, first of all, in agriculture [10]. Water deficit and deteriorating quality of river flow aggravate the addressing of the socioeconomic and environmental issues. For this reason, the access to water resources has become one of the crucial issues for the regional countries [11].

3 Legal Regulation: Results and Problems

The issues of water management at the regional level had not been legally regulated so far. In the 1990s the regional countries made attempt to develop documents that would ensure the rational and fair sharing of water resources and also create conditions for their effective management. Thus, in 1992 the Agreement on Cooperation in Joint Management of Use and Protection of Water Resources of Interstate Sources was signed by the Republic of Kazakhstan, the Kyrgyz Republic, the Republic of Uzbekistan, and the Republic of Tajikistan and Turkmenistan. They arranged to respect "the established structure and principles of water sharing" and to be committed to "the effective regulatory documents on division of water resources of interstate sources."

The Agreement of March 18, 1992, did not alter the principles of management applied in the Soviet time. This document did not take into account the changes occurred after the USSR breakup. First of all, the Central Asian countries faced the lack of financing from the federal center that permitted to maintain the infrastructure performance. The decrease of funds allotted to maintenance of the hydraulic facilities affected significantly the subsequent relationships among the regional countries in the water and energy area. The countries failed to formulate on the political level the new approaches, and within the legal framework, they conformed solely to the national laws. Here the differences in approaches to water use had been revealed. The interests of the countries located in the upstream of major rivers where their flow was formed were associated with the use of the hydropower potential of the transboundary river. This policy contradicted the interests of the downstream countries which preferred the use of waters of these rivers for irrigation of agricultural crops.

Each state started developing its own legal base for water management. In 1933 the Water Code was adopted in Kazakhstan and Tajikistan. In the same year Uzbekistan passed the Law on Water and Water Use and Turkmenistan approved the Water Code. In 1994 the Water Law was adopted in Kyrgyzstan. With time on when it became clear that the regional countries failed to find the common acceptable solutions for water management, some states made improvements in their national legislations. Accordingly, in 2000–2024 the new versions of the Water Codes were adopted in Tajikistan and Kazakhstan and the new Water Law in Turkmenistan.

In 1995 the Central Asian countries made one more attempt to settle the water disputes having adopted the Nukus Declaration that stressed the importance of the previously signed agreements regulating relationships in the water sphere. The regional countries confirmed their commitment to the principle of water use in the interests of all states and the ideas of fair interstate collaboration in water issues. Later on some more documents were adopted, but they did not resolve the conflicts among the Central Asian countries. Then the Bishkek Declaration of the heads of states was made public on May 06, 1996, where the regional countries admitted for the first time the need to accelerate development of a new strategy of water sharing and economic methods of management of water and energy resources use.

In 1998 Kazakhstan, Kyrgyzstan and Uzbekistan signed the Agreement on the Use of Water and Energy Resources in the Syr-Darya River Basin. Tajikistan joined this document in 1999. This was the framework document although it sets the principles of compensations. But it did not describe the economic mechanism of relations between hydropower generation and irrigation [12]. As a result, the downstream countries started suffering the water deficit in summer when the water requirements were the highest, while in winter they had to deal with impoundment and flooding of water management facilities.

In the same year the Agreement on Cooperation in Environment Protection and Rational Use of Natural Resources was signed which stressed the need to establish the water-energy consortium in the countries of this region. The most debatable issues were the shares in this consortium and unpreparedness for compromise.

These documents failed to resolve the problem on transboundary water sharing in Central Asia as they did not contain the practical mechanisms of compensations. The downstream countries were not ready to compensate losses to the upstream countries appeared due to changes in the operating regimes of reservoirs. Moreover, each state decided to solve the arising problems in the water sphere independently and through pressure on their neighbors to get positive results for its country. In fact, this was the conflict of national development programs of all Central Asian states [13]. Accordingly, the adopted decisions and declarations did not bring the countries closer to resolving the water sharing issue and to creating the legal basis for water use. From time to time, the relations between Turkmenistan and Uzbekistan, Kyrgyzstan and Tajikistan, and Kazakhstan and Kyrgyzstan concerning the transboundary water use became rather strained. The so-called water egoism dominated in the policy of the Central Asian countries. But still the countries periodically returned to addressing this issue.

In the recent decade, the Central Asian countries had discussed the issues of the joint use and management of water resources more than once. In September 2006 Astana welcomed the unofficial summit of the leaders of the Central Asian states at which they considered the regional problems of water use. After this the Central Asian countries were seeking to address the problem of the joint water management on the bilateral basis.

Some hopes to resolve this issue appeared after in late 2016 Shavkat Mirziyoyev won the elections and became the President of Uzbekistan. He made fundamental changes in the country's foreign policy, primarily, in the relationships with the Central Asian countries. The conflicts between Tashkent and its neighbors lapsed into oblivion. Uzbekistan managed to restore its bilateral relations with the Central Asian countries, first of all, with Tajikistan and Kyrgyzstan. The approaches of these countries to settling the water and energy issues did not often coincide with the Uzbekistan's approaches. Uzbekistan was interested in resolving the problems facing the country in the water and energy sphere; however, it was not a simple task. Nevertheless, in March 2018 the Uzbek President visited Tajikistan where 27 documents were signed, including those related to the trade and economic cooperation. The presidents made public their intentions to increase in the nearest future the cargo turnover to $1 billion (for comparison, it was only $240 million in 2017). Uzbekistan said about its readiness to increase the supply of its goods to the Tajik markets. Seeking to promote its goods to the foreign market, Uzbekistan started using more actively the new mechanisms stimulating trade relations with the Central Asian countries. In particular, the intergovernmental agreements with Tajikistan and Kyrgyzstan were signed concerning the opening of credit lines of $100 million (https://podrobno.uz/cat/economic/tovarooborot-uzbekistana-so-strana/. Accessed on 2 Oct 2018).

Compared to a rather successful solution of the trade and economic issues, the discussions of the problems related to the water and energy area were not easy. As one of the potential ways here, the Uzbek side considered the possibility of extending the regional cooperation and improvement of relationships with its neighbors in Central Asia. However, the countries failed to find a compromise and arranged to continue discussions in the future.

The contradictions between Uzbekistan and Tajikistan were most acute over the construction of the Rogun HPP in Tajikistan. For a long time, Uzbekistan was against this construction. But Dushanbe (capital of Tajikistan) made attempts to implement this project relying on its own means and attracting Russian and European investments. On the part of Tajikistan, great expectations were connected with the World Bank that initially had supported the Dushanbe policy, but later on withdrawn its support. However, this did not discourage Tajikistan from building the Rogun HPP. The first block was commissioned in late 2018 and the second in 2019. Tajikistan intends to supply electricity via the territory of Afghanistan to Pakistan and India. However, this scenario is realizable only after construction of the high-voltage power transmission line that is included into the regional project CASA-1000 and other infrastructure projects. The commissioning of these facilities is scheduled to 2022 [14].

But this tension may be relieved by inviting Uzbekistan to become a shareholder in the Rogun HPP project, thus opening a possibility for Uzbekistan to participate in its management. But even in this case, the environmental issues remained acute (https://ia-centr.ru/publications/rogun-zarabotaet-uzhe-osenyu-no-ostayutsya-voprosy-i-voznikayut-novye/. Accessed on 26 Aug 2018). However, regardless of the accumulated contradictions and diverging views with Tajikistan, Uzbekistan had succeeded to settle one of the most critical issues in bilateral relations between the countries – the construction of the Rogun HPP proper. In March 2018 Shavkat Mirziyoyev said that Uzbekistan was interested in development of power generation in Tajikistan. In the joint declaration of the presidents of two countries, it was stressed that "the Uzbek side expressed its readiness to consider comprehensively the likely participation in construction of hydropower facilities in Tajikistan, including the Rogun HPP, provided the generally recognized international norms and standards for construction of such projects were observed" [15].

The retreat of Uzbekistan from its resolute non-acceptance of the Rogun HPP project which was observed until 2016 may be attributed not only to revision by Tashkent of its foreign political course. The Uzbek side is interested in purchase of electricity from Tajikistan and movement of energy-intensive enterprises to the territory of a neighboring state. The implementation of this scenario will provide considerable economic benefits to both countries.

Certain hopes of the regional countries are connected with international organizations involved in addressing the water and energy issues. In 2017 the UN Regional Center for Preventive Diplomacy for Central Asia established in Ashgabad developed the draft convention on water division in Central Asia (https://www.gezitter.org/politic/59293_rekomendatsiya_oon_po_resheniyu_vodnogo_voprosa_v_tsentralnoy_azii_. Accessed on 23 Sept 2018). This draft convention that was directed to the governments of Kyrgyzstan, Kazakhstan, Tajikistan, and Uzbekistan focused on the Syr-Darya and Amu-Darya river basins. These waterways play the crucial role in water relations of the Central Asian countries. It is quite obvious that the growing water intake of Afghanistan may exacerbate the water problems and affect the economic and political development of Turkmenistan. In general, the normalization of relationships between Kyrgyzstan and Tajikistan in water issues was assessed by Uzbekistan in terms of addressing the problems of economic development and achievement of the social stability.

4 Orientation of the Regional Countries to National Legislations

The causes of conflicts among the regional countries on transboundary water sharing should be sought, among others, in the provisions of the national legislations. In the basic legal documents of the Central Asian countries, water is described explicitly as the state-owned resource. Thus, the Water Code of Kazakhstan (Article 8) adopted in July 2003 states that water resources are the exclusive property of the state. A similar provision in contained in the Water Law (Article 5) adopted in Kyrgyzstan in January 1994. In the Water Code of Tajikistan (Article 4) adopted in December 1993, the water resources are also considered the exclusive property of the state. The Law on Water and Water Use of Uzbekistan (Article 3) adopted in May 1993 states that water resources belong to the state. A similar provision can be found in the

Water Code of Turkmenistan adopted in June 1993. With time on these documents have been revised and enlarged, but the main idea remained unchanged – the water resources are the exclusive property of the state that can regulate their use at its own discretion.

Such approach was most vivid in the upstream countries which started asserting that the water resources were in their sole possession. In 2001 Kyrgyzstan passed the Law on Interstate Use of the Water Bodies, Water Resources and Water Facilities in the Kyrgyz Republic that stressed the rights of a country to water resources and water facilities within its state borders. It also noted that water had its price. The similar stand was taken by Tajikistan that in 2001 approved the Concept on the Rational Management and Protection of Water Resources. This document identified the main directions of the water management complex development. In 2004 Turkmenistan passed the new Water Code.

In 2005 after adoption of the Water Code, Kyrgyzstan reformed its system of water resources management. The National Water Center established for this purpose was headed by the country's prime minister.

The regional countries hold on to their own ideas concerning the transboundary water use. Moreover, many national laws of the Central Asian countries as well as bilateral and multilateral agreements lacked the very definition of "transboundary river." More often such terms as "water resource," "water and energy resource," and others are applied. Such approach contradicts the international law that considers the issues of transboundary water resources and creates considerable difficulties in application of the international legislation [16].

The Central Asian states, except Kazakhstan, did not ratify the international documents, and in implementing their policy in respect of transboundary water resources, they preferred to conclude bilateral agreements. Rather vague understanding and poor application by the Central Asian states of the principles and norms of the international law in the use and protection of transboundary rivers was one of the limiting factors in addressing the problems existing in this region [17].

Each Central Asian country has governmental bodies in charge of water resources use and the system for management of water protection activities. At the same time, the intergovernmental agreements that are called to regulate the use of transboundary rivers in Central Asian failed to address successfully this problem. Accordingly, the development of a mechanism that will take into account the interests of all Central Asian countries in the use of water and energy potential remains the priority task for these states.

Regardless of the arrangements attained from time to time by the countries of this region, they still have no mechanism for joint management of water resources. The main obstacle for achieving the integrated management of the water and energy complex is the contradicting approaches to addressing the water issues. The lack of the explicitly worded legislation regulating the use of transboundary waters impedes the search for the mutually beneficial solutions. The Central Asian countries face difficulties with balancing the fuel-energy resources and water resources which each country in the region still prefer to exchange [18]. The main drawback of the water legislations in the Central Asian countries is the lack of sections stating the priority of water resources management in each regional country and at the regional level, too.

5 Conclusions

The Central Asian countries more than once made attempts to develop the legal norms regulating the water resources use. These efforts were accomplished both on the national and regional levels. The respective documents developed in the Central Asian countries are mostly declarative, do not reflect all intricacies in the relationships among the regional countries, and do not take into consideration in full measure the water use problems.

The lack of the effective mechanisms for water division, water use management and settlement of conflicts, the inadequate exchange of information on water quality, and its use hamper the regional cooperation in water use. Moreover, the littoral states try to share the benefits from access to water and not the water proper which complicates the joint use of transboundary rivers.

The Central Asian countries consider the possibility to improve the transboundary water management on the basis of the international law norms. But so far each country develops its own strategy of water use which leads to the growing rivalry in Central Asia.

In all Central Asian countries the governmental bodies demonstrate commitment to the centralized water resources management. Such approach not only reflects the established system of state management but also the crucial role of water resources in economic development of these countries [19].

Water resources management at the national level is determined by the socioeconomic and ecological situation in the countries. The legislation reflects the problem of the water deficit which tends to grow with every passing year. This very fact explains the growing attention to the issues related to the legal aspects of water resources management.

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Main Problems of Water Resources Use in Central Asia

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Igor S. Zonn, Sergey S. Zhiltsov, Andrey G. Kostianoy, and Aleksandr V. Semenov (eds.), *Water Resources Management in Central Asia*, Hdb Env Chem (2020) 105: 77–98, DOI 10.1007/698_2020_601,
© Springer Nature Switzerland AG 2020, Published online: 7 July 2020

Abstract The problems with water resources use appeared in Central Asia after 1991 when the USSR had broken up. Before this all problems concerning water use in the Central Asian republics were resolved from the center with regard to the interests of all parties and taking into account the goals and long-term plans of economic development of the Soviet Union. The Soviet system of water relations among republics was based on water sharing limits allotted to each of them and the balance of contractual obligations between the republics and the union center. The USSR disintegration entailed the breakup of the "common pot" principle, and the most sensitive issue here was water sharing.

The system that had been operating for many decades collapsed leaving a wealth of unsettled claims which were primarily connected with determination of water intake volumes in conditions of the market economy, reduction of investments into the water use sector, changed operating regimes of large reservoirs (changeover from irrigation to power generation regimes), and others.

Disintegration of the Soviet Union put forward the issue of water ownership. Likewise other resources, water happened to be divided by state borders of the new Central Asian states. The time when water was supplied free-of-charge in the USSR had come to an end. This forced the Central Asian countries to start negotiations and to become engaged in water diplomacy. However, the countries failed to reach agreement on direct pay for water, and the barter solutions were adopted: gas for water (Uzbekistan to Kyrgyzstan and Tajikistan), water for electricity (Tajikistan to Kazakhstan), etc. It is quite obvious that the actions to ensure water supply should outpace the formation of water needs or, at least, go abreast. Taking into account the time required for designing and construction the planning of such actions will take many decades.

The climate changes produce great effect on water resources and their use. It is expected that the consequences of climate changes will be witnessed in all regions of the planet, and Central Asia is no exception to this end. Central Asia covers the territory of five countries: Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, and Uzbekistan. It is situated in the center of the Eurasian continent extending over an area of 3,882,000 km^2 and supporting the population of around 72 million. It borders on Afghanistan and Iran in the south, on China in the east, and on Russia in the west and north. Further climate changes will aggravate the complicated situations that has already established here which is distinguished by low precipitations, aridity, sharp weather fluctuations, and uneven distribution of resources.

Keywords Central Asia, Climate, Conflicts, Ecology, Water resources

1 Introduction

Serious problems concerning the use of water resources being an important factor of sustainable development are found in all Central Asian countries. Here practically all reserves of water supply are exhausted. According to different estimates, the annual river flow in the region is around 120 km^3. It is provided by two major rivers of the region – the Amu Darya and Syr Darya.

The Syr Darya River flows from Kyrgyzstan via Tajikistan to Uzbekistan (including via the densely populated Ferghana Valley) and Kazakhstan, while the Amu Darya River from Tajikistan to Uzbekistan and Turkmenistan. The downstream countries, i.e., Turkmenistan, Uzbekistan, and Kazakhstan, that are rich in oil, gas, and other mineral deposits are water dependent on poor upstream countries: the share of Tajikistan and Kyrgyzstan in surface runoff formation in the region is around 85%. The flow of the Amu Darya is regulated for 96%, while of the Syr Darya for more than 85%.

In the late 1980s, the scientists stated that all waters of the Amu Darya and Syr Darya rivers were used which caused the Aral Sea disaster [1]. The possibility to restore this sea is meager, except the Smaller Aral belonging to Kazakhstan. The example of the Aral Sea should be a warning against attempts to take quick and unreasonable solutions of water problems [2]. However, the countries of this region are still committed to old relationships in the water sphere.

In the Central Asian countries, the irrigation systems are worn out enormously. The availability of great volumes of collector drainage and wastewaters after irrigation is typical of the water management systems in this region. This concerns, first of all, the Syr Darya and Amu Darya rivers. The natural river flow regime has been changed significantly as a result of intensive water intake for irrigation and other needs. For this reason every time the interstate contradictions in the region are aggravated the performance of river and water saving systems, and also the financing of their upgrading appears in the focus of attention.

Water resources in the Central Asian countries are one of the crucial factors responsible for the state of many branches of the economy, first of all, agriculture. Water deficit and deteriorated quality of river waters interfere with addressing the social and economic issues, making worse the environmental situation. For this reason the reliable access to water and availability of water in adequate quantity are of priority significance for each Central Asian state.

Accordingly, the water issue has become most pressing for the Central Asian countries. On the one hand, the river systems as well as inland seas (the Aral Sea, the Caspian Sea) unite the region, while, on the other hand, the water deficit and endeavor of each state to use water resources most intensively make the situation in the region more acute and may even lead to interstate conflicts. Around 60% of the population in Central Asia has no access to centralized water supply. According to forecasts, by 2025 it will add 40%; thus, the demand for water will also grow [3].

2 Contradictions over Water

From late 2016 the situation in Central Asia started changing which was connected with alterations in the foreign policy of Uzbekistan after Shavkat Mirziyoyev won the presidential elections. He identified new priorities in the foreign policy of the country (Fig. 1).

The need to make changes in the foreign policy was dictated by the growing number of unresolved issues in relations with the Central Asian countries, first of all, in the water and energy area. For Uzbekistan which depends strongly on water brought to the country by transboundary rivers, the settlement of water issues is most vital. Dismissing the confrontational approach to addressing this issue in relations with the neighbor states, the new President of Uzbekistan suggested some integration initiatives aimed at development of interaction mechanisms in the water and energy areas which will take into consideration the interests of all parties. In addition, Uzbekistan extended its interaction in the transport area that determines the perspectives for the country to get access to foreign markets [4].

Most acute interstate contradictions concern the water use regimes in the basins of the Syr Darya River, reservoirs of the Naryn-Syr Darya cascade, first of all, Toktogul Reservoir [5]. Water resources of the Syr Darya are divided as follows: 74% receives Kyrgyzstan, 14% Uzbekistan, 9% Kazakhstan, and 3% Tajikistan [3]. The main problem is that over 80% of the surface water resources in the region are controlled by Kyrgyzstan and Tajikistan. In the Soviet time (1965–1985), some reservoirs were

Fig. 1 Samarkand City, Uzbekistan (https://yandex.uz/collections/card/5b7f99c372221400ac569e02/)

built in the upper reaches of the rivers, and now the upstream countries can regulate the flow going to the downstream countries. Possessing such powerful lever, Kyrgyzstan and Tajikistan have a possibility to influence the neighbor countries – Kazakhstan, Uzbekistan, and Turkmenistan.

The issues of water sharing and joint use of water resources in Central Asia have been discussed for over 25 years. Still in 1993 the disagreements of the regional countries on this issue should have been resolved by the Agreement on Cooperation in Joint Management, Use and Protection of Interstate Sources of Water Resources. However, this document was not practicable as it did not propose the mechanism to alleviate contradictions. After this some more documents were adopted that also failed to settle the problem of water sharing and use. As a result, the relations between Turkmenistan and Uzbekistan, Uzbekistan and Tajikistan, and Kazakhstan and Kyrgyzstan concerning this issue were rather tense.

In case of normalizing the situation in Afghanistan that has been unstable in the recent decade and changeover to a peaceful development, this country may lay lawful claims for water intake from the Amu Darya for agricultural purposes in the amount around 10 km^3 according to the norms of the international basin law. This will decrease nearly twofold the freshwater supply of Uzbekistan and Turkmenistan which in the second decade of the twenty-first century, satisfied only 70–85% of the needs.

The attempt to find the mutually beneficial solution of the water problem was made on September 1, 2006, at the summit meeting of Kazakhstan, Tajikistan, Uzbekistan, and Kyrgyzstan held in Astana. The key issue discussed at the meeting was water problem. Each country pursued its own goals. While Kazakhstan was seeking leadership in the region, Tajikistan was concerned about improving its status of the "Central Asian partner," especially in relations with Uzbekistan. The contradictions between Tajikistan and Uzbekistan often reached the acute phase. Kyrgyzstan considered the water supply issue in the context of consolidating its positions in relations with Uzbekistan. The meeting demonstrated once again that the water issue that had not yet reached the "boiling point" was used by the countries to attain their own political and economic goals moving the water issue to the background.

The low-water years occur more and more often in Central Asia, and in the foreseeable future, they become a norm in view of the global climate warming. Meanwhile, in the recent five decades, the area of glaciers from where the Amu Darya and Syr Darya take their waters has decreased by nearly 40% which reduced significantly the flow of these rivers. As a result, the situation with the supply of the population with quality drinking water gets worse in Turkmenistan, in the south of Kazakhstan and Uzbekistan. For the lack of appropriate coordination in water use, the prerequisites for sharping the relations among Kyrgyzstan, Kazakhstan, and Uzbekistan appear from time to time.

All known ways of rational water use have their technical and economically reasonable limits. According to different estimates, it may be expected that they will provide water to the Central Asian region only by 2025. In this period the total water consumption by priority economic branches may reach such level beyond which the requirement in water may be met by decreasing the water supply for agrarian needs, which in the future will force to cut down the irrigated lands in the region.

By estimates of international organizations and experts, the main problems existing among the Central Asian states in regulation of water and energy relations which are in the base of contradictions are advisory character of decisions taken by the established regional management authorities and lack of responsibility for implementation of these decisions; lack of harmonization at the regional and national levels between the actions of water management and energy authorities; contradictions between the interests of the upstream and downstream states; lack of real interstate bodies with appropriate authorities for joint management of the water-energy resources; and lack of any unbiased party that may be an arbitrator between conflicting parties and that possesses real power to influence the decisions of the disputing parties.

3 Potential Projects for Central Asia

Water scarcity in the region spurs the interest to the projects that may ensure the required water supply from the outside. That is why the Central Asian countries turn their eyes to the north of Russia possessing enormous water reserves. It is meant here the projects on river flow transfer which provide for mutually beneficial use of water resources in geostrategical terms.

The researches and project designs conducted in the late twentieth century concerning partial transfer of the Siberian rivers' flow to Central Asia and Kazakhstan had shown that during a long time, the water would be the key factor that held back the development of production forces in the Circum-Aral area.

The main purpose of these projects should be the guaranteed water supply of the population in the region with quality drinking water, while all other requests for use of the water imported from Siberia by other water users should be unconditionally subordinate to the main purpose. In particular, the presidents of Uzbekistan and Kazakhstan discussed more than once the mutually beneficial idea of Siberian rivers flow transfer with regard to environmental, economic, and political issues.

It is regarded that water supply from Russia to the Central Asian region will resolve the problem of water deficit in some regional countries and will also bring additional earnings to Russia. The same proposal was voiced more than once by Kazakh President Nursultan Nazarbayev while speaking about revival of the Soviet project on reversal of Siberian rivers (Fig. 2).

This project assumed construction of the canal 2,550 km long, 200 m wide, and 16 m deep from Khanty-Mansi to Kazakhstan and Central Asia where 6 or 7% of the Ob flow is planned to be diverted. The proposal of N. Nazarbayev to return to this scheme is dictated by practical considerations. Kazakhstan understands that the interstate contradictions that may soon arise over water are capable to trigger the political turmoil in the Central Asian region. Without settlement of the water issue and the more so, if a wide-scale regional conflict arises over the access to water, all

Fig. 2 Irtysh River (http://obshe.net/posts/id800.html)

plans of the economic breakthrough of the Central Asian region and entering of its leading countries into the circle of global players will be challenged.

If this ambitious project is implemented, Kazakhstan will not only resolve the problem of water deficit but will also take the dominating positions among the Central Asian countries where quite soon water may become the commodity like oil. Kazakhstan leader said that soon “water will cost money” and the Asian leaders whose countries are not abound in water resources should study all aspects of this issue [3].

Uzbekistan focuses attention on the southern scheme of donor water transfer: the project on construction of the Arabian-Aral water conveyance route. This project will enable joint use of a part of the flood flow of rivers in the Arabian Sea basin having directed it with the help of pumping plants to vast dry territories in Iran, Pakistan, and Afghanistan with subsequent replenishment of the Amu Darya and Murghab rivers.

The other Central Asian country Turkmenistan located in the Karakum Desert designed the Turkmen Golden Age Lake. Upon completion of this project, the lake will span 3,000 km^2 and hold 140–150 km^3 of water which is comparable with the remaining volume of the Aral Sea. The project was designed to accumulate saline collector and drainage waters from irrigated lands of Turkmenistan and partially of Uzbekistan. This will help, in particular, to improve water quality in the middle and lower reaches of the Amu Darya by stopping disposal of drainage waters into it.

The plans of many countries to improve the life quality of their people are closely intertwined with the growing water use. At the same time, the groundwater reserves used for drinking water supply of the population are depleting, their natural recharge goes on at a slower pace, while the water demand is growing rather quickly.

4 International Experience

While the former Soviet republics are seeking ways and principles of cooperation in water use, other countries accomplish energetically the water transfer projects. In 1997 the Yellow River (Huang He) in China, one of the world's largest rivers, did not reach the sea due to water intake for irrigation in the upstream provinces. In 2003 the water level in this river was the lowest in the recent five decades. In general, out of 560 rivers and their tributaries running across the territory of China, 60 have dried out or nearing extinction.

China that is on the threshold of the water crisis implements the grand project of south-north water transfer: conveyance of around 60 km^3 of water from the Yangtze River to the north. The project cost is evaluated at US$100 billion. This project will possibly permit to make up for the water shortage in the northern provinces and Beijing. It should be noted here that the water deficit in the north of the country reaches currently to 6 km^3 per year.

In India the life of 400 million people depends on the permanently shallowing Gang River. To improve the situation with water supply, India prepared the project on rearrangement of the whole hydrographic map of the country. Similar projects are found in Spain and Mexico. There is also a project on construction of a water conduit from Russia to the north of China where the water deficit is most acute. Mongolia is also contemplating the construction of a waterway to the south of the country suffering strongly from water shortage. In the past Armenia proposed the project on selling water to Qatar by construction of a pipeline from the Araks River via the territory of Iran as far as the Karun River from where the Iran-Qatar water conduit will start off. However, this project was abandoned. Summing up the above, it can be said that many world countries suffering water deficit have come up close to implementation of the water transfer projects.

5 Conflict Potential

Very uneven distribution of water resources, which is typical of the Central Asian states, adds to tension existing among the regional countries. They locate in the zone where droughts occur from time to time, and their consequences affect, first of all, the agricultural production based on irrigation. This leads to enhancing the social tension and undermining the economic security of states, especially taking into consideration the fact that the geopolitical importance of Central Asia has grown significantly after breakup of the USSR. After declaring independence, the newly formed states took a course to development of the market economy and started pursuing their independent policy in water resources control and distribution.

The situation with water resources and their distribution in the Central Asian region may be considered as a source of potential public, political, ethnonational, and interstate conflicts. The crises occurring from time to time in the water sphere, such as deficit of drinking water in Turkmenistan (Dashoguz Region) and Uzbekistan (Khorezm Province and the Republic of Karakalpakstan) and the water level drop in the reservoir of the Shardara HPP in Kazakhstan, are capable to influence seriously the geostrategic, social, and economic situation in this region. Taking into account considerable mineral resources in these countries, a high birthrate and the continuing high unemployment as well as the availability of authoritarian political regimes, it may be expected that the water problem may turn into a serious destabilizing factor in this region.

The situation established in this region is quite specific: the most industrially developed countries with a great number of the population – Kazakhstan and Uzbekistan – are dependent in the water area on Kyrgyzstan and Tajikistan because the latter countries control, in fact, the main water arteries of Central Asia, the Amu Darya and Syr Darya rivers.

The current geopolitical and economic situation makes more difficult for the Central Asian states to achieve the transboundary balance of water resources in the interests of all parties. However, the existing probability of conflicts over water sharing in the region forces the Central Asian countries to start negotiations and to continue search for the mechanisms of cooperation that will help organization of collective management of water resources and also to develop the harmonized regional strategy of power generation.

6 Climate Changes in Central Asia

Beginning from 1980, the heat-provoked diseases or mortality is constantly growing. Currently around 30% of the world population is living in climatic conditions at which the mortally dangerous temperatures are recorded during 20 days a year [6].

One of the unfavorable consequences of the climate variability and changes is migration of the population. The people mostly move within a country and this process is caused by extreme climatic events. In 2016 around 23.5 million people moved to some other places due to disastrous weather. Similar to the past years, the greater part of internal resettlement was connected with floods or storms [7].

The intensive climate warming is observed over whole Central Asia [8]. In many areas of this region, the tendency to warmer winters and drier summers provokes the retreat of glaciers and melting of permafrost ground in the Pamir and Tien-Shan mountains. Thus, the rise of the mean annual air temperature in the recent century by less than 1°C resulted in a more than threefold reduction of mountain glaciers in Central Asia [9]. The risk of heavy precipitations, droughts, floods, and mudflows is

Fig. 3 Climate change (http://www.liderhaber.org/wow-sinyali-ve-uzaylilar-5901g-p15.htm)

growing. Such climate changes may influence the quantity and quality of water resources and their seasonal dynamics, agriculture, and human health and may aggravate the existing problems, such as desertification and degradation of ecosystems and natural resources. For the countries in the Aral Sea basin suffering from the growing water deficit, the issues related to changes of climate and water resources are crucial for their economic development and satisfying the vital needs in the future (Fig. 3).

In the recent decades, the regularities of climate changes were assessed in the National Assessment Reports of the republics within the UN Framework Convention on Climate Change (UN FCCC) and published in some documents by individual countries and for the whole territory of Central Asia. According to regional studies of temperature variations in Central Asia, it may be concluded that the climate in the region has generally became warmer. This is confirmed by the data on the temperature rise in all five regional countries. Comparison of the surface temperatures during two periods: 1942–1972 and 1973–2003 show that the mean annual temperature has increased by 0.5°C [10]. The Intergovernmental Panel on Climate Change (IPCC) notes that in the past century, the mean air temperature in Central Asia has become 1–2°C higher [11].

The temperature rise over the land and in the Northern Hemisphere is somewhat higher than over the water surface and in the Southern Hemisphere [12]. Accordingly, the pace of climate changes in Central Asia exceeds greatly the average pace observed globally.

According to the Seventh National Report of the Kazakh Republic to UN FCCC Secretariat [13], the general notion about the current changes of the temperature and atmospheric precipitations has been formed on the basis of the time series for the period from 1940 through 2015 calculated by comparison with the basic period of 1961–1990 and spatially averaged for the territory of Kazakhstan. The mean annual rate of temperature growth in Kazakhstan in this period made 0.28°C each 10 years: the highest rates in spring and autumn by 0.30 and 0.31°C per 10 years, respectively while in winter by 0.28°C/10 years. The slowest rate of temperature rise is recorded in summer – by 0.19°C/10 years [14]. Studying the linear trend of abnormal air temperatures (compared to the base period of 1961–1990) per a year, all tendencies in the series of annual and seasonal ground air temperatures are positive and statistically significant which proves the permanent air temperature rise in Kazakhstan from 1941 to 2015.

The mean annual air temperature rise is the highest in the Western Kazakhstan Region (by 0.38°C per 10 years), while the slowest in Southern Kazakhstan, Almaty, the East Kazakhstan, Pavlodar, Atyrau, Aktyubinsk, Karaganda, and Akmolinsk regions – by 0.22–0.29°C/10 years. In other regions the mean annual temperature has risen by 0.30–0.31°C/10 years.

The meteorological data for two mountain countries – Kyrgyzstan and Tajikistan – also reveal the clear-cut tendency to climate warming. In the recent five to seven decades, the temperature in the mountain regions of these countries has added on the average 0.3–1.2°C [15]. It should be noted that the rate of temperature variations in Kyrgyzstan has a nonlinear character and has demonstrated a considerable increase in the past decades. While for the whole period of observation, the rate of the mean annual temperature growth was 0.0104°C per year for the republic, then in the period from 1960 through 2010, this rate has doubled and made 0.0248°C/year, and in the period of 1990–2010, it was already 0.0701°C/year. The growth of the mean annual temperature is observed in all climatic zones and regions of the republic as well as at all elevations in the mountains [16].

In 1940–2012 the temperature in the flat territories of Tajikistan [17] has increased by 0.1–0.2°C for a decade. The highest temperature rise was recorded in Dangara and Dushanbe; on the rest territory the temperature rose by 0.5–0.8°C, in Khudzhande by 0.3°C (such small growth is due to the effect of irrigation and presence of a reservoir). In mountain regions the annual growth of temperatures was 0.3–0.5°C, except isolated areas where these tendencies are less pronounced. In the high mountain zone (above 2,500 m), the temperature has risen by 0.2–0.4°C.

In the modern period (1976–2012), the warming trend in Tajikistan was in winter +0.15°C, in spring +0.3°C and higher, in summer minor warming and cooling (zero trend), and in autumn +0.2°C per a decade. By elevation zones the warming trend in valleys and mountain regions is currently 0.2°C per a decade; in high-mountain areas, the uncertain trend is recorded.

In Turkmenistan the period of 1961–2017 was warmer by 0.5°C than the reference period (1961–1990), and the trend in this period was around 0.43°C/10 years. In the western and southern areas of the territory, the air temperature in 1961–2017 was higher than the reference by 0.5°C, in the northern and eastern areas by 0.4°C, and in the central area by 0.6°C. In winter the temperature over the whole territory of Turkmenistan has grown by 0.6°C, in spring by 0.5°C, and in summer and autumn by 0.4°C [18].

The annual tendency is indicative of the increase of the maximum temperatures, while the minimum temperature level drops. In winter the highest temperature rise was registered equaling 2.0°C [19]. The quantity of atmospheric precipitations in Turkmenistan in 1961–2017 decreased compared to the reference period (1961–1990). The regularity is visible most clearly in spring and autumn. In winter the decreased amount of frozen precipitations was recorded [20].

The rise of mean annual air temperatures in Uzbekistan goes on against high natural variability contributing to considerable year-by-year variations. The highest pace of climate warming is witnessed in the north of the republic and in large cities (0.30–0.43°C per 10 years), the lowest in the mountains (0.10–0.14°C/10 years). The moderate pace of warming is observed in the regions where in this period the irrigated lands appeared. The average rate of warming in Uzbekistan was 0.27°C per 10 years [21].

A considerable air temperature rise was observed in all seasons. However, the rate of warming in winter has slowed down in Uzbekistan. The average rise of air temperatures in the period of 1950–2013 was in winter 0.13°C, in spring 0.39°C, in summer 0.25°C, and in autumn 0.31°C per 10 years.

The results of observations over atmospheric precipitations in Central Asia are more diverging than the temperature data. IPCC did not register any clear regional tendency of precipitations [22]. The amount of precipitations varies widely in the region, including in mountain areas. According to the data contained in national reports to UN FCCC, some increase of precipitations is registered in Tien-Shan and Western Pamir and in mountain areas of Uzbekistan, while in Central Tien-Shan and Eastern Pamir, the decrease of precipitations is recorded. Unlike air temperature, the change of the precipitation regime in Kazakhstan in the studied period is quite uneven: in some regions the increase of precipitations is observed, while in others, decrease. Here the growing tendency is traced in winter, and the decrease tendency in other seasons.

There are no clear-cut tendencies of precipitation increase or decrease across Kyrgyzstan. In the northwest of the country, the precipitations are tending to increase, while in the southwestern region, the annual precipitations mostly decreased. According to the Third National Report of Tajikistan to UN FCCC, in the period from 1940 through 2012, the annual amount of precipitations has shown the 5–10% increase. However, similar to Kyrgyzstan, the amount of precipitations is varying over the territory of the country [23].

The information about precipitations falling in the territory of Turkmenistan is scant, but it is recorded their slight increase, especially in spring, while in summer the least changes were observed [24]. However, such increase is found in semidesert flatlands, while in the southern and eastern regions of the country occupied by mountains, the precipitations tended to decrease [25].

The observation data on precipitation changes in Uzbekistan are also limited, but they indicate that the climate became more humid and more intensive precipitations are recorded. Beginning from 1950, the number of days with precipitations over 10 mm has increased in flatland and piedmont areas. Small increase of the number of days with precipitations over 20 mm was observed in mountain regions [26].

Therefore, according to the national reports to the UN FCCC Secretariat, over the greater part of the Central Asian region, the temperature rise was more pronounced in winter than in summer. Observations over precipitations show their great differences; the temperature data also vary widely across the whole region, including in mountain areas.

7 Climate Change Tendencies

The comparison and generalization of data on temperature and precipitation variations for the whole Central Asian region present certain difficulties as the changes were assessed in different periods of observations, using different techniques and different reference periods (sometimes this was not noted by users or was not specified by the authors). This was also stressed by experts of IPCC (2013): the observation data of climate changes and their consequences in Central Asia were insufficient and required additional investigations to obtain the more accurate view of the climate changes in the region, including its mountain territories.

Regarding differences in the covered periods and approaches to analysis of the tendencies of climate changes applied by the Central Asian countries and international researchers [27], the data of the North EurAsia Climate Centre (NEACC) are based on the single period of observations and the single technique. To describe the intensity of climate changes, NEACC uses the gradient of the linear trend in the period from 1976 [20].

According to the data of NEACC 2018, in the Central Asian region, the mean annual temperature rises on the average from 0.18°C (in Tajikistan) to 0.35°C (in Kazakhstan, Turkmenistan) per 10 years; the greatest growth of temperatures is recorded in spring (0.33–0.70°C per 10 years) and in autumn (0.18 and 0.34°C/10 years.) In winter the linear trend of air temperature changes becomes somewhat smaller and decreases to 0.13°C (in Kazakhstan) and 0.37°C (in Turkmenistan) per 10 years. In summer, except Turkmenistan, the least temperature rise of 0.03–0.06°C/10 years is observed in mountain republics of Tajikistan and Kyrgyzstan, respectively, and 0.19°C/10 years in Kazakhstan to 0.26°C/10 years in

Table 1 The linear trend of mean annual and seasonal air temperatures (°C) averaged by territories of states in the period of 1976–2017

Country	Year	Winter	Spring	Summer	Autumn
Kazakhstan	0.35	0.13	0.70	0.19	0.34
Kyrgyzstan	0.22	0.21	0.43	0.06	0.18
Tajikistan	0.18	0.18	0.33	0.03	0.18
Turkmenistan	0.35	0.37	0.51	0.34	0.30
Uzbekistan	0.31	0.24	0.58	0.26	0.26

Source: NEACC, 2018 [20]

Uzbekistan (Table 1). The absolute minimum temperature was recorded in Kazakhstan in 2013 when the anomaly was equal to 1.94°C having exceeded the record year of 1983 with anomaly of 1.86°C which for three decades, had been the warmest year in the territory of Kazakhstan through the whole history of instrumental observations. The abnormal air temperature in 2016 was +1.66°C higher compared to the average temperatures in 1961–1990.

According to the 2018 Summary Report on Climate Changes in the Territories of the CIS Member Countries, beginning from the mid-1970s, the global and regional air temperatures had risen. In Central Asia the mean annual air temperatures rose most quickly near the Caspian Sea and in the internal regions. In the Aral Sea area and in southern desert regions of Central Asia, i.e., in the south of Kazakhstan, Uzbekistan, and Turkmenistan, the amount of precipitations has dropped by more than 5% during a decade. The most intensive temperature rise in this region was observed in spring, especially in the internal regions of Central Asia between the Aral Sea and the Balkhash Lake. The summer temperatures have increased significantly in the Caspian region and also across the whole territory of Turkmenistan and Uzbekistan. The summer warming in the east of Kazakhstan, Tajikistan, and Kyrgyzstan is not significant. The tendency to temperature rise in autumn was traced over the whole of Central Asia, in particular, in the Caspian area and in the northern regions.

In the south of Central Asia, for instance, in Turkmenistan and the Circum-Aral region, the precipitation reduction was recorded. Some increase of precipitations occurred in mountains. The smaller amount of precipitations in winter was registered in Turkmenistan and also in some areas of Northern Kazakhstan. On the contrary, the precipitations in high-mountain areas of Central Asia are growing.

In spring the amount of precipitations in the southern desert areas of Central Asia has dropped, while in the northern steppe areas, it has grown. The precipitations in summer have decreased in some areas, but increased in others, especially in mountain regions. Over a greater part of Central and Northern Kazakhstan, the precipitations in autumn have dropped by more than 5% per a decade. In this region the combination of high surface temperatures and smaller precipitations has led to the growing evaporation and lowering soil humidity, thus enhancing the risk of droughts and reduction of vegetation.

It should be noted that considerable warming even in combination with insignificant increase of precipitations results in extension of the arid zone in the desert and semidesert areas of Central Asia. These tendencies were confirmed by data from 60% of monitoring stations in Kazakhstan.

Already now the consequences of climate change are visible. The list of likely consequences of the global warming is rather large. Thus, the climate changes may be reflected in changes of the frequency, intensity, scale, duration, and terms of disastrous hydrometeorological events (DHME) which may bring unprecedented extreme events. In Kazakhstan around 148 cases of DHME [28] were recorded on the average per a year. The most frequent DHME here are strong winds, inundations/floods, heavy rains, heavy snow storms, heavy snowfalls, heavy mists, abnormal cold, abnormal heat, droughts, and dust storms. The summed-up frequency of these events is 94.3%. In 2003–2015, compared to 1990–2002, the average annual number of cases with heavy rains (49.3) has increased by nearly 2.5-fold, with heavy snowfall (24.9) by 2.7-fold. The cases with strong winds and hail also occur more frequently (by 20% and 30%, respectively). On the contrary, in the recent years, the frequency of the following DHME has decreased: heavy snowfalls 1.8-fold, heavy mists 2.7-fold, and heavy sandstorms 3.4-fold.

The effect of climate change in Central Asia is most vivid in the mountains regions where in the recent century, the area of glaciers has shrunk threefold [29]. The greatest glaciers are found in Tajikistan and Kyrgyzstan, and they are also present in Kazakhstan and Uzbekistan. The glaciers in this region which area is 27,677 km^2 (Tien Shan – 15,417 km^2, Pamir – 12,260 km^2) keep the enormous water reserves, but their annual melting rate is estimated at 0.6–0.8% [30].

In the recent five to six decades, the glaciers of Tien-Shan and Pamir which are stretching across the whole territory of Kazakhstan, Tajikistan, and Kyrgyzstan became 6–40% smaller. The intensity of glacier melting in the Tien-Shan is usually higher at small altitudes and in humid outer ranges and is lower in the eastern ranges of the Tien-Shan [31]. In the North Tien-Shan located in Kazakhstan, the glaciers are melting at a special rate; the annual amplitude of ice mass loss varies from 0.36 to 0.75% [32].

Forecasts say that melting of glaciers, permafrost zones, and snow cover will result in the decrease of water resources in Central Asia. Moreover, high temperatures and intensive precipitations will also increase the frequency and intensity of natural disasters, such as droughts, heat, floods, landslides, mudflows, and avalanches [33]. Floods affect the whole territory of Central Asia. In 1990–2011 they accounted for 48% of all registered natural disasters in the region. Only in Kazakhstan there were 300 cases of floods in 1994–2003. Floods usually occur due to abnormally heavy and long rains as well as melting of the snow cover and ice mass in mountains as well as due to breaks of glacial lakes [33]. In the recent decade, the natural disasters took toll of over 2,500 people. About 5.5 million people or 10% of the population of Central Asia fall victims of the hazards of natural disasters [33].

The greatest temperature rise and increase of precipitations are expected in the wintertime in the northern regions of Central Asia and also in the mountains of Tajikistan and Afghanistan [34]. In summer and autumn, the climate more likely will become more arid over a greater territory of Central Asia, while the highest temperature rise in summer is expected in southern regions [34].

In mountain and piedmont areas of Uzbekistan, the increase of precipitations in winter and their decrease in summer are expected, although their annual volume will most likely remain the same. The forecasts predict with greater confidence that the climate changes will result in reduction of precipitations in the whole Mediterranean region up to Iran, including the south of Central Asia [13]. However, the exception here may be the Tien-Shan and Pamir for which the global climatic models show the general reduction of precipitations, while the regional climatic models demonstrate the humidity growth tendency. Unlike IPCC data, other information indicate that the whole Central Asian region will suffer from reduction of precipitations by 3% [35].

8 Climate Changes in Central Asia in the Twenty-First Century

Assessment reports of the Central Asian republics for the UN Framework Convention on Climate Change prepared in 2014–2017 contain many different assessments of climate changes in Central Asia in the twenty-first century. There is consensus for some geographical zones, while for others the development scenarios remain uncertain.

The expected climate changes in Central Asia will be felt more sharply (and this is already observed) as the warming in the northern hemisphere has occurred and will occur at a higher pace than on the planet in general (Fig. 4).

The climate in Kazakhstan will be generally warmer and more humid. Calculations of the future changes of the air temperatures and precipitations for the periods of 2016–2035, 2046–2065, and 2081–2099 have been conducted for two scenarios of anthropogenic impact on the global climatic system: RCP4.5 and RCP8.5. In both scenarios the mean annual air temperature over the whole territory of Kazakhstan will go on growing till the end of the considered century. And in the northern part of Kazakhstan, this growth will be more intensive than in its southern part. Thus, at the end of the twenty-first century in Northern Kazakhstan where main grain-growing areas are found, the temperature growth may be 2.8–3.2°C by the milder scenario (RCP4.5) and 4.7–5.4°C by the tougher scenario (RCP8.5) compared to the period of 1986–2005.

The expected change of the amount of precipitations in Kazakhstan in the twenty-first century is not ambivalent: it may either increase or decrease. And these changes in most cases do not exceed 10–15% of the norm. In view of insignificant precipitations over the greater part of Kazakhstan, the variability of precipitations in the future may be neglected, so the existing climatic norms may be applied in calculations.

In Kyrgyzstan the forecasts predict the climate warming, but the scenarios of precipitation changes are still uncertain. The models of climate changes in

Fig. 4 Climate change in Central Asia (https://www.belnovosti.by/world/41777-konferentsiya-po-klimatu-cop21-otkrylas-v-parizhe-minutoj-molchaniya.html)

Kyrgyzstan show continuation of the current tendency of climate warming with most visible changes in the summer months and less changes in winter. According to two scenarios comparing the temperature rise at the low and high concentrations of carbon dioxide, the temperatures will rise by 2.0–2.7°C by 2040 and 4.6–6.2°C by 2,100 compared to the reference period (1961–1990). By 2,100 the summer temperatures are expected to grow by 5.3–7.0°C.

Due to the low resolution of the general circulation models (GCMs), the diversity of topography of Kyrgyzstan is not accounted for properly which makes the extrapolation of precipitation changes over the country more difficult. However, it is assumed that the slight increase of precipitations by 1.3–3.1% compared to the reference period over the whole territory of the country will occur, except the southernmost part where the amount of precipitations may drop by 2.0–3.1%. In general, the wintertime is expected to be more humid, while summer more dry [36].

The analysis data of future climate changes in Tajikistan [37] are limited, but the current tendency of climate warming will persist. The air temperature in the Pamir and Hindu Kush may rise quicker than on flatlands and in arid regions. The climatic model shows that by the end of the century, the most drastic rise of temperature – by about 5°C – compared to the reference period (1961–1990) may be expected in the south of Tajikistan and also in the mountains of Central Tajikistan and the Western Pamir. It is difficult to include the data about the impact of the mountain regions of Tajikistan on the climate into the general climate model. Consequently, there is no consensus among the forecasts showing different tendencies of future precipitations.

However, the random fall of precipitations and increase of their intensity are expected to continue. Apart from this, summer and winter will be more humid, while spring and autumn drier [28].

The climate warming and reduction of precipitations are expected across the whole territory of Turkmenistan [19]. Both climate models constructed for low and high levels of carbon dioxide emissions predict the temperature rise by approximately 2°C by 2040. It is expected that by 2,100 the temperature will go on rising by 2–3°C to 6°C. By 2020 the amount of precipitations will slightly grow, but then it will take a downward trend, and by 2,100 it may be decreased by 8–17%.

The data for Uzbekistan [21] show that the mean annual air temperatures in the country will go on growing. According to a mild scenario, the temperature by 2030 will grow by 1.0–1.4°C. By 2,100 the moderate scenario gives the global temperature rise by 3°C and the extreme scenario even by 4.9°C. Meanwhile, these data vary depending on the season and locality. In the piedmont zone, the temperatures in summer may rise by 4–5°C. The scenarios of precipitations are more uncertain than those for temperature variations. While the "high impact" scenario predicts the drop of precipitations, the "low impact" scenario forecasts their increase. But the "medium impact" scenario predicts the increase of precipitations from 40 to 50 mm in desert, steppe, and piedmont zones and their decrease by 10 mm in the mountains [38]. The conclusions presented in the National Reports of the Republic of Uzbekistan to UN FCCC state the decrease of precipitations in summer and their slight growth in winter. The enhanced precipitation intensity and increase of the number of days with heavy rainfalls are also forecasted [37].

The above results of the future climate change assessments contained in the reports of the Central Asian republics cannot be compared. The forecast assessments diverge mostly due to differences in resolution of the applied climate models, account of local conditions, and ranges of the greenhouse gas emission scenarios. These factors are most important for the future of the global climate system.

The comparable results of the assessments of climate changes in the twenty-first century are presented in SEAKS which were carried out applying the single technique. Below there are given the calculation results of future regional climate changes applying the assembly of global atmosphere-ocean general circulation models (AOGCM) of the new generation (CMIP3 – Coupled Model Intercomparison Project for atmosphere-ocean general circulation) [39].

All CMIP3 models forecast the climate warming in the Central Asian countries in the twenty-first century for all three considered scenarios. Already in the early twenty-first century, the climate warming indicators exceed the standard deviations reflecting the intermodel span of assessments. Temperature variations exceed significantly the standard deviations for the whole territory in question, even in the cold season when the existing temperature variability not connected with anthropogenic impact is especially great.

9 Conclusions

The global climate changes will have serious consequences for all Central Asian countries that locate in arid zones and that may be affected by climate changes most severely. Regardless of their territorial and climate specifics and economic development level of each of five countries, they all face similar environmental, social, and economic challenges related to climate change, such as:

- Growing water deficit and deterioration of water quality, including the quicker melt of glaciers and shrinking of a snow cover, change of the hydrographic regime of surface waters, diminishing access of population to the quality drinking water, accelerated desertification, land degradation and salinization, loss of biodiversity, growing deforestation, and also negative consequences for such key sectors of the national economies as agriculture and power generation
- Threat to irrigated farming, forecasted drop of the yields of cultivated agricultural crops, deteriorating pasture productivity, reduction of the forage base affecting the animal husbandry, changing structure of the rural population occupation, threat to the food security of the countries
- Source of tension among neighbor states in coordination and regulation of the irrigation and energy regime of water use, effect on hydropower generation which may threaten the energy security of the countries
- Growing risk of hazardous and extreme hydrometeorological events, such as hail, drught, extremely high or low temperatures, and others which may provoke more frequently the emergency situations, including rainstorms, mudflows, landslides, avalanches, floods, and droughts
- Growing hazards for the existing ecosystems and threat to biodiversity, including the shift of climatic zones and changes of habitat by flora and fauna, changes in land use and Earth's cover
- Growing risks for human health, including heat stresses, increasing risks of escalation of infectious and parasite-induced diseases which may increase the mortality rate of people

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Water Bodies and Water Resources of the Kyrgyz Republic and Challenges in Their Transboundary Use

Salamat K. Alamanov and Elena A. Markova

Contents

Abstract The article studies the geography of water bodies and water resources of Kyrgyzstan and examines the dynamics of water management related to the restructuring of the water sector under the new conditions of economic development in different countries. The article analyzes expert opinions to the Kyrgyz Republic standpoints on using transboundary water resources in Central Asia. The article presents expert recommendations for solving the problems of cross-border water sharing and offers a number of measures and activities to address them, among which international legal initiatives should play a decisive role.

Keywords Central Asia, Kyrgyz Republic, Water resources management, Water supply, Water use

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Igor S. Zonn, Sergey S. Zhiltsov, Andrey G. Kostianoy, and Aleksandr V. Semenov (eds.), *Water Resources Management in Central Asia*, Hdb Env Chem (2020) 105: 99–110, DOI 10.1007/698_2020_619,

© Springer Nature Switzerland AG 2020, Published online: 20 July 2020

1 Introduction

Water resources in the countries of Central Asia are characterized by their unequal distribution and used by the countries along the main basins of the Syr-Darya and Amu Darya rivers which cross the borders of several countries as transboundary flows.

The assessment of river water resources and the issues on their use have been the subject of disputes between governments and water management institutions in the Central Asian republics of the former Soviet Union. The collapse of the USSR in 1991 and the formation of the independent states such as Kyrgyzstan, Tajikistan, Uzbekistan, Turkmenistan, and Kazakhstan escalated disputes due to the divergence of their national interests and priorities. A unified water management system previously regulated by decisions of the Central Committee of the Communist Party of the Soviet Union met the fundamental interests of the country but impeded the development of water management in the republics.

In the post-Soviet period, the problem of water resources distribution counting rational and optimal use was under discussion at intergovernmental and regional levels, not only with the stances taken by the heads of states but also by the international organizations and the United Nations General Assembly.

The parties propose different solutions on interstate use of water resources, but they still have not reached a full understanding currently. The exchange of objective information on water resources and their use in the regions of the countries, as well as opinions on optimizing water use based on goodwill, is the only way to contribute into the convergence of positions and the mutually acceptable construction of water relations in new economic and political conditions.

2 Water Bodies and Water Resources

The basis of the hydrographic identity of the territory of the Kyrgyz Republic is river systems, the catchment areas of which are separated by watershed mountain ranges (Fig. 1).

The river basin hydrographic system of the Kyrgyz Republic consists of lakes, glaciers, groundwater, and their outlets to the surface (springs), marshes and wetlands. Being the products of orography, topography, land surface, and climate, they are in a state of interaction and mutual influence and directly involved in the watersheds water balance forming and river runoff regime. More than 2,040 watercourses over 10 km long consisting of rivers, streams, and their tributaries, with the total length about 35,000 km, form a flow on the territory of Kyrgyzstan, which occupies 198.5 km^2 (Tables 1 and 2) [1, 2].

According to our calculations, the total value of river runoff in the Kyrgyz Republic is 48.6 km^3, with return waters and runoff of sources such as "karasuu," the surface water resources are close to 52 km^3/year. The river runoff resources are

Fig. 1 Naryn River, Kyrgyzstan (https://3.bp.blogspot.com/-RF4rXJcVibc/UmZGOWfZG9I/AAAAAAAAP_8/rf4cL3OdIng/s1600/Кыргызстан+(3).jpg)

Table 1 The number and length of rivers in Kyrgyzstan [1, 2]

Watercourses gradation	Length, km	Number of watercourses		Total length	
		Number	%	km	%
Smallest	10–25	1,616	78.9	12,117	34.7
Small	26–50	321	15.7	10,916	31.2
	51–100	82	4.0	6,061	17.3
Medium	101–200	24	1.2	3,216	9.2
	201–300	1	0.05	253	0.8
	301–500	–	–	–	–
Large	501–1,000	2	0.1	1,239	3.5
	Over 1,000	1	0.05	1,186	3.3
Total		2047	100	34,988	100

unequally distributed and concentrated mostly in economically underdeveloped areas (Table 3). On average, 1 km^2 of Kyrgyzstan's area accounts for 258 thousand m^3 of water per year [1].

The most supplied by water region is Jalal-Abad, where on average 1 km^2 accounts for 386,000 m^3 of river runoff; Naryn and Talas regions, respectively, 272,000 m^3 and 246,000 m^3. One km^2 of Issyk-Kul region accounts for 244,000 m^3 of river runoff, and individually, in the Issyk-Kul basin, where most people of the region live, the resources of river runoff make 250,000 m^3. The total value of the

Table 2 Main characteristics of the Kyrgyz hydrographic systems [3, 4]

Hydrographic systems	The area of formation of river flow		The volume of average long-term runoff	
	km^2	% the catchment area of the country	km^3	%
Naryn River basin	53,700	31,4	14,6	30.0
The rivers of the Ferghana Valley	43,100	25.1	12.4	25.5
Chatkal River basin	5,700	3.3	2.74	5.65
Chui River basin	15,900	9.3	3.84	7.90
Talas River basin	8,300	4.8	1.72	3.54
Lake Issyk-Kul basin	11,200	6.5	3.96	8.15
Lake Balkhash basin	600	0.3	0.37	0.76
Tarim River basin	25,500	14.8	6.99	14.4
Kyzyl-Suu River (Western Alay)	7,800	4.5	1.98	4.10
Total	171,800	100	48.6	100

Data of the Atlas of the Kyrgyz SSR [3], hydrometeorological data from the meteorological stations of the Kyrgyz Republic, the Institute of Water Problems and Hydropower of the National Academy of Sciences of the Kyrgyz Republic [4]

Table 3 Distribution of river runoff resources by the regions [1]

Regions	Area, thousand km^2	River runoff resources			
		km^3/year	%	thousand m^3/1 km^2	Per capita, 1 thousand m^3/year, 2015–1992 2015 (1992)
Osh	29.22	6.8	13.3	233	6.0 (6.6)
Batken	16.98	2.4	4.7	141	5.55 (5.5)
Jalal-Abad	26.9	10.7	20.3	386	10.2 (14.3)
Issyk-Kul Within the basin	43.1 15.8	10.5 3.96	20.5	244 250	23.3 (24.3) 8.8 (9.2)
Talas	11.44	2.8	5.5	246	11.7 (10.7)
Naryn	52.2	14.2	27.7	272	54.2 (65.7)
Chui	18.7	4.1	8.0	219	2.3 (2.9)
Total	198.5	51.2	100	258	8.5 (11.2)

river runoff resources in the Chui Valley and Osh Region, where 62% of the country's population is concentrated, is 25.9% [1].

Unfairly forgotten when assessing the potential of the country's water resources, mineral and thermal waters have a special place among water supplies. This is due to the lack of attention to the development of their medical and socioeconomic opportunities. In the future, they should provide the population of the country with medical and health-improving resources and form a significant part of the resort and sanatorium services in the international market. Currently, more than 250 deposits of mineral waters have been identified in Kyrgyzstan. Depending on the degree of mineralization and chemical composition, they are divided into salty water and brines, carbonic, thermal silica, radon, sulfide, ferrous, and iodine bromine minerals.

Mineralization of saline waters and brines of Kyrgyzstan varies from 10 to 350 g/L. The main deposits with maximum mineralization (64 g/L) were discovered at coastal area of the Issyk-Kul basin; in the central part of the Chui Valley the Bishkek deposit with mineralization of 50 g/L; Tuz in Leilek District, 253 g/L; Jyrgalan (138 g/L); and Uch-Kashka-Chaar-Kuduk (200 g/L), the foothills and the midlands of the Issyk-Kul basin; and Uch-Terek in the Ketmen-Tobo Valley, 346 g/L. Such waters could be used as therapeutic agents in the manufacture of medicines.

Carbonic waters of Kyrgyzstan, discovered in 30 deposits, are the analogs to medical-table waters such as Borjomi, Essentuki, Narzan, and others. The content of carbon dioxide in the waters is more than 500 mg/L, their mineralization ranges within 1.8–40 g/L. Most of the deposits are located in the Fergana Ridge in the Zhazy (sections of Arkar-Shoro, Baibiche, Kara-Shoro, etc.), Tar (Kulun, Terek, Sook), Kara-Kulja (Karakol, Kara-Kulja), and Arpa (Karakol, Kyzyl-Beles) rivers' basins. Carbonated waters are spread in the Ak-Sai Valley and its mountain framing (Besh-Belchir, Usyolyok, Chatyr-Kul), in the Jumgal Valley (Kara-Keche, Chamyndy), the Issyk-Kul basin (Ulakol, Arabel, Tuura-Suu).

Siliceous thermal waters of Kyrgyzstan with temperatures from 20 to 100°C and low mineralization (0.4–2.0 g/L) are mainly confined to hydrothermal lines of regional faults of the crust, located on the northern slopes of the ridges of Kyrgyz and Teskei Ala-Too. The most famous balneo-climatic places are Kara-Balta, Alamudun, Issyk-Ata, Tuyuk, which are located on the Kyrgyz Ridge, and Jeti-Oguz, Chon-Kyzyl-Suu, Kerege-Tash, Ak-Suu (Teploklyuchenka), and Boz-Uchuk on Teskei Ala-Too. Their waters are used for treating diseases of the musculoskeletal and nervous system, gynecological diseases.

Radon waters in the country are formed in the zone of crustal faults, where radioactive mineralization is manifested. Radon waters of the Jeti-Oguz deposit located on the northern slope of the Teskei Ala-Too Ridge at heights of 2,200–2,400 m have unique characteristics. The content of radon is in the range of 10–100 nKu/L, and the water temperature reaches 20–44°C, with mineralization equal to 0.9–13 g/L. The chemical composition is chloride-sodium-calcium. The approved reserves amount to 430 m^3/s, only about 20% of which are used. Slightly radonous waters (5–14 nKu/L) of the deposits of Kara-Balta, Kokomeren, Ak-Suu (Teploklyuchenka), and Tuura-Suu are known. These waters are used for treating nervous, gynecological diseases.

Sulfide waters are confined mainly to the foothills of the Ferghana Valley. Waters of the Rishtan deposit with chloride-sulfate calcium-sodium composition, and mineralization of 3–6 g/L, contain 50–110 mg/L of total hydrogen sulfide (H_2S). The discharge of the source is 4 L/s. Mineral water of the Kyzyl-Jar area is hydrochloride sodium in chemical composition with mineralization of 4–5 g/L, containing 175–240 mg/L of H_2S. Sodium-chloride water of the Chon-Kara deposit with mineralization of 24 g/L contains 480 mg/L of hydrogen sulfide. Sulfate-chloride sodium-calcium water of the Changyr-Tash area (550 mg/L) with mineralization of

10–31 g/L is richest in hydrogen sulfide. Sulfide waters are effective in balneological treatment.

The focused discharges of ferruginous waters in Kyrgyzstan were found on the south-eastern slope of the Fergana Range, in the upper reaches of the Zhazy River basin. The highest content of iron – 120 mg/L – was recorded in the deposit of Kara-Shoro. These waters lying at a depth of 80 m, with sodium chloride in the composition, have mineralization of about 25 g/L. High iron content (45 mg/L) among the natural sources was recorded at Arkar-Shoro located in the Sabai tract, at the absolute height of 2,870 m. An increased concentration of iron is also observed in the sources of Chon-Chabai, Zhol-Chabai, Chon-Agatan – 10–20 mg/L.

There are three groups of springs, with iron content of 3 mg/L, in the Jumgal Valley in the Chamyndy River basin. In medicine, such waters are useful for treating anemia.

Iodine-bromine waters in the Kyrgyzstan are connected mainly to the oil-bearing geological foothills structures of the Fergana Valley. They were found in the basins of the Maily-Suu and Sharkyratma rivers in Nooken District at the depths of 3–4 km. Their iodine content ranges within 6–25 mg/L, bromine content – 3–390 mg/L. The water temperature reaches 55°C. These waters are sodium chloride in chemical composition with mineralization of 55 g/L and are used in hospitals for aquatic therapy [5].

3 Transboundary River Allocation Issues

After the collapse of the USSR, the Central Asian countries faced the problem with regulation of national water allocation and water resources use. Every state in the region developed their own positions on the issue to serve their national interests and raised them at the relevant international meetings.

The position of the Republic of Kazakhstan on water relations with neighboring states is characterized by its strong dependence on rivers, which bring 44% of surface water resources to the country. In his speech at the Shanghai Cooperation Organization summit in Bishkek (September, 2013) President of Kazakhstan Nursultan Nazarbayev said: “Once again I want to focus on the water problems, no one except us will resolve these problems, and we must reach a peaceful consensus. The problem does not need to be hushed up it needs to be solved jointly with the stakeholders. We encourage for talk openly about the water problems, and we are ready for further interaction and dialogue” [6, 7].

The position of the Republic of Kazakhstan in water interests in the Syr-Darya River basin are due to the following circumstances:

– Kazakhstan owns 34.3 million hectares in the basin with a population of 2.6 million people, covering two administrative regions: South Kazakhstan and Kzyl-Orda.

- The share of the region in the national gross output is about 15% and has an agrarian-raw material orientation, in which plant growing, with prevailing production of cotton, rice, and animal feedstuffs, plays the leading role.
- There are several large enterprises in the basin, which account for about 60% of the total industrial production of Kazakhstan.
- Due to land improvement in the Syr-Darya River basin, the nature and economy indicators have improved up to 1.5–2.0 times in the upper and middle reaches of the river but worsened by 2.5–3.0 times in the lower reaches.
- Kazakhstan lost large lands of the Syr-Darya and the Aral Sea deltas.
- Water interests and the position of Kazakhstan in the Chui and Talas River basins are due to the following circumstances:
- The Chui River flowing from Kyrgyzstan to Kazakhstan supplies about ⍰131,000 ha of irrigated farming lands of Kazakhstan.
- The Talas River flowing from Kyrgyzstan to Kazakhstan supplies about 63, 000 ha of irrigated farming lands of Kazakhstan.
- The population of Kazakhstan within the Chui and Talas River basins is 615 thousand people.

Further changes in water allocation are possible only by means of increasing the share of Kyrgyzstan, but to the detriment of the interests of Kazakhstan. Therefore, maintaining the existing water use pattern in the basins of these rivers meets the present and future interests of Kazakhstan.

Water interests and positions of Kazakhstan in the Karkyra River basin are based on the following circumstances: the Bestobe water reservoir is constructed on the Charyn River (it is the second tributary of the river Karkyra) ensuring the Moinak Hydro power station with 300 MW capacity and an annual average power generation of 1.027 billion kW/h; a grove of relic Sogdian ash, which has a special ecological value, is located in the valley of the Charyn River.

President Emomali Rahmon expressed the water policy and water position of Tajikistan at the International Conference on Water Cooperation [8]: “When significant water resources are generated on the territory of some states, but maximum use of these water resources falls on other states, proper cooperation on sustainable management and water resources is the key to long-term development.”

Thus, Tajikistan uses only 10–11 km^3 out of 64 km^3 of water formed on its territory, which is 10% of the total flow of the basin. Meanwhile, the country’s specific indicators of water volume and irrigated lands per capita in Central Asia are the lowest. The Water Development Strategy of the Republic of Tajikistan indicates that: “The main strategy in irrigation and drainage is the maintenance of all available irrigated lands as useable and that their current technical condition should not be reduced, land development of the remaining 856.4 thousand hectares suitable for irrigation . . . .”

Hydropower is known to be far more profitable than agriculture. For example, with current electricity tariffs in Tajikistan, the Nurek hydropower station profit is higher than the cost of the whole cotton crop in the country.

Fig. 2 Agriculture fields in Kyrgyzstan (http://www.kyrgyzkorm.kg/news/fermer-vnedrenie-kapelnogo-orosheniya-uvelichilo-urozhajnost-v-2-raza.html)

The main cause of the current problems in the water and energy sector of Central Asia is the immanent crisis in the most irrigated agriculture and irrigation which may only increase in the future due to population growth. Therefore, a further focus on the water resources use mainly for irrigated agriculture is a dead-end path for the development (Fig. 2).

More than 80 large hydroelectric power stations might be built only in Tajikistan alone. Cooperation among the countries of Central Asia is focal and the most efficient point in modern geopolitics. Joint property on the transboundary rivers may improve the relationship between economic agents and states in the water and energy sector [9].

The position of the Republic of Uzbekistan in water-related policy on the water resources use of the Syr-Darya and Amu Darya rivers was clearly identified by President Islam Karimov in his speech at the UN summit (September 2010): "It is worth considering that the Amu-Darya and the Syr-Darya rivers supply the Aral zone with water and any weakening of these rivers is a violation of the fragile ecological balance in the region. In these conditions, any construction of large hydro power stations with giant dams projects developed 30–40 years ago, at the upper reaches of these rivers, considering seismic zone (8–9) can cause irreparable damage to the environment as most dangerous man-made disasters."

His position, at the Shanghai Cooperation Organization summit in Bishkek (September 2013) was as follows: "The use of the transboundary rivers resources in Central Asia must be addressed with the interests of more than 50 million people living in the region. Any actions on transboundary rivers should not have a negative impact on water and ecological balance of the region. The current international legal framework of water use and ecology should become the basis for an effective transboundary rivers resource sharing system in Central Asia."

This position is determined by one of the most important national interests, which is to preserve the status quo in water allocation of regional and local rivers between the countries of the region and was formed in the USSR, in the interests of all union. This is related to the following circumstances:

– With the development of irrigation in the region in the middle of the twentieth century, Uzbekistan gained most of the benefits, having increased increasing several-fold the production of valuable agricultural products. If in 1960 the collection (purchase) of cotton amounted to 2,949 thousand tons, then in 1987 it increased to 4,858 thousand tons. Although the annual average flow of the Syr-Darya River generated in the Republic of Uzbekistan is about 4.1 km^3 per year, or only 11% of the total flow of the entire Syr-Darya River basin, it consumed 19.7 km^3 (53% of the river flow).
– There are six regions of Uzbekistan located in the Syr-Darya river basin: Andijan, Namangan, Fergana, Tashkent, Djizak, and Syr-darya with a total area of 59,74,000 ha (including 1,892,000 ha of irrigated farmlands) with population of more than 14 million who live off the flow of the Syr-Darya and its tributaries.
– Water interests of Uzbekistan are related to desire for using of the Syr-Darya tributaries as their own main water resources, though the sources of them are originated in the territory of the Kyrgyz Republic and regulated by water distributing agreement between Uzbekistan and Kyrgyzstan concluded during period of former Soviet Union (Naryn, Sokh, Shakhimardan, Isfairamsai, Maily-Suu, Aravansai, Padysha-ata, Kara-Daria, Kasan-Sai rivers, Toktogul water reservoir.

The position of the Kyrgyz Republic in national water relations is formulated in the Constitution of the Kyrgyz Republic; in the Law of the Kyrgyz Republic "On the interstate use of water bodies, water resources and water management facilities of the Kyrgyz Republic" (of 23.07.2001); and in the Decree of the President of the Kyrgyz Republic "About the bases of foreign policy of the Kyrgyz Republic in the field of the use of river water resources formed in Kyrgyzstan and flowing in the territories of neighboring states" of 06.10.1997 [10, 11].

The Constitution of the Kyrgyz Republic states: "The land, its mineral wealth, water resources, air space, forests, flora and fauna, all the natural resources are the property of the state."

The Presidential Decree of 06.10.1997 states "that the Kyrgyz Republic gives special importance to solving the problems of common water use, to the need to accelerate the development of new water allocation strategy and economic management levers in the field of protection and use of water and energy resources. The solution of these problems is possible only considering the interests of the Kyrgyz Republic and other interested countries through successive negotiations and the conclusion of the relevant international treaties, based on the characteristics of water use on each river flowing out of the Kyrgyz Republic. The issues of water supply, regulation of river runoff and the requiring of payment for water use or allocation of benefits from the use of water resources are the subject of intergovernmental negotiations."

The Law of the Kyrgyz Republic “On the interstate use of water bodies, water resources and water management facilities” provides market mechanisms for transboundary water management. These documents define the main provisions in the position of the Kyrgyz Republic in water policy as follows:

- The Kyrgyz Republic implements its sovereign right to ownership of water resources, formed in its own territory.
- The Kyrgyz Republic will act to change the unfair interstate water allocation in the region.
- The Kyrgyz Republic will consistently implement market mechanisms of transboundary water resources management.

Analysis and synthesis of the positions of the expert community of the Kyrgyz Republic, represented primarily by specialists of the Department of Water Resources and Land Reclamation of the Ministry of Agriculture and Water Resources of the Kyrgyz Republic, the Problem Council for Water Issues at the Institute of Water Problems and Hydropower and the Department of Geography of the National Academy of Sciences of the Kyrgyz Republic, show that the implementation of the provisions of the Decree and the Law is in an unsatisfactory condition. The weakest point in the water policy of the Kyrgyz Republic is the absence of approved National Strategy and Concept for the development of water relations with the states of a single hydrographic system of the Aral Sea. As a country that is located in the upper reaches of the river basins of Syr-Darya, Chui, and Talas and possesses water resources originated within its territory, Kyrgyzstan needs establishing a procedure for the use of these resources by adjacent countries. The conceptual document for use of water resources should become the water strategy of the Kyrgyz Republic under which water as one of the basis of life and activity of the Kyrgyz people, and in accordance with the Constitution of the Kyrgyz Republic, it is the property of the state. As a strategic goal, the National Water Policy should ensure guaranteed satisfaction of the needs of the population and sectors of the economy in water resources in the required quantity and appropriate quality in the present and future.

These provisions do not exclude that the Water Strategy should consider the paramount importance for the life and economy of the entire Central Asia region of the waters belonging to the Kyrgyz Republic. Such approach provides for the principles in relations between the Kyrgyz Republic and other states using waters rising in the Kyrgyz Republic to be established.

The Department of Water Resources and Land Reclamation of the Ministry of Agriculture, Food Industry and Reclamation of the Kyrgyz Republic and the Institute of Water Problems and Hydropower of the National Academy of Sciences of the Kyrgyz Republic developed strategic and conceptual documents on water policy, sent them to the government, but they still have not been adopted. Experts believe that the absence of the guidance documents, which determine the position of the country, is a barrier in the regulation of negotiations, which is often manifested in the inconsistency of the position of the Kyrgyz government and the fear of making responsible decisions.

According to experts, the intergovernmental treaties adopted in the period of 1992–2000 are the USSR water policy prolongation, which not only infringed national interests of the Kyrgyz Republic but prevent the development of hydropower engineering and agriculture sector of the Kyrgyz Republic [12].

At the same time, the presence of divergencies in national interests among the Central Asia countries is the main factor hindering the formation of a regional legal base of water relations. Therefore, we are far from achievement of the convergence of the positions of these countries on the global Conventions of 1992 and 1997, and regional documents too, including: Therefore, all interested parties still have not achieved a convergence of the positions, both on the global conventions of 1992 and 1997 and on the draft regional documents, including:

- The general water allocation strategy, sustainable use and protection of water resources in the Aral Sea basin (World Bank project)
- Agreements on the principles of sharing participation in cost recovery for operation and maintenance of water facilities of the joint interstate use (Kyrgyz Republic project)
- Agreements among the Republics of Kazakhstan, Kyrgyz Republic, Tajikistan, and Uzbekistan on the basic principles of cooperation in water relations (Kyrgyz Republic project)

4 Conclusions

To implement its water policy, Kyrgyzstan must take and implement a number of measures and activities, among which the following international legal initiatives should take a decisive role:

1. To continue developing and adopting multilateral regional document on water relations. Systematic negotiations on the rational distribution of the region's water resources on a mutually beneficial basis are needed. The objective of the negotiations should be development and adoption of fundamental document at the conventional level on the use of water resources in the Central Asian countries, where it is necessary to realize the potentials of the following principles of cooperation in the water sector, which have already been recognized by the states of the Aral Sea Basin: "The participating States recognize as common tasks: streamlining the system and improving the discipline of water use in the basin, developing appropriate intergovernmental legal and regulatory acts providing for the application of regional principles for the recovery of losses and damages." (Article 1 of the Agreement on joint actions to solve the problem of the Aral Sea and the Aral Sea region, environmental rehabilitation, and ensuring the socioeconomic development of the Aral region, signed by the heads of Central Asian states on March 26, 1993, in Kyzyl-Orda).
2. To continue to promote the idea of Integrated Water Resources Management for all neighboring states, together with Tajikistan, which offered to carry out

comprehensive examination of water use system in Central Asia together with the UN, including consideration of the issues of effectiveness and efficiency of the functioning of all the reservoirs and environmental situation in the region.

3. To initiate the adoption of new water allocation schemes on small transboundary rivers, flowing down the slopes of the mountains in the Fergana Valley.
4. To abandon the Almaty Agreement of 1992 that just consolidated an agreement existed in the Soviet period and to hold negotiations on revision of the terms or on a new agreement.
5. To seek payment (in terms of money) for the storage of water, water infrastructure, flood prevention, as well as compensations for unproduced energy. Arguments should be based on real calculations and discussed at a high political level.
6. To make systematic analysis and research in order to develop and propose alternative institutional mechanisms of the transboundary water energy resource management to all countries in the region.
7. To train professional experts personnel on the water problem and to pay more attention to the development of the art of negotiation, mediation, and arbitration.

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Tajikistan Water Resources and Water Management Issues

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Contents

Abstract The chapter addresses water resources, formation, use, and management in Tajikistan. The natural and geographical conditions and distribution of water resources by economic regions are analyzed. After the collapse of the Soviet Union in 1991, the problems of water use and water management in Central Asia moved to the interstate level and were accompanied by an aggravation of political relations.

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Igor S. Zonn, Sergey S. Zhiltsov, Andrey G. Kostianoy, and Aleksandr V. Semenov (eds.), *Water Resources Management in Central Asia*, Hdb Env Chem (2020) 105: 111–124, DOI 10.1007/698_2020_602,
© Springer Nature Switzerland AG 2020, Published online: 12 July 2020

Such factors as demographic growth in the countries of the region, desertification processes, and climate warming had a negative impact. This has given particular relevance to the problem of water resources management in Tajikistan.

Keywords Central Asia, Hydropower plants, Management, Regulation, Tajikistan, Water allocation, Water and energy resources, Water use

1 Introduction

Tajikistan and Kyrgyzstan have problems in accumulation and transportation of runoffs to areas with a shortage in water resources which are limited only by technical and economic difficulties, but lower reaches of the Syr Darya and Amu Darya have water shortages associated with a lack of their own water resources. At the same time, Tajikistan and Kyrgyzstan control up to 90% of the region's water resources [1]. During the period of the unified state planning and economic system, the issue of the water resources distribution between the republics of the region was resolved under the minutes of the USSR Ministry of Water Economy on the principle of "allocating water withdrawal limits" from the river trunk on an appropriate scale of the total river flow, with preference given to the main cotton producers. As a result, Tajikistan and Kyrgyzstan "received" only 25% of their own flow, but Kazakhstan, Uzbekistan, and Turkmenistan, respectively, 3.5, 5, and 12 times the amount of their own water resources.

Such water allocation hampered the exploration of new irrigated areas and the development of agriculture in Tajikistan and Kyrgyzstan, but this was offset by various supplies and the union construction of large cascades of waterworks on the Vakhsh and Naryn rivers.

After the collapse of the Soviet Union in 1991, when all states of the region gained independence and secured the right to monopoly ownership of their own natural resources in their constitutional acts, and water resources acquired the status of the most valuable economic product in the arid conditions of Central Asia, the outdated politically and economically water allocation limitation scheme continued to operate. However, water management in the new political and economic conditions required significant costs. They related to the protection of the watershed landscape, gullying prevention, river banks strengthening, and operational costs connected with seasonal, monthly, and operational regulation of the runoffs of the Kayrakkum and Nurek water reservoirs.

2 Water Resources of Tajikistan

Tajikistan occupies only 11% of the territory of Central Asia. However, more than 65% of the region's water resources are formed in the country [2]. Tajikistan is a country with the most powerful mountain ridges, starting from the Turkestan Range in the north and including the Vakhansky Range in the south. They extend in the latitudinal direction. The Academy of Sciences and Sarykolsky Ridges, extended in the meridional direction, are on average of 5–5.5 thousand meters high with individual peaks rising to marks of 6–7 thousand meters (Fig. 1).

The most water-independent states of the region are Tajikistan and Kyrgyzstan, on the territory of which the bulk of the annually renewable water resources of the Aral Sea Basin is formed: 48.7% and 25.3%, respectively. At the same time, 71.0% of the flow of the Amu Darya river is formed in Tajikistan and 75.4% of the flow of the Syr Darya river in Kyrgyzstan [3].

Despite the high rates (first place in the region and second place in the Commonwealth of Independent States after Russia), Tajikistan is experiencing quite serious problems with the availability of water resources. This is due to the extremely uneven distribution of river flow, both across the territory and with the seasons. The most severe water shortages occur in the northern and southern regions of the Republic, where the main irrigated areas and the main volume of agricultural production are concentrated. The situation is aggravated by the fact that sometimes quite rich groundwater reserves here have limited use due to pollution, increased

Fig. 1 Pamir Mountains, Tajikistan (https://pixabay.com/ru/photos/таджикистан-памир-высокие-горы-4787891/)

mineralization, and unsuitability for irrigation and household and drinking water use [2].

Tajikistan is located in the territory of the two largest river systems in Central Asia: Syr Darya and Amu Darya. All rivers in Tajikistan belong to these two river systems. The Amu Darya system also includes the basin of the Zeravshan River, which does not reach it [4].

The total volume of Tajikistan's own water resources is significant. Water reserves in the lakes reach 46 km^3, water reserves in glaciers – 460 km^3, and groundwater reserves are estimated at 6.6 km^3. The total water volume generated in Tajikistan in the Amu Darya river basin is estimated at 59.45 km^3 per year [5].

The north of the country is occupied by a part of the Syr Darya river with an area of 13.4 thousand km^2. The rest of the country (129.7 thousand km^2) is located in the Amu Darya river basin. Part of the river flow enters the territory of Tajikistan from the neighboring states.

General and specific indicators of water availability in the states of the region are formed from the annual mean runoff of the Aral Basin rivers, which is 115.6 km^3/year, including the Amu Darya river 78.5 km^3/year and the Syr Darya river 37.1 km^3/year.

3 Water Arteries of Tajikistan

In terms of absolute water availability, the largest rivers in Tajikistan are the Vakhsh, Zeravshan, Kafirnigan, and Pyanj, which waters within the borders in the border zone of Tajikistan–Afghanistan belong to two states. The specific water flow of the rivers in Tajikistan depends on the height of the watersheds and varies in wide range. The greatest specific water flow is characterized by water streams, the feeding area of which is located on the southern slopes of the Gissar, Zeravshan, and eastern Turkestan ranges (Fig. 2).

Many Tajik rivers have their special feature – mudflows are observed on almost all streams of the middle and lower tiers of the mountains. This is due to the presence in the river basins of easily soluble soil, large slopes of the channels and a significant amount in the channels and on the slopes of loose material, intense snowmelt, and heavy rains in the spring–summer period.

The duration of a mudflow hazard period within a year is on average 4–5 months; the highest mudflow activity is observed in April–June. Mudflows can carry thousands (sometimes millions) of cubic meters of rock from the mountains, sweeping and destroying everything along the route. Such were, for example, the mudflow that passed along the channel of the Zebon River (the left tributary of the Zerafshan River) in 1871 and covered Penjikent with a mud-stone mass; mudflows that passed through almost all tributaries of the river Varzob in 1961 and 1981; and mudflows throughout Tajikistan in 1969, 2014, and 2016, which caused the destruction of roads, bridges, settlements, etc.

Fig. 2 Amu Darya and Syr Darya water basins https://yandex.ru/images/search?p=4&text=Amu%20Darya%20and%20Syr%20Darya%20water%20basins&pos=245&rpt=simage&img_url=https%3A%2F%2Fi0.wp.com%2Fna.unep.net%2Fgeas%2Farticleimages%2FJan-14-figure-1.png&from=tabbar (https://na.unep.net/api/geas/articles/getArticleHtmlWithArticleIDScript.php?article_id=108)

In the territory of Afghanistan bordering on Tajikistan, only the Kokcha River with an average annual flow of 6.6 km^3/year (which significant part is taken for irrigation and household and drinking needs) reaches the Pyanj River. Other water streams are small and they are disassembled, not reaching the Pyanj River. The total runoff of the left-bank tributaries of the Pyanj River is only 15% of the total flow of the river. This is due to extremely small precipitation on the left-bank part of the basin and poor development of the hydrographic network. The flow of the Zerafshan, Kafirnigan, and Karatag–Shirkent rivers in the Surkhandarya river basin, the Vakhsh without the Kyzyl-Suu River flow, and the right-bank tributaries of the Pyanj River are completely formed on the territory of Tajikistan.

The total flow passing through the territory of the Republic is 65.1 km^3. 64.0 km^3 of this volume are formed within Tajikistan, including 50.5 km^3 in the Amu Darya river basin and 0.8 km^3 in Syr Darya river basin. The Panj, Vakhsh, Kafirnigan, and Zeravshan rivers give the main runoff. In general, it is Tajikistan where about 43% of the total flow of the Aral Sea Basin is formed [6]. Table 1 shows the long-term runoff of the largest rivers in Tajikistan [2].

Table 1 Water resources of the largest rivers (km^3) [2]

River basin	Average long-term annual runoff	Including formed within Tajikistan	Water extraction	Volume used	Losses
Panj	33.4	17.1	1.97	1.5	0.47
Vakhsh	20.2	18.3	4.6	3.5	1.1
Kafirnigan	5.1	5.1	2.5	1.95	0.55
Karatag	1.0	1.0	0.64	0.38	0.26
Zeravshan	5.3	5.1	0.43	0.4	0.03
Syr Darya	15	0.8	2.96	2.6	0.36

4 Drainage Basin of the Amu Darya River

The water drainage area of the Amu Darya Basin, despite its southern position and high snow line, is characterized by an exceptionally large distribution of glacier covering and permanent snow cover. The territory of Tajikistan accounts for about 50% of the area of glacier covering throughout Central Asia. The area occupied by glaciers in Central Asia is 8.5 times the glacier covering of the Greater Caucasus and 28 times of Altai [1].

In total, there are almost ten thousand glaciers in Tajikistan with a total area of about 8,500 km^2. Glaciers with an area of up to 1 km^2 make up 80% and an area of more than 1 km^2 – about 20% of their total number. The main area of glacier covering is glaciers larger than 1 km^2 – up to 85%. Small glaciers, despite their large number, are only 15%. In length, the most widespread glaciers – about 60% of the total number – are the glaciers of 2–6 km [7].

In river basins, the majority of glaciers and the largest area of glacier covering are attributed to the Amu Darya Basin, 82% and 84%, respectively – far less is glacier covering of the Zeravshan River Basin, Lake Karakul Basin, and the Markansu River [8]. Table 2 shows the distribution of glacier covering for the basins of some rivers.

The largest area of recent glaciation in the region is Pamir, the glaciation area of which is almost 7,900 km^2, which is 3.5 times greater than the glaciation of the entire Caucasus. With the same snow-line elevation – 4.4–4.5 km above sea level – the West Pamir glaciation (6,400 km^2) is four times the area of the East Pamir glacier covering, which confirms the extremely low moisture of the latter.

Table 2 Distribution of glacier covering for the river basins of Tajikistan [8]

River basin	Number of glaciers		Glaciation area	
	Number	%	km^2	%
Kafirnigan	380	4.0	85	0.3
Zeravshan	1,225	14.0	575	7
Vakhsh	2,595	26.0	3,150	57
Panj	4,700	50.0	2,960	29
Lake Karakul and the Markansu River	575	6.0	555	7
Sum total	9,475	100	7,325	100

There are 16 glaciers of more than 15 km in length and 7 glaciers of over 20 km in length in the Pamirs. The largest glacier, one of the largest valley glaciers in the world, is Fedchenko Glacier which has about 77 km in length with the area of 907 km^2.

Another vast glacial zone is Gissaro-Alai and Zeravshan. The total area of the numerous glaciers of this zone, together with firn fields, is about 1,500 km^2. The largest glacier here is Zeravshan. Its length is 24.7 km. The glacier's feeding area lies at an altitude of 4,200–5,000 m.

The alpine, sharply crossed relief has a strong influence on climatic and hydrological processes. First of all, the relief is a powerful condenser of moisture, which causes the development of a dense hydrographic network in Tajikistan. There are 947 rivers of more than 10 km in length, 4 of which are more than 500 km long, 16 are 100–500 km long, and more than 10 thousand small rivers are less than 10 km long situated on the territory of the country.

5 Water Resources of Lakes in Tajikistan

In addition to rich river resources, about 72% of all lakes of the Amu Darya Basin are concentrated in Tajikistan. In total, there are 1,449 lakes in Tajikistan with a total surface area of 716 km^2 (0.5% of the republic territory) and a total water volume of 46.5 m^3. Most of them have an area of not more than 1 km^2. 78% of the lakes are located in mountainous regions at an altitude of 3,500–5,000 m. Until recently, lakes have been poorly studied due to their inaccessibility [9].

Lakes of Tajikistan are nonuniformly distributed, and the conditions for their formation are most favorable in the highlands, characterized by slow flow and the presence of permafrost. By the origin of the hollows, the lakes are divided into tectonic, glacial, dam, karst, and floodplain. In the mountains, most of the lake basins arose as a result of tectonic processes, glaciers, or landslide activities. The largest lakes, especially of dammed and tectonic origin (Sarez, Zorkul, Karakul, Yashilkul, etc.), are distributed mainly in the East Pamirs in the basins of the Bartang, Pamir, and Gunt. The total area of the water surface of these lakes is 634.42 km^2, i.e., 90.7% of the area of all lakes of the Pamir and Pamir-Alai (Fig. 3).

At an altitude of over 1,000 m, there are 1,435 lakes with a total area of 702.0 km^2. Most of the lakes, both in number (585) and in the area they occupy (640 km^2), are located on high plateaus and in the river valleys of the East Pamirs. The largest of them is the drainless bitter Lake Karakul with an area of 364 km^2 and a depth of up to 236 m. Initially, water in the lake was fresh, and then it began to salt out due to the dissolution of saliniferous rocks. The lake water contains salts of sodium chloride, potassium, sodium sulfate, magnesium sulfate, etc.

Besides the Karakul, many lakes of the Pamir can be attributed to glacial lakes: Lake Chapdara at an altitude of 4,529 m, Lake Zorkul 4,126 m, Lake Turamtaykul 4,213 m, etc. On the Shugnan Ridge, there is a so-called lake plateau, on which at an altitude of 4,100–4,200 m, there are hundreds of small- and medium-sized deep

Fig. 3 Iskanderkul Lake, Tajikistan (https://yandex.ru/collections/card/5afb12dbe3226fdcb9323265/)

lakes that remained in hollows after the disappearance of glaciers. Lake Iskanderkul, widely known for its beauty, in the Zeravshan Basin is also of glacial origin. It is located in a woodland among the mountains at an altitude of 2,200 m, its area is about 3.5 km^2, and the maximum depth is up to 72 m. Landslide lakes are widespread in the highlands of central and eastern Tajikistan. The large lakes of the Pamir – Lake Sarez and Lake Yashilkul – also belong to this type.

In recent years, Lake Sarez, which was formed in a narrow mountain basin after a massive rock fall, has gained worldwide fame. This phenomenon was caused by a 9-magnitude earthquake in the valley of the river Murghab in February 1911. In October 1997, an international conference on the problems of the Sarez was held in Dushanbe with the participation of scientists from near- and far-abroad countries, at which it was recognized that the scale of possible consequences in the event of a lake breakthrough (due to soil mobility) would be catastrophic and they could be attributed to the environmental problems of the world community. The most promising proposals related to the use of Lake Sarez as a recreational zone, that is, a zone for recreation, tourism, and hunting. However, first of all, the problem of lake safety should be solved. This task, both economically and technically, is extremely difficult and practically unsolvable without the help of other Central Asian states.

6 Hydropower Potential Management

Significant water resources present Tajikistan with increasing the efficiency of their management and use for energy and irrigation purposes. The main issues for water resource use of Tajikistan until the 1990s of the twentieth century were hydroenergetics and, above all, the use of significant water resources. Their total potential reserves are estimated at 527 billion kWh. In the specific relation, it is 2,100 thousand kWh per 1 km^2 of territory.

The largest hydropower facility in Tajikistan is the Nurek hydroelectric station on the Vakhsh River with an installed capacity of 2.7 million kW. Earlier in the 1960s and 1980s, the long-term plans included the construction of eight hydropower plant cascades on the Vakhsh River with a total installed capacity of 8 million kW and, on the Pyanj River from Khorog to the mouth of the cascade, also of eight hydropower plants with a total installed capacity of 16.6 million kW. In total, it was supposed to bring a total capacity of large hydropower plant cascades for complex energy and irrigation purposes to 550–600 million kW. However, these plans were subsequently adjusted [10].

Nevertheless, in the past century, the number of reservoirs with a volume exceeding 100 million m^3 has increased by 74 times, and their total volume has grown by 459 times [11]. For Tajikistan, the rational use and management of reservoirs can increase the returns on investment and ensure the socioeconomic call of the times. The total capacity of 11 existing reservoirs in the country in recent years has been 15.68 km^3, efficient – 7.605 km^3, and the total surface area of the reservoirs is 706.7 km^2 (Table 3) [9].

During the period of intensive irrigation, the existing water-collecting areas operate according to the irrigation regime, regulating the natural hydrological regime of the rivers.

Table 3 Characteristics of water-collecting areas on the rivers of Tajikistan [9]

Total capacity	Efficient	Year	Volume, km^3		Surface area, km^2
			Total capacity	Efficient	
Farhad	Syr Darya	1947	0.33	0.2	46.0
Kayrakkum	Syr Darya	1956	4.16	2.67	520.0
Muminabad	Obishur	1960	0.031	0.030	2.86
Golovnoye	Vakhsh	1962	0.095	0.024	7.5
Selbur	Kyzylsu	1964	0.031	0.027	2.3
Kattasay	Kattasay	1965	0.055	0.036	2.9
Nurek	Vakhsh	1979	10.5	4.5	98.0
Daganasay	Syr Darya	1981	0.028	0.014	2.8
Baipazin	Vakhsh	1986	0.125	0.087	8.04
Sangtudin					
1	Vakhsh	2010	0.25	0.012	9.6
2	Vakhsh	2013	0.75	0.005	6.7
Sum total			15.68	7.605	706.7

The main drawback in the operation of water-collecting areas located on the territory of the country is their intensive siltation, which exceeds and advances project-related volumes and terms by 2–3 times. This is explained by the increased turbidity of the rivers, a large amount of suspended particles in the flow of power water, etc.

The management of irrigation systems in Tajikistan in the period 2016–2025 involves further water sector reform, the transition to integrated water resources management in river basins, and the creation of basin water management structures, including for amelioration and irrigation [12].

7 Climate Impact on Water Management

Climate change will have a major impact on water management. Due to climate change, water resources in the northern lowlands of Central Asia may decrease in the first half of the twenty-first century [13]. In mountainous areas, runoff up to 2030 will vary within the limits of natural variability, and by 2050 it may decrease by 7–17% [14]. In the future, as the water reserves in the glaciers decrease and the losses in the surfaces of the river basins freed from ice increase, the flow of water into the river due to mountain glaciation degradation can decrease. As a result of the almost complete mountain glaciation degradation, expected in the last decades of the twenty-first century, the water resources of mountain regions will decrease by 10–12% [14].

The problem of glacier degradation in the mountainous regions of Central Asia arose in the second half of the twentieth century. However, at that time the main attention was focused on the development of new lands. When distributing water resources between the Soviet Republics, the specialization of each region was mainly taken into account in the context of a planned economic system.

Although Tajikistan has significant reserves of water resources, their consumption in the country is low. Of the total runoff generated in the country, only 18% or all of 11.3% of the water runoff in the Aral Sea Basin is consumed. Of this volume, more than 83% of the water resources is accounted for irrigated agriculture. Only 4.5% goes to the needs of industry, and 3.5% goes to household and drinking water supply. 8.2% goes for other needs [15].

8 Water Management and Energy Potential of Tajikistan

Kazakhstan, Kyrgyzstan, Tajikistan, and Uzbekistan signed a framework agreement on the joint use of water and energy resources of the Syr Darya river basin (1998). It was supposed to regulate the exchange of energy in the autumn–winter and spring–summer seasons and compensatory actions. However, this agreement hardly works.

The analysis of Tajikistan's energy supply problem shows that there is no alternative to hydroenergetics in the country. Oil and gas fields here are mostly thin and scattered, whereas relatively large reserves require deep drilling and are not yet technically and economically accessible. On the other hand, hydrocarbons are not a renewable source of energy. At the same time, small hydropower and solar energy can be widely used at the household level. At the same time, only power plants created on large water-collecting areas can make the basis of Tajikistan's energy supply. In addition to generating large volumes of electricity, such areas regulate runoff for irrigation or other purposes, as well as protect the underlying territories from catastrophic floods and mudflows.

The complexity of water management is the main obstacle to the resolution of numerous regional, internal, and local conflicts. It is insoluble for the parties involved. Five Central Asian states (Tajikistan, Kyrgyzstan, Turkmenistan, Uzbekistan, Kazakhstan) are divided into the countries of the upper reaches of the Amu Darya and Syr Darya rivers, provided with water (Tajikistan, Kyrgyzstan), and the lower reaches (Turkmenistan, Uzbekistan, Kazakhstan), facing water shortages.

One of the important tasks of Tajikistan in solving environmental and food security in the region is the construction of large hydropower plants. The construction of large hydropower plants, with reservoirs, on the one hand, will strengthen the country's real energy potential and, on the other hand, will increase the level of regulation, in terms of safety and avoiding natural disasters and, therefore, the controllability of water resources in river basins [16].

The development of the untapped Vakhsh River energy resources and the construction of the Pyanj hydroelectric power station cascade may become a qualitatively new stage in mutually beneficial cooperation on energy between the Russian Federation, Tajikistan, and other Central Asian countries.

At the same time, some scientists indicate a number of problems. In particular, they note that "the future of the Amu Darya also depends on the possible use of the river and its two main tributaries – the Vakhsh and Pyanj Rivers, hydropower potential. Planned, as well as already under construction hydropower plants, such as Rogun HPP, for example, can already at the filling stage have an impact on runoff, comparable to the effects of climate change and population growth. The modes of their subsequent work may introduce even greater uncertainty without clear mechanisms for coordination" [17].

To date, the regulation of water runoff in the region and the management of water resources in Central Asia are one-sided. Regulation of runoff means the implementation of measures for the efficient use of water in land masses along the entire length of the river basins. Downstream countries overspend water in enormous proportions. Uzbekistan alone overruns irrigation water in the amount of 7–8 km^3 of water yearly.

The construction of large hydropower plants and water reservoirs in the region, on the contrary, will eliminate the phenomenon of water shortages in the lower reaches, provided that the irrigation water is used there carefully. During the construction of the Rogun Hydroelectric Power Station and the water reservoir, only 5% of the water is taken annually from the volume of the Vakhsh River flow during the entire period of filling the reservoir.

Since 2017, Uzbekistan has changed its position regarding the Rogun hydropower plant, moving away from harsh criticism of Tajikistan [18].

9 Conclusions

In the future, countries of Central Asia along with Russia can address the water and energy problems of the region on the basis of integration. The use of hydropower has led to a significant reduction in the use of coal, oil, and wood and reduced emissions of harmful substances into the atmosphere on a large scale. On the other hand, demographic growth in Central Asian countries, regional climate change, desertification processes, water shortage, and their consequences will have a negative impact on the sustainable development of the economies of Central Asian countries. These factors will exacerbate the problem of water resources management in Tajikistan.

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Current Hydropower Potential of Kazakhstan

Lidiya A. Parkhomchik

Contents

Abstract The article considers the strategy of Kazakhstan toward hydropower facilities development, as well as defines the current achievements of the country in the water management. The author pays special attention to the national strategy of the Kazakhstani government in the sphere of the renewable energy sources development giving detailed information about the role of the hydropower plants in the further increase of the total energy generation in the country. The article also highlights specific features of the hydropower sector development in Kazakhstan focusing on evaluation of exciting and projected facilities in the three hydropower resource-rich regions of the country.

Keywords Electricity generation, Hydropower potential, Kazakhstan, Large and small hydropower plants, Renewable energy sources

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Igor S. Zonn, Sergey S. Zhiltsov, Andrey G. Kostianoy, and Aleksandr V. Semenov (eds.), *Water Resources Management in Central Asia*, Hdb Env Chem (2020) 105: 125–142, DOI 10.1007/698_2020_620,
© Springer Nature Switzerland AG 2020, Published online: 22 July 2020

1 Introduction

As an energy-rich developing country, Kazakhstan is deeply concerned over its role in the global energy security. The second wave of the world economic crisis (2011–2012) accompanied with the sharp drop in oil prices clearly demonstrated the necessity for Kazakhstan to accelerate the process of moving from a hydrocarbon-oriented economy to diversified and "green" energy technologies-oriented model of economic development. In recent years the strategy on the extension of the scope of the renewable energy sources (RES) could be considered as one of the key action areas of the Kazakhstan's government regarding the energy complex modernization. Increased attention paid to the establishing of a stable complex of RES in Kazakhstan is reflected in shaping relevant legislation that provides opportunities for local and foreign investors to implement projects on construction of the energy generation facilities with the use of the RES.

Despite the fact that the technical implementation of the renewable and alternative energy sources such as solar, wind, water, and geothermal heat, which could be used for the electricity generation, faces many difficulties during the process of their further integration into the national energy system, the Kazakhstani authorities are looking forward to increase the installed capacity of the RES in total energy generation of the country. Kazakhstan intends to update and develop much of its infrastructure over the coming 20 years by implementing green technologies. Actually, there is a strong political momentum to move toward green economy.

For instance, Kazakhstan-2050 Strategy and other strategic program documents declared ambitious goals to achieve 50% share of alternative and renewable energy by 2050 in its power generation sector, as well as to decrease energy intensity of GDP by 10% by 25% by 2020 compared to 2008 baseline [1]. In fact, the strategy was announced by the First President Nursultan Nazarbayev during his annual state of the nation address on December 15, 2012. It calls for widespread economic, social, and political reforms to position Kazakhstan among the top 30 global economies by 2050. Nowadays, Kazakhstan is going to implement several landmark projects aimed at contributing to sustainable development of its renewable energy strategy such as the Green Bridge Partnership Program.

To date, the hydro energy segment is the most developed renewable and alternative energy source in Kazakhstan. The hydropower generation facilities installed both in the Soviet and post-Soviet periods play an important role in the power sector of the country. According to the International Energy Agency (IEA), the gross electricity production by the hydropower plants (HPP) in Kazakhstan increased from 7,366 GWh in 1990 to 11,210 GWh in 2017 (Fig. 1) [2]. As of January 1, 2019, the total installed capacity of Kazakhstan's power plants was 21,901.9 MWh; the available capacity was 18,894.9 MWh [3].

According to the International Renewable Energy Agency (IRENA), in 2018 the installed capacity of hydropower plants in Kazakhstan amounted to 2,755 MW, which is 0.2% of world total (Fig. 2). Actually, Kazakhstan ranks third among the

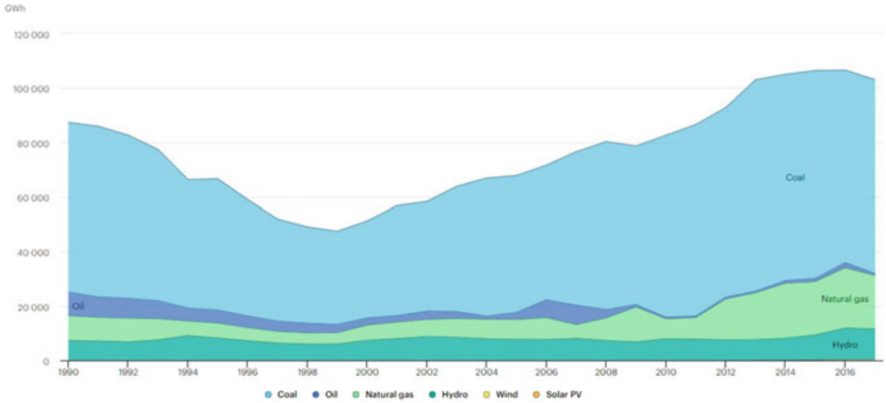

Fig. 1 Electricity production in Kazakhstan by fuels in 1990–2017 (GWh). Source: IEA Energy Statistics (https://www.iea.org/statistics/)

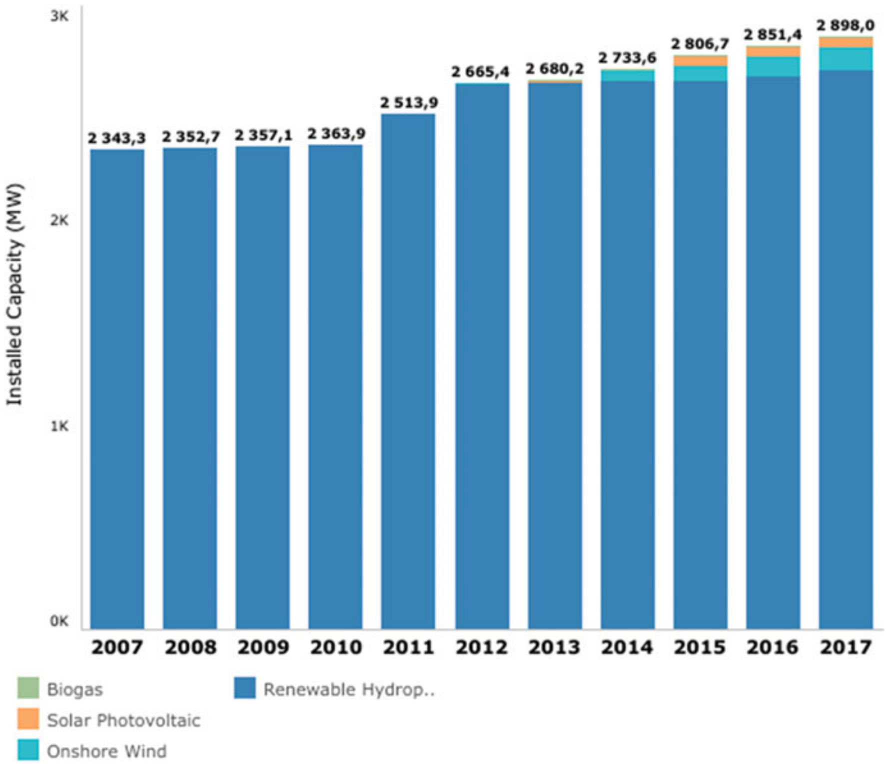

Fig. 2 Kazakhstan's renewable power capacity in 2000–2017 (MW). Source: IRENA (http://resourceirena.irena.org/gateway/countrySearch/?countryCode=KAZ)

Central Asian countries after Tajikistan (5,631 MW) and Kyrgyzstan (3,679 MW) in terms of installed hydropower capacity [4].

Therefore, further development of hydropower production fully corresponds with the Nur-Sultan's ambitious green economy plans. Consequently, there is no doubt that Kazakhstan will continue to improve its hydropower system by developing and implementing more profitable and less capital-intensive technologies.

2 National Legislation Related to the RES Development Strategy

Kazakhstan is the first Central Asian state, which started to develop policies that contribute to transitioning to a low-carbon economy. For instance, in 2009 within the framework of the Kyoto agreements, Kazakhstan adopted voluntary commitments to reduce its greenhouse gas emissions to 15% by 2020 and to 25% by 2050 below 1990 levels. Adopted in 2009, the law on the support of renewable energy has established the legal basis for promoting the use of renewable energy sources for gross electricity and heat production in Kazakhstan. In particular, the law provides investment preferences for implementation of the renewable energy projects and establishes strategic priorities that would facilitate transition to green energy. In accordance with the strategic plan on development of Kazakhstan till 2020 approved in February 2010, the share of alternative energy sources in total of Kazakhstan's energy consumption should have reached 1.5% by 2015 and more than 3% by 2020. Within the framework of the state program of industrial-innovative development of Kazakhstan for 2010–2014, the government sets goals, according to which the renewable energy production should reach 1 million MW per year in 2014 and power consumption of green energy is to amount more than 1% of total consumption.

In order to stimulate the innovative researches in the energy sector, the Center for Energy Research (CER) was established in the Nazarbayev University in 2011. It is expected that the CER would become the leading research center in Central Asia in the field of renewable energy technologies, energy, physics, and technology of high-energy, numerical modeling of the energy balance and its impact on the environment and climate [5]. Therefore, the state program of industrial-innovative development of Kazakhstan for 2015–2019 approved in August 2014 pays special attention to the Nazarbayev University activities, whose role would be to develop basic, applied and technological research and developments in the field of energy efficiency, renewable energy, and environmental protection.

However, the real movement and positive developments in relation to renewal energy strategy implementation took place in 2013 after approval of the Concept for Transition of Kazakhstan to Green Economy. For instance, in accordance with the Green Economy Concept, up to 50% of investments that is to be allocated in the energy sector in the amount of around $50 billion by 2030 and around $100 billion by 2050 would be assigned to renewable and alternative energy. Moreover, the Concept aims to bring the share of renewable energy in electricity generation to 3% by 2020 rising to 30% by 2030 and 50% by 2050. However, it should be highlighted that the Concept prioritizes development of the renewable energy facilities through building wind and solar power plants achieving 10% of wind and solar plants in the total volume of electricity generation by 2030 with installed capacity of 4.6 GW for wind and 0.5 GW for solar [6].

As far for the hydropower potential development within the Concept, Kazakhstan relies on construction of small hydropower plants with installed capacity below 1 MW. It also should be noted that there are ambitious plans on modernization of large hydropower plants operating in the country. Since the HPPs are already widely used in the energy generation, the Ministry of Energy of Kazakhstan annually prepares a detailed plan of action addressing the problems faced by the hydropower sector.

For instance, in accordance with the ministerial action plan for development of the RES for 2013–2020, it is expected that over 106 renewable energy facilities with installed capacity of 3054.55 MW should be created. It is expected that Kazakhstan will have a total hydropower capacity of 539 MW, bringing the number of new small hydropower stations to 41 toward the end of 2020 [7].

In order to reduce costs of electricity generated by renewable energy sources, the government decided to implement the auction system that would enable the Ministry of Energy to choose renewable energy projects offering the lowest prices. The auction winners are entitled to sign a 15-year contract with a single renewable electricity purchaser. In fact, the auction system was successfully implemented in the United Arab Emirates, Saudi Arabia, Chile, and Mexico, where a record low price for electricity generated by RES was registered. Kazakhstan's first auction of investment projects for the construction of generating facilities that operate using RES was held on May 23, 2018. According to the approved schedule, the total capacity planned for the auctions in 2018 was 1,000 MW, namely, 620 MW, 290 MW, and 75 MW for wind, solar, and hydroelectric power stations, respectively [8].

It is understandable that with the auction system Kazakhstan planned to attract foreign investors and give impetus to the development of renewable energy. According to the Kazakhstan Electricity and Power Market Operator (KOREM), the government received 3,204 MW in offers from a total of 113 companies. However, as a result of auctions held in May and October, Kazakhstan has awarded only 857.93 MW of green power supply contracts via tenders in 2018. KOREM reported that 500.85 MW were contracted for wind power stations, while solar, hydroelectric, and bio power stations were contracted for 270 MW, 82.08 MW and 5 MW, respectively.

As a result, there is a clear vision of how the sector should be improved. However, it is worthy of notice that Nur-Sultan has just started the process of shifting from traditional energy source-oriented economy toward development of the renewable energy facilities. Therefore, it should not been expected that transitioning the economy and power sector toward sustainable development occurs in the short term.

3 Practical Issues

Despite increasing interest in renewable alternatives due to their environmental sustainability and economic development potential, Kazakhstan's energy mix is still dominated by fossil fuels [9]. The total electricity generation in the country decreased by 3.3% from 93.9 billion kWh in 2014 to 90.8 billion kWh in 2015 reaching 93.9 billion kWh in 2016. In 2017 and 2018, 103.14 billion kWh and 106.79 billion kWh of electricity were produced in Kazakhstan, which is 9% and 4.3% increase compared to the previous year.

The volume of electricity consumption in the country amounted to 90.85 billion kWh in 2015, which is 0.9% decrease compared to 2014. However, in 2016 and 2017, the electricity consumption in Kazakhstan increased to 91.1 billion kWh and 95.4 billion kWh, respectively, reaching 103.2 billion kWh in 2018. Recent increase in electricity production shows that the country is on its way to overcome a general decline in rates of the economic development caused by low oil prices and Russia's economy recession. Despite the current slowdown in economic activity, the Kazakhstani larger institutional and commercial consumers of electricity could manage to increase their energy consumption.

As it is shown in Table 1, hydropower accounts for approximately 9.7% of Kazakhstan's total generating capacity delivering around 10.3 billion kWh from the large and small hydropower plants in 2018. The amount of energy generated by the hydropower plants decreased to 11.1 billion kWh in 2017, while in 2016 the total amount of generated hydroelectricity reached to 11.6 billion kWh. Accordingly, there is a trend for systematic decrease in the share of hydropower plants in total electricity production from 12.3% in 2016 to 10.9% in 2017 and 9.7% in 2018 [10].

Table 1 Energy generation in Kazakhstan by sources 2016–2018, million kWh

Power station type	Energy generation	Share in total production	Energy generation	Share in total production	Energy generation	Share in total production
	2016		2017		2018	
Thermal power stations	74,702.8	79.41%	82,424.8	80.5%	86,795.1	81.27%
Hydropower stations	11,605.9	12.34%	11,157.9	10.9%	10,343	9.68%
Gas power plants	7,407.6	7.87%	8,372.6	8.2%	9,119.3	8.54%
Wind power plants	274.1	0.29%	338.5	0.33%	400.5	0.38%
Solar power plants	86.1	0.09%	89.8	0.09%	137.9	0.13%
Total	*9,4076.5*	*100%*	*102,383.6*	*100%*	*106,797.1*	*100%*

Source: KOREM (www.korem.kz)

Table 2 Energy generation by small hydropower stations in Kazakhstan in 2015–2019, million kWh

	2015	2016	2017	2018	First half of 2019
Small hydropower stations	524.03	577.5	649.1	807.4	393.8
RES in total	*703*	*927.9*	*1102.4*	*1,352*	*922,95*

Source: Ministry of Energy of Kazakhstan (www.energo.gov.kz)

Actually, Kazakhstan systematically implements projects related to small hydropower stations commissioning. For instance, due to putting into operation over 14 renewable energy projects with a total capacity of 119.9 MW in Almaty, Akmolinskaya, Zhambyl, Kostanay, Kyzylorda, and Turkestan regions, in 2015 the amount of electricity generated by renewable energy sources increased by 22% to 0.704 billion kWh. This figure continued to increase in 2016 and 2017 reaching 1.3 billion kWh in 2018 (see Table 2).

During 2015, Kazakhstani authorities could manage to implement a number of hydropower projects such as Intumak HPP with a capacity of 600 kW in the Karaganda region, Ryszhan HPP with a capacity of 2 MW in the Turkestan region, and Karash HPP and Upper-Baskan HPP in the Almaty region with a capacity of 125 kW and 4.2 MW, respectively. Furthermore, in 2016 the Almaty region's authorities launched small hydroelectric power stations with a capacity of 17 MW located on the Lepsy River in Sarkan district. Two more HPPs with a total capacity of 13 MW will be commissioned in the Almaty region in 2020. The Verkhne-Baskanskaya HPP-2 and Verkhne-Baskanskaya HPP-3 would have capacity of 8.8 MW and 4.2 MW, respectively [11].

The Zhambyl region's officials have already confirmed their intention to install four chains of small hydropower stations in Koksai of Zhualyn district in addition to the hydropower plant at the Tasotkel reservoir with capacity of 9.2 MW and Karakystak HPP with capacity of 2.3 MW launched in 2013 [12].

We need to specify that recently established small hydropower facilities are classified by the Kazakhstani authorities as the RES. However, large- and medium-sized hydropower plants are mostly categorized separately from the RES causing problems in relation to provision of reliable statistic data on the issue of Kazakhstan's hydropower potential development.

4 Kazakhstan's Water Basins

According to the United Nations Development Program research, there are four major hydrologic regions in Kazakhstan, namely, the Ob River basin, the Caspian Sea basin, the Aral Sea basin, and internal lakes. It is worth mentioning that water resources are extremely disproportionately distributed within the country and are marked by significant seasonal dynamics. For instance, the Balkhash-Alakol and Irtysh River basins in the east and northeast regions account for almost 75% of

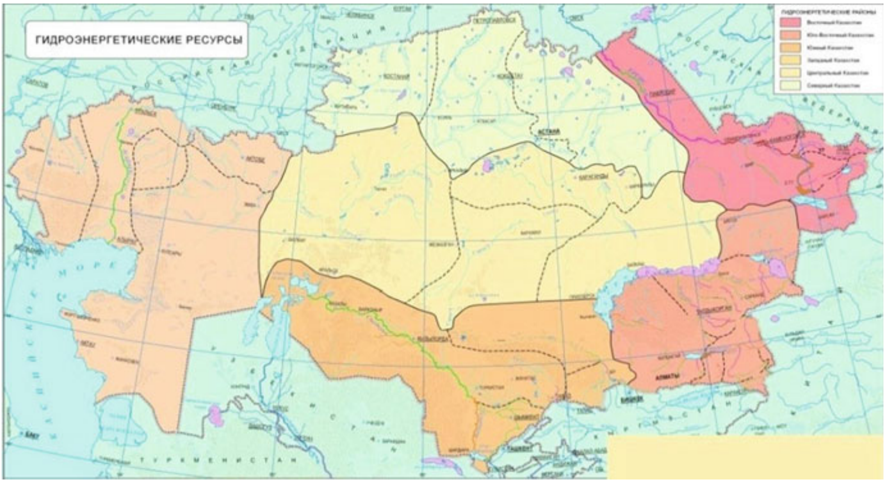

Fig. 3 Hydropower resources of Kazakhstan. Source: KazEnergy Annual Energy Report 2015 (www.kazenergy.com)

surface water resources generated within the country, while the western and south-western regions are significantly water deficit. About 90% of the runoff occurs in spring, exceeding reservoir storage capacity [13]. To date, there are eight main river basins in Kazakhstan (Fig. 3):

- The Syr Darya river basin
- The Balkhash-Alakol basin
- The Chu-Talas-Assa basin
- The Irtysh River basin
- The Nura-Sarysu basin
- The Ishim River basin
- The Tobol-Torgai basin
- The Ural-Caspian basin [14]

As stated in the Aquastat Report presented by the Food and Agriculture Organization of the United Nations, Kazakhstan is under the strong tendency toward possible reduction of surface water resources in the country [15]. This indicates the need for Kazakhstan as the downstream state to regulate the water management issues with China, Russia, and Kyrgyzstan (Table 3).

To overcome persisting problems between China and Kazakhstan in managing their 24 shared rivers, the parties entered a period of long-term negotiations in 1999. The water talks resulted in signing the first agreement on water cooperation in 2001. The next set of key agreements was signed from the mid-2000s onward [16]. In fact, the Kazakh-Chinese Joint River Commission managed to ink agreements on cooperation, management, and operation of the joint waterworks facility Dostyk on Khorgos River. However, key agreements on water allocation and distribution of cross-border rivers are still in the course of preparation.

Table 3 Kazakhstan's system of water management agreements

River basins	Secured by the agreements with
Chu-Talas-Assa	Kyrgyzstan
Irtysh	China
Balkhash-Alakol	China, Kyrgyzstan
Tobol-Torgai	Russia
Ural-Caspian	Russia
Syr Darya	Uzbekistan

Source: prepared by author

As for the Kazakh-Russian water cooperation, it could be stated that partners launched quite constructive interrelations. In 1992, Kazakhstan and Russia signed the agreement on the shared use and protection of transboundary water objects. However, there was still a problem of establishing an intergovernmental system for assessment and monitoring the water resources of joint basins. The issue was addressed in 2010 by inking a new intergovernmental agreement [17]. Indeed, the parties introduced more control of the quality of water flown to Kazakhstan and Russia, paying special attention to the Irtysh River basin.

Since all facilities for the transboundary Chu and Talas rivers' regulation are located upstream in the territory of Kyrgyzstan, this determines the necessity for Kazakhstan to establish a legal basis for the joint water management. Under agreements signed in 1992 and 2000, the parties established the bilateral Commission on the Use of Water Management Facilities of Intergovernmental Status on the Chu and Talas rivers. Nowadays Nur-Sultan and Bishkek are trying to strengthen their activities in the use of water resources and related ecosystems [18].

According to the estimations, over 66% of total water withdrawal in Kazakhstan, mainly from the Syr Darya, Ili, Chu, Talas, and Irtysh rivers, is used for agriculture including irrigation and livestock, while 30% is used for industry. The rest 4% is used for human consumption. Actually, nowadays Kazakhstan faces the necessity to improve the regional water strategy and strengthen measures for preservation of the resource potential of the river system and its ecological security. Moreover, one of the main aims of water management is to decrease the volume of water consumed and to implement efficient water-saving technologies in order to overcome the anthropogenic effects on water resources and to prevent possible reduction of surface water sources in Kazakhstan.

5 Current and Potential Hydropower Facilities

According to the current estimations, the total hydropower potential of Kazakhstan is 170 billion kWh per year, while its technical potential, which is a part of the total potential that can be efficiently utilized, amounts to 62 billion kWh per year, and its economic hydropower potential is over 27 billion kWh annually. However, Kazakhstan generates over 8 billion kWh annually on average [19]. As it can be seen in

Fig. 4 Energy generation facilities in Kazakhstan. Source: SEEPX Energy (http://www.kazenergy.com/upload/document/energy-report/NationalReport15_English.pdf)

Fig. 4, there are three hydropower resource-rich regions in the country, namely, the Irtysh River basin with the large hydropower stations (Bukhtarma, Shulbinsk, Ust-Kamenogorsk), the Ili River basin (Kapshagai, Moinak), and basins of the Syr Darya, Talas, and Chu rivers (Shardarinsk).

As it was already mentioned, due to their low cost, reliability, and apparent environmental friendliness [20], the lion share of the small- and medium-sized hydropower projects is fulfilled in the East Kazakhstan, Turkestan, Zhambyl, and Almaty regions. In fact, the local authorities of the Almaty region have already formed a special program for the development of hydropower potential. According to the program, three HPPs with a total capacity of 26–29 MW each would be commissioned on the Kara River. Moreover, as result of the research made by a specialist in the Turkestan region, over 43 potential locations for small HPP on 20 rivers with a total capacity of 119.84 MW were indicated. For instance, to date, the Memorandum of Cooperation on construction of two small HPPs with a total capacity of 4.2 MW on the Mashat River in Tyulkubas district of the region was signed with the Turkish company Endustriyel Elektrik Elektronik [21].

There are 2,174 rivers longer than 10 km with a total length of more than 83.2 thousand km in Kazakhstan; 90% of them are small rivers, making construction of small HPPs economically feasible. According to the results of studies, 100 rivers out of 2000 are suitable for construction of small HPPs. Currently, there are at least 453 potential small HPPs with a total potential capacity of 1,380 MW which could be constructed in the country. It also should be admitted that some of them could be built by using the existing irrigation canals that would reduce costs, resources, and the time spent on their construction. Economic potential of small HPPs is about 10% of the total economic potential of renewable energy sources; however, less than 0.1% of this potential is being used [22].

5.1 The East Kazakhstan Region

More than 40% of the Kazakhstani water resources are concentrated in the East Kazakhstan region. There are about 885 rivers with a total length of more than 10 km in the region. The main waterway of the region is the Irtysh River with three largest HPPs in the country, namely, Bukhtarma, Shulbinsk, and Ust-Kamenogorsk. In 2017, the total production of energy in the region amounted to 9.999 billion kWh, 74% of which, or 7.437 billion kWh, was generated by three largest HPPs in the country. Produced energy is usually consumed by local citizens and partly exported to Russia. Moreover, the oldest cascade of the HPPs in Kazakhstan, namely, Leninogorsk Cascade, was constructed in 1928, located in the East Kazakhstan region. In fact, the lowest price costs for hydropower energy generation in the country are indicated in the Bukhtarma HPP – 4.5 tenge per kWh. In fact, the Shulbinsk HPP and Ust-Kamenogorsk HPP produce an average of 120 MW and 240 MW per year, while the Bukhtarma HPP generates 356 MW per year on average. Table 4 gives an overview of key HPPs in the East Kazakhstan region.

5.2 The Almaty Region

The main waterway of the region is the Ili River, which forms a highly developed swampy delta flowing into the western part of the Balkhash Lake. About 65% of the reserves of hydropower resources of the mountain rivers in Kazakhstan is concentrated in the Almaty region. However, most rivers (the Kurta, Kaskelenka, Talgar, Esik, Turgen, Chilik, Charyn, etc.) that originate in the mountains usually do not reach the Ili River. The region shares four lakes of the Alakol Depression (the Alakol, Sasykkol, Koshkarkol, and Zhalanashkol lakes) with the East Kazakhstan region.

In 2013, the Moinak HPP with a total capacity of 300 MW was finally put into operation in the Almaty region. Producing over 1.27 billion kWh of electricity per year, the Moinak HPP is the largest hydropower plant that was commissioned in Kazakhstan over the past two decades. The project is aimed to reduce electricity deficit, cover peak load, and ensure the reliability of power supply to consumers of the region and the city of Almaty together with the Kapshagai HPP. One of the

Table 4 Large and small HPPs in the East Kazakhstan region

Name of HPP	Total capacity MW	Energy generation million kWh	Commissioning	Location
Bukhtarma HPP	675	2,600	1953–1966	Irtysh River
Shulbinsk HPP	702	1,660	1976–1994	Irtysh River
Ust-Kamenogorsk HPP	331.2	1,520	1939, 1948–1959	Irtysh River
Leninogorsk cascade	11.775	72		Gromotuha and Tishinskaya rivers
• Khariyuzovskaya HPP	5.625	36	1928	
• Tishinskaya HPP	6.15	36	1949	
• Ulba HPP	27.6	108	1937	
Zaisanskaya HPP	2		1965	Zaisan River
Aksuskaya HPP	2		2008	Aksu River
Urdzharskaya HPP	0.175		1949	Karakol River
Turgusun HPP	24.9	79.8	2018 under construction	Turgusun River
Keles River cascade	3.3	18.4	1997–2015	Keles River
• Koshkar-Ata HPP	1.3	7	1997–2001	
• Ryszhan HPP	2	11.4	2015	

Source: prepared using Ministry of Energy of Kazakhstan data

characteristic features of the regional energy generation is the large number of cascade of the HPPs. For instance, there are the Almatinskiy, Karatal, Issyk, and Lepsy River cascades of the small HPP in the region. Table 5 gives an overview of key HPPs in the East Kazakhstan region.

5.3 *The Zhambyl Region*

The major water resources of the Zhambyl region comprise the Chu, Talas, and Assa Rivers. There are 140 small rivers in the Chu River basin, 20 small rivers in the Talas River basin, and 64 small rivers in the Assa River basin. The flow of the rivers Chu, Talas, and Kukureu-su (the main tributary of the Assa River) is formed completely in Kyrgyzstan [23]. Due to the fact that every year, in the summer, the Zhambyl region suffers from a lack of irrigation water, there is a strong necessity to further strengthen interregional cooperation with the Kyrgyz authorities on the issue of water discharge. Table 6 gives an overview of key HPPs in the region.

Table 5 Large and small HPPs in the Almaty region

Name of HPP	Total capacity MW	Energy generation million kWh	Commissioning	Location
Kapshagai HPP	364	972	1965–1980	Ili River
Moinak HPP	300	1,270	1989–2013	Charyn River
Almatinskiy cascade	49.15	280.9	1944–1954	Bolshaya and Malaya Almatinka Rivers
• Verkhne-Almatinskaya HPP	15.6	67	1953	
• Almatinskaya HPP-2	14.3	85	1959	
• Almatinskaya HPP-5	2.5	18	1944	
• Almatinskaya HPP-8	2.5	16	1948	
• Almatinskaya HPP-6	2.5	15	1946	
• Almatinskaya HPP-7	2.5	15	1948	
• Almatinskaya HPP-9	2.5	19.5	1944	
• Almatinskaya HPP-10	2.5	19.5	1944	
• Almatinskaya HPP-11	2.5	19.5	1944	
• Almatinskaya HPP-8a	1.0	6.4	1954	
• Eksperimentalnya HPP	0.75		1932	
Karatal cascade	21.98			Karatal River
• Karatalskaya HPP	10.08	50	1950–1954	
• Karatalskaya HPP-2	4	19.5	2007–2008	
• Karatalskaya HPP-3	4.4		2009	
• Karatalskaya HPP-4	3.5		2010	
Issyk cascade	19.9	32		Issyk River
• Issykskaya HPP	5.3		Under construction	
• Issykskaya HPP-2	5.1	25	2008	
• Issykskaya HPP-3	0.8	5.9	2014	
• Issykskaya HPP-4	0.14	1.1	2014	
Lepsy River cascade	18.59	78.78		Lepsy River
• Antonovskaya HPP	1.6	11	1960	
• Lepsy HPP-2	16.99	67.78	2016	
Talgarskaya HPP	3.2		1959	Talgar River
Sergeevskaya HPP	2			Imish River
Aksuskaya HPP	2	12.93	2008	Aksu River
Uspenskaya HPP	2.5	4.55	1960	Tentek River
Georgiyevskaya HPP	1.7			
Sarkandskaya HPP	2.4	2.58	1998	Sarkand River
Karakystakskaya HPP	2.3	9.78	2013	Karakystak River
Verkhne-Baskanskaya HPP	4.5	30	2015	Verkhne-Baskanskaya River
Intalinkya HPP-5	0.6			
Karash HPP	0.125		2015	Turgen River

(continued)

Table 5 (continued)

Name of HPP	Total capacity MW	Energy generation million kWh	Commissioning	Location
Korinskaya HPP	28.5	107.5	2017	Kora River
Horgos HPP	2		2013	Horgos River
Turgen HPP	1.4			Turgen River
Bartogai HPP	20		Under construction	Shelek River

Source: prepared using Ministry of Energy of Kazakhstan data

5.4 *The Turkestan Region*

The Turkestan Region's water potential is mostly formed by the Syr Darya River, which begins in the Fergana Valley in Uzbekistan at the junction of the rivers Naryn and Karadarya originating in Kyrgyzstan. The length within Kazakhstan from Chardarya Reservoir near the border with Uzbekistan to the Aral Sea is 1,627 km. The largest tributaries within Kazakhstan are the Keles, Arys, Badam, Boroldai, Bugun, and some smaller rivers, flowing from the southwestern slopes of the Karatau ridge. Despite the fact that the Turkestan region has a significant hydropower potential of small mountain rivers and a system of irrigation canals, which are very promising for electricity generation, there is still shortage of power capacities. Local power generating facilities including the Shardarinskaya HPP could provide only 50% of energy consumed in the region. Such figures make the Turkestan region one of the most energy-scarce areas in the country. Table 7 gives an overview of key HPPs in the region.

Therefore, it could be stated that despite the fact that since 2013 the country started to actively launch new HPPs facilities, the average age of the hydropower plants in Kazakhstan is over 37 years. Moreover, since the HPPs facilities in Kazakhstan except large hydropower stations have a relatively small capacity, they are aimed at regulating the electricity load distributions rearranging energy supplies during the consumption peaks. Taking into account the fact that the available capacity of the Kazakhstani HPPs facilities is twice as much in the summer period compared to the winter time, the hydropower sector is a key element of the energy security of the country. As it is shown in Fig. 5, after decades of ups and downs, the total energy production generated by the HPPs in Kazakhstan is finally stabilized giving prospects for further development of the industry.

Table 6 Small HPPs in the Zhambyl region

Name of HPP	Total capacity MW	Energy generation million kWh	Commissioning	Location
Tasotkelskaya HPP	9.2	45.6	2013	Chu River
Karakystakskaya HPP	2.3	9.78	2013	Karakystak River
Merkenskiy cascade	3.62	17.15	1956–2010	Merke River
• Merkenskaya HPP	0.62	3.2	1956	
• Merkenskaya HPP-2	1.5	7.45	1965	
• Merkenskaya HPP-3	1.5	6.5	2010	

Source: prepared using Ministry of Energy of Kazakhstan data

Table 7 Small HPPs in the Turkestan region

Name of HPP	Total capacity MW	Energy generation million kWh	Commissioning	Location
Shardarinskaya HPP	100		1960–1967	Syr Darya River
Koshkar-Ata HPP	1.3		2001	Keles River
Ryszhan HPP	2		2014	Keles River
Darkhan HPP	4.5		Under construction	Keles River
Mankent HPP	2.5		Under construction	Shelek River

Source: prepared using Ministry of Energy of Kazakhstan data

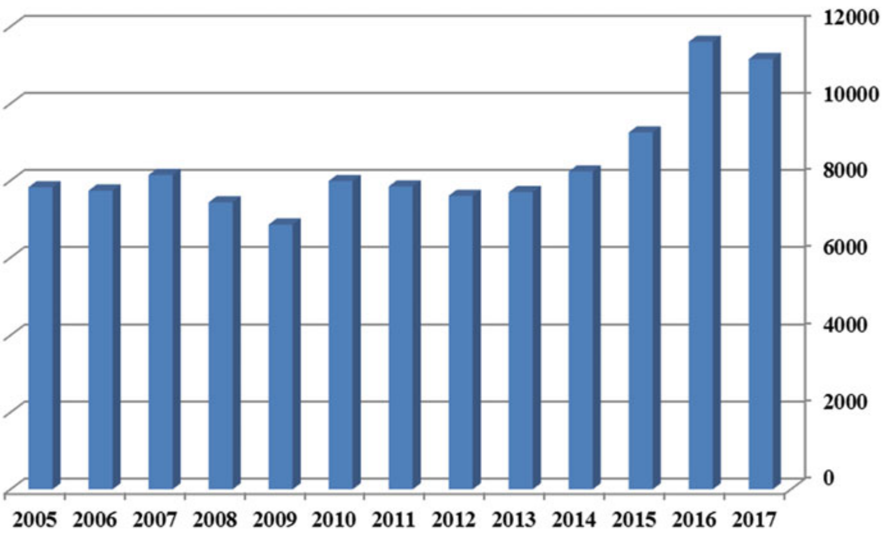

Fig. 5 Energy generation at the hydropower stations in Kazakhstan 2005–2017 (million kWh). Source: KOREM annual reports (www.korem.kz)

6 Conclusions

Kazakhstan is relatively poor in water resources in comparison with the countries of the Commonwealth of Independent States. The surface water resources in the country are distributed extremely unevenly and subjected to considerable time fluctuations (90% of the river runoff takes place during the spring period), causing strong water resource deficit, which is characteristic mainly for the irrigated land cultivation. Moreover, the water resource deficit is also caused by the fact that formation of about half of the flow takes place on the territory of neighboring countries. However, Kazakhstan still has significant hydropower potential especially in the regions that have sufficient water supply. Within the framework of the country's strategy for establishing green economy, Kazakhstan mostly focuses on launching small hydropower projects that are both environmental friendly and relatively inexpensive. The implementation of the mentioned strategy is of great importance for the Turkestan region, which is still suffering from the energy scarcity. In fact, the program of small HPP development in Kazakhstan includes reconstruction and renovation of previously constructed facilities and construction of new power stations that would generate electricity for users in the outlying districts of the Kazakhstani electric power system. Actually, in order to stimulate the small HPP construction, the government encourages the private investors by both providing state short-term credits and ensuring a favorable tax regime during the project realization. Therefore, it could be concluded that the Kazakhstani authorities would keep their interest in promoting mainly small hydropower plants rather than large hydropower facilities.

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The Level of Anthropogenic Pollution of the Kapshagay Water Reservoir, Republic of Kazakhstan

Nariman A. Amirgaliyev and Laura T. Ismukhanova

Contents

Abstract The paper presents the results of our own research at the Kapshagay Reservoir in the Republic of Kazakhstan. Heavy metal contamination of water and bottom sediments, their spatial distribution, and interannual variability are discussed. The influence of flow of the Ili River, and the southern tributaries, is regarded. The sources of anthropogenic pollution of the reservoir are considered.

Keywords Accumulation, Anthropogenic pollution, Bottom sediments, Concentration, Heavy metals, Kapshagay water reservoir, Kazakhstan

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Igor S. Zonn, Sergey S. Zhiltsov, Andrey G. Kostianoy, and Aleksandr V. Semenov (eds.), *Water Resources Management in Central Asia*, Hdb Env Chem (2020) 105: 143–162, DOI 10.1007/698_2020_603,
© Springer Nature Switzerland AG 2020, Published online: 16 July 2020

1 Introduction

Kapshagay water reservoir was built in 1970 in the middle reaches of the River Ili, 60 km north of Almaty City in the area of the Kapshagai Gorge, and is located in the Ili-Balkash Basin. The basin is located in the southeastern part of Kazakhstan and includes the territories of Almaty Region, the southeastern part of the Karaganda Region, the southwestern part of the East Kazakhstan and the eastern part – the Zhambyl Region, and the northwestern part Province Xinjiang of the People's Republic of China (Fig. 1). The main purpose of the Kapshagay Reservoir is energy production and irrigation. It is widely used for navigation, fishery purposes, and recreation.

Among the numerous components of modern pollution of Kazakhstan's water bodies, heavy metals with high stability and cumulative effect are particularly distinguished. It is these substances, accumulating along trophic chains up to a concentration of hundreds and thousands of times exceeding their content in water, can cause profound disturbances in physiological and biochemical processes in aquatic organisms.

Metals belong to the group of microelements contained in natural waters in very small concentrations. The content of microelements in water is one of the important indicators that determine the ecological state of water bodies; they play an important role in the development of living organisms and regulate many biochemical processes. However, their excess in the reservoir, created under the influence of various anthropogenic factors, leads to disruption of the normal functioning of aquatic ecosystems. They are able to accumulate in various objects of the aquatic environment, including fish, without undergoing chemical and biological degradation.

The Kapshagay Reservoir is polluted not only by the transboundary runoff of the Ili River but also undergoes negative influence of a number of other sources within the territory of Kazakhstan. These include contaminated drains of the southern tributaries of the reservoir, such as the rivers Kaskelen, Esik, Shelek, et al., flowing through cities and large settlements, wastewater from Shengeldi, Akdala irrigation array, and drains from Kapshagay City.

The basis of this paper includes the results of the master's thesis and is published in well-known editions of the authors' articles [1–3].

2 Accumulation and Dynamics of Metals in Water

The results of the analysis of water for the content of heavy metals (HM) show an excess of the maximum permissible concentration (MPC) level by elements such as zinc and copper. Elevated concentrations in the water reservoir were observed in previous periods (2006–2008) of the study of the reservoir. The maximum values of the metal concentration were registered in area flows into the rivers Kaskelen, Talgar, and Esik. The seasonal observations of the HM regime are shown in

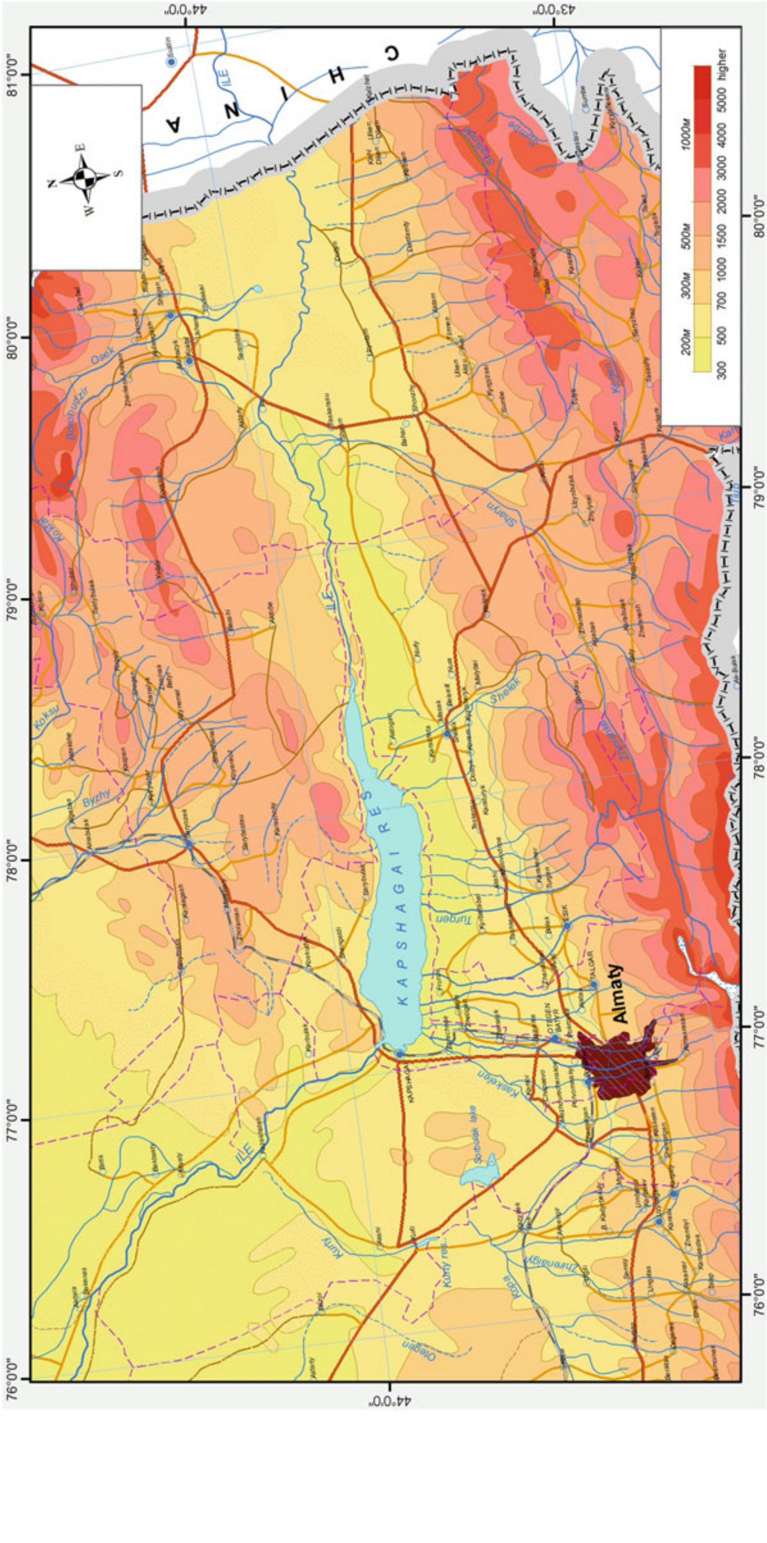

Fig. 1 Physico-Geographical conditions of the territory of the Kapshagay Reservoir, Kazakhstan

Table 1 Seasonal distribution of the concentration of HM in the water of the Kapshagay Reservoir for 2009–2014, μg/L

Years		Zinc	Cadmium	Lead	Copper
2009	Spring	31.6	4.8	3.3	18.9
	Summer	60.5	3.6	3.1	8.3
2010	Spring	47.0	4.8	4,1	33.6
	Summer	41.3	3.4	6.1	48.0
2011	Spring	47.7	2.9	5.7	45.3
	Summer	29.6	2.3	1.3	36.9
2013	Autumn	10.8	2.1	32.7	2.9
2014	Spring	22.4	1.9	36.9	14.4
	Autumn	22.4	0.7	44.7	23.2

Table 1. For 2009–2014 years, the average concentration values for copper were from 2.9 to 48.0 μg/L, for zinc 10.8–60.5 μg/L, for lead 1.3–44.7 μg/L, and for cadmium 4.8 μg/L. The average concentration exceeded the maximum allowable concentration for copper by 48 times, for zinc and lead by 6.0 and 4.4 times, respectively, and for cadmium exceeding the maximum permissible levels of MPC was not recorded.

The nature of the spatial distribution of HM over the individual zones of the reservoir is shown in Fig. 2. The concentration of zinc is markedly increased in the water of the upper reaches, in the zone of influence of the Ili River flow, and also in the dam zone, where the polluted runoff of the southern tributaries spreads (rivers Kaskelen, Talgar, and Esik). Zinc was present in significant concentrations in the near-dam part of the reservoir, even if it was not present in the water of the Upper and Central zones.

Analysis of the concentration of HM in 2009–2011 shows the excess of MPC in the water reservoir of the zinc from 3.7 to 7.5 times and in copper by 81 times (Fig.2). In the zone of influence of Kaskelen River runoff and of some other southern tributaries, we observe increased concentrations of zinc, copper, and cadmium. In 2013 and 2014, higher concentrations were detected in lead which were recorded in the dam and central zone of the reservoir up to 39.8 and 42.3 μg/L (3.9–4.2 MACs).

The distribution of cadmium over different zones of the reservoir is generally uniform. The average concentration of cadmium does not exceed the MPC level. There is a noticeable spatial heterogeneity in the distribution of copper and zinc with maximum average concentrations in the southern part of the dam zone and in the area of the Kaskelen and other rivers. The greatest accumulation for copper and zinc occurs in the dam zone of the reservoir.

The increase in lead concentration in the Kaskelen Bay area, near Shengeldy Island and in the left bank of the reservoir, reached an average of 60.0 μg/L and shows an excess of MPCs in the reservoir water up to 6.0 times.

The analysis of interannual dynamics of HM for 2009–2014 (Fig. 3) shows the similarity of their average concentrations in these years. There is some increase in the content of zinc and copper in 2010 and 2011 and lead in 2013 and 2014 (27.8 and 40.8 μg/L, respectively). Cadmium concentration shows more stable behavior from year to year.

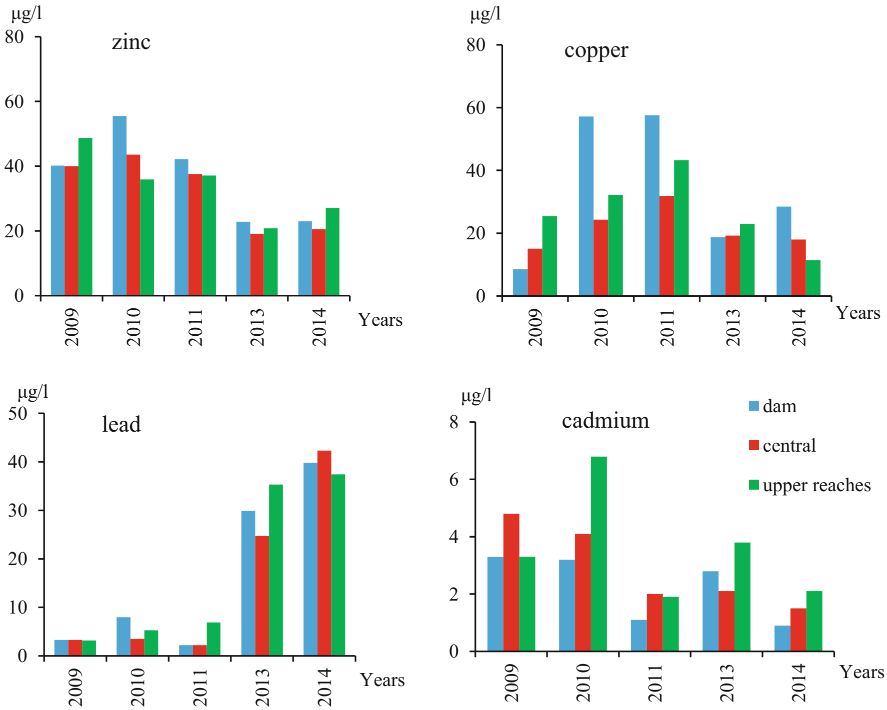

Fig. 2 Average values of metal concentration by zones of the Kapshagay Reservoir in 2009–2014, μg/L

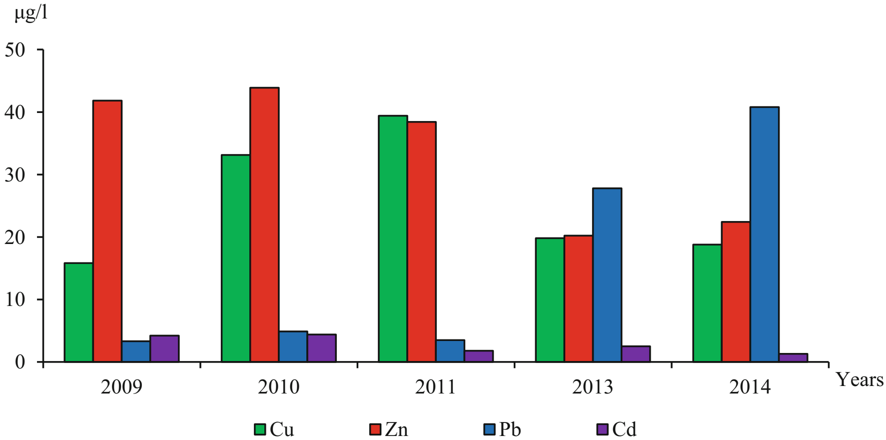

Fig. 3 Average concentration of HM in water Kapshagay Reservoir for the years 2009–2014

The observed slight interannual difference in the copper and zinc content, and in recent years the lead in the water of the reservoir, is obviously associated with a marked seasonal and interannual fluctuation in the Ili River runoff, as well as the influence of some anthropogenic factors.

Thus, there is a contamination of the reservoir. The local manifestation of elevated concentrations of certain metals obviously does not contribute to the formation of subpopulation of fish groups. However, it should be assumed that these circumstances lead to certain undesirable consequences in the distribution of fish by the water areas of the reservoir. The concentration of HM in the water of the Kapshagay Reservoir is subject to significant interannual and seasonal fluctuations, especially the dynamic mode of copper and zinc, which are the main pollutants of fishing basins of Kazakhstan, including the Balkhash-Ili Basin.

3 Accumulation of HM in the Bottom Sediments

Accumulation of toxicants in the bottom sediments is one of the main ways of their migration in the ecosystem of reservoirs. It is known that in sediments the concentration of toxicant is expressed as the sum of the amount of the substance in the sludge solution and the amount of substance in the solid phase referred to the volume of rainfall. The processes that promote the retention of toxic compounds by the solid phase of bottom sediments include physicochemical sorption, the formation of sparingly soluble compounds, and biological absorption, and the intensity of sorption processes depends on the properties of the toxicant, solvent, and sorbent [4]. Thus, petroleum products, for example, are capable of being absorbed by bottom sediments by 30% and copper ions up to 86%. The toxicants accumulated in the sediments are included in the cycle when the physicochemical conditions of the medium change, with the sedimentation of bottom sediments, and also through trophic chains [5–7]. It is also known that the concentration of many toxicants in the bottom sediments (including solid and liquid phases) has several orders of magnitude higher than in water, and an estimate of what part of them is mobile and accessible to hydrobionts has not been studied sufficiently [5, 6]. A number of scientific papers have been devoted to the study of HM in sediments of water bodies. For example, bottom sediments in the seas and oceans were investigated in [8, 9]; the distribution of a number of metals in the sediments of the continental reservoirs of the Russian Federation is considered in the papers [6, 10–13]. Behavior in the sedimentation processes of cobalt, nickel, copper, and zinc in the silt sediments of salt lakes in Kazakhstan was studied in [14, 15]; data on the dynamics of HM in the bottom sediments of some of Kazakhstan's artificial water bodies are available in papers [16–20].

As can be seen in Table 2, the content of HM in the bottom sediments of the Kapshagay Reservoir is characterized by an uneven distribution across its water area. This is especially characteristic feature for elements such as Pb, Cd, Mn, and Cr.

Table 2 Content of HM in the bottom sediments of the Kapshagay Reservoir

Elements	mg/kg	
	Average	Limits
Zn	33.6	30.0–36.0
Cu	22.6	12.1–38.2
Pb	51.8	12.6–87.8
Cd	4.56	1.64–9.62
Ni	19.5	9.10–35.7
Mn	19.7	7.04–65.3
Cr	36.1	5.26–69.5
Co	22.9	3.48–36.9

Table 3 Average content of HM in the lithosphere, gray desert soil, and the bottom sediments of the Kapshagay Reservoir

Elements	Content, mg/kg		
	Clark for the lithosphere (according to Vinogradov, 1957) [24]	Common gray desert soils of the territory (Durasov, Tazabekov, 1981) [22]	In the bottom sediments of Kapshagay Reservoir
Zn	83	76	33.6
Cu	47	27	22.6
Pb	16	–	51.8
Cd	0,13	–	4.56
Ni	58	–	19.5
Mn	1,000	794	19.7
Cr	83	–	36.1
Co	18	8.9	22.9

When quantifying HM in the bottom sediments, a higher average content is characteristic of zinc, lead, and chromium.

A criterion for assessing the level of soil contamination in reservoirs is a comparison of the results obtained with background indicators, i.e., Clarke of elements in the lithosphere and in the soil cover of the region in which there is a reservoir. This technique is often used due to the fact that at present in the CIS countries, including in Kazakhstan, there was no developed sanitary and fishery MPC for toxic substances contained in the sediments. In the literature [21, 22] there are reports indicating that the soil cover of the region of the location of the Kapshagay Reservoir is mainly formed by gray desert soil of ordinary and meadow-gray soils (Semirechye or low carbonate). Gray desert soil within Kazakhstan is located in the foothills and foothill plains, and this zone is usually cut by numerous riverbeds and streams, the largest include the Ili River and its tributaries [23].

To estimate the migratory ability of metals in the bottom sediments of the reservoir, we combined in Table 3 the following data: the average content of elements according to our data with their content in the lithosphere [25, 26] and in

Table 4 Coefficients of accumulation (CA) of elements in the sediments of the reservoir

Heavy metals	Cd	Pb	Co	Cu	Zn	Cr	Ni	Mn
CA	35	3.2	1.3	0.5	0.4	0.4	0.3	0.02

the gray desert soils of the reservoirs widespread in the region of the reservoir. Comparison of the average concentration of elements in the sediments of the Kapshagay Reservoir with background indices indicates an excess of the average levels for lead, cadmium, and cobalt. In the study [15], the excess of Clark was observed for cadmium and lead also. This behavior of cadmium and lead is explained by the adsorption of ions by bottom sediments, depending on the acidity of the medium. In neutral and slightly alkaline (pH = 7.5–8.0) media, the free ion of cadmium and lead is almost completely sorbed by particles of bottom sediments [27]. It has also been established that a decrease in pH leads to an increase in the solubility and, consequently, the mobility of potentially toxic elements [28]. In the opinion of a number of foreign authors [29, 30], the decisive role on the observed forms and the level of metal content in the bottom sediments and suspended substances is provided by the pH of the medium, i.e., determined by oxidation-reduction conditions in the bottom sediments. The change in these conditions in the bottom sediments leads to a change in the valence of metals in natural waters of any types, regardless of their chemical composition or hydrological regime [31].

The concentration of other elements is much lower than their own Clarke, which indicates a low migration activity in the sediments of the reservoir and the intensity of the process of leaching of these elements [26]. All those found in the bottom sediments of HM are located in the next row in the order of decreasing their content: Pb > Cr > Zn > Co > Ni = Mn > Cd > Cu. It should be noted that this series is not analogous to a number of heavy metals contained in water.

In gray desert soils, the content of those elements, for which data are available, is also lower than their Clarke.

As a comparison of the data obtained by us, we note that according to studies [18], a greater accumulation of zinc, copper, nickel, manganese, and chromium metals was recorded in the bottom sediments of the Bukhtarma Reservoir than in Kapshagay Reservoir, which is explained by the receipt of sewage from the Zyryanov lead factory in Bukhtarma Reservoir and other nonferrous metallurgy enterprises.

The degree of accumulation of metals in the sediments of water bodies is estimated by the coefficient of accumulation (CA), which is the ratio of the content of elements in the bottom sediments to their content in soils and rocks. For the calculation we used the values of Clarke for the lithosphere. The values of this coefficient in the reservoir for individual elements, on the base of data mentioned in Table 3, are characterized by the following values in a decreasing series (Table 4).

It can be seen from the data given that the concentration of cadmium, lead, and cobalt in the bottom sediments of the reservoir is greater than in the rocks (CA > 1); therefore, there is a tendency to accumulate these elements in the bottom sediments [27]. This process is due to increased migration ability, biological activity, and sorption of these metals from water by suspended particles. The accumulation coefficient for the rest of the studied metals was less than one, which characterizes the relatively lower mobility of these elements in the conditions of this reservoir. Processes such as leaching them from silt appear to have an impact, along with more intensive biological uptake of these elements.

As mentioned above, the maximum permissible concentration of chemical substances, including HM, for bottom sediments of water basins in the CIS countries is not developed. However, there are standards adopted in a number of foreign countries [32, 33], the values of which are shown below (in mg/kg):

Pb	Cu	Zn	Ni	Cd	Cr
10	21	30	29	0.16	28

If we compare our data with the above standards, it turns out that in the bottom sediments of the Kapshagay Reservoir, Pb exceeds the MAC by 5.2 times, Cd 28.5 times, and Cr by 1.3 times. Of the remaining elements, the content of zinc and copper within the limits of MPC and nickel does not reach the normative values. The elevated levels of Cd and Pb are obviously related to the reaction of the aquatic environment and the significant content of organic substances in the sediments.

4 Spatial Distribution of HM in the Bottom Sediments

A schematic map of the Kapshagay Reservoir and spatial distribution of HM in the bottom sediments by the water area of the reservoir is shown in Figs. 4 and 5.

For almost all the studied elements, their spatial distribution is characterized by an increased accumulation in the bottom sediments of the dam part of the reservoir. At the same time, there is a noticeable difference in the spatial accumulation of elements by the water area of the reservoir. The zinc accumulation levels are the same in the bottom sediments of the central part and in the dam area and copper in the upper and central zones. The concentration of lead in bottom sediments is distributed unevenly across zones. Accumulation of this element continuously increases in the direction from the upper zone to the dam (Fig. 4). The distribution of cadmium in the water area of the reservoir is slightly different from other metals by its smaller accumulation in the bottom sediments of the central part.

The nature of the spatial distribution of HM by the water area of the reservoir can be more clearly seen using the ArcGIS software. This way of interpreting the obtained analytical material allows us to look deeper into the natural and anthropogenic factors that influence the level of accumulation and distribution of heavy metals over the water area of the Kapshagay Reservoir.

As can be seen in Fig. 6, an increased copper content of 35–40 mg/kg in the bottom sediments is strongly pronounced in the mouths of the Kaskelen and Turgen Rivers. Dispersion of the concentration of copper goes from the mouths of these rivers to the central part of the reservoir, that is, in this direction, the metal pollution

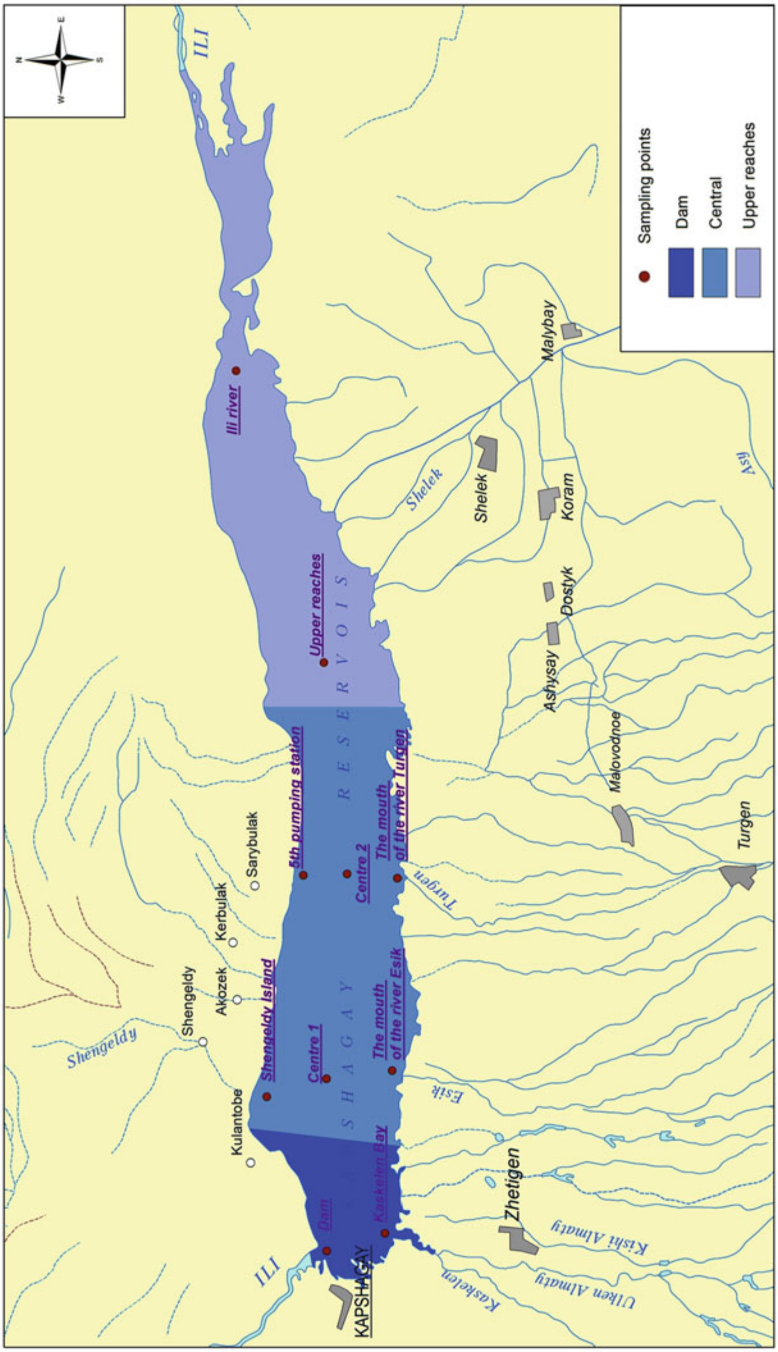

Fig. 4 Schematic map of the Kapshagay Reservoir

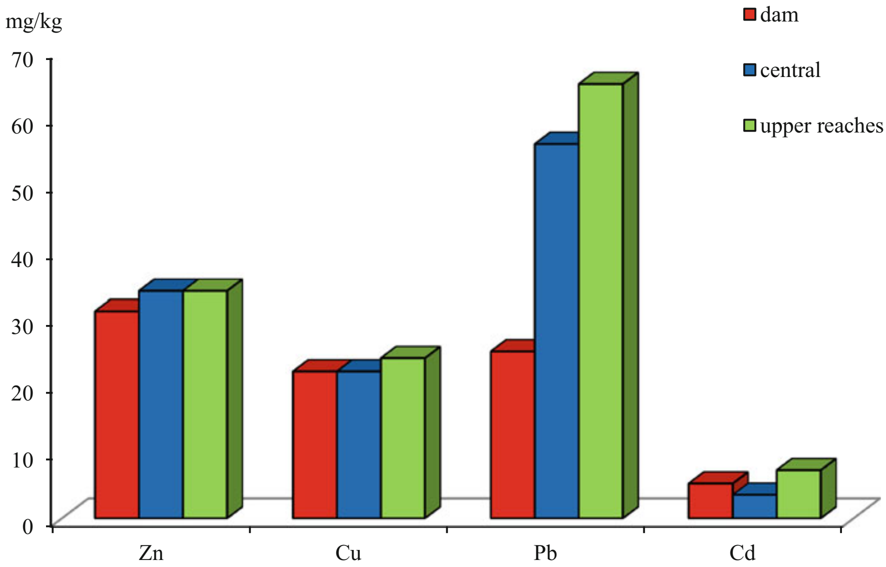

Fig. 5 Spatial distribution of mean concentrations of HM in the bottom sediments of the Kapshagay Reservoir

activity decreases. And the influence of this source of contamination of bottom sediments with copper, which is the stock of the River Turgen, reaches the northern shore of the reservoir, spreading over a fairly wide area. The local zone with a high concentration of copper in the bottom sediments is manifested in the area of the flow of the Shelek River. The effect of cross-border Ili River on the accumulation of copper in the sediments in the top part of the reservoir is not clearly shown, because of the fact that the bulk of the sedimentation of suspended sediment and traction brought by a river occurs in the central parts of the reservoir and the dam area.

The concentration of zinc in the bottom sediments of the reservoir was in the range from 30 to 40 mg/kg. The main pollution by this element is introduced into the reservoir by the effluent of the Turgen River (Fig. 7). Contaminated with zinc of 36–38 mg/kg, the sediments spread to the central part of the reservoir. In the sediments, of the zone of distribution of the runoff of the Kaskelen and Shengeldy Rivers, the zinc concentration is recorded in the range of 36–38 mg/kg. The lowest level of zinc accumulation is observed in the upper part of the reservoir.

In general, the content of zinc in the bottom sediments of the Kapshagay Reservoir is low, and the Clarke in the lithosphere according to A.V. Vinogradov [24] is 83 mg/kg, which indicates the high migration activity of this metal and the ability to leach it and carry it out in a dissolved form [34].

The spread of lead in the bottom sediments of the reservoir is extremely uneven (Fig. 8). Accumulation of it at higher concentrations is recorded in the central and dam zones. The increased sedimentation level of lead in the bottom sediments of the

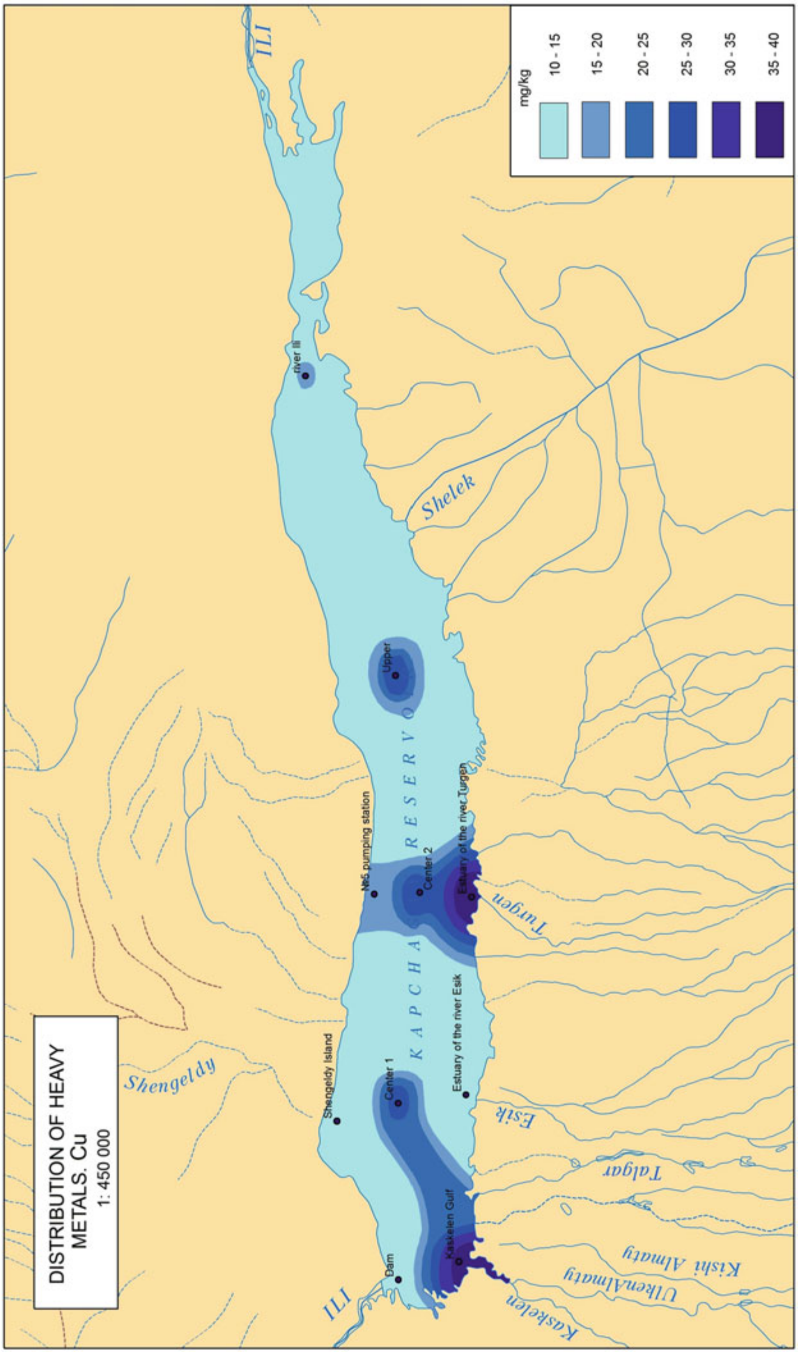

Fig. 6 Spatial distribution of copper in the bottom sediments of the Kapshagay Reservoir

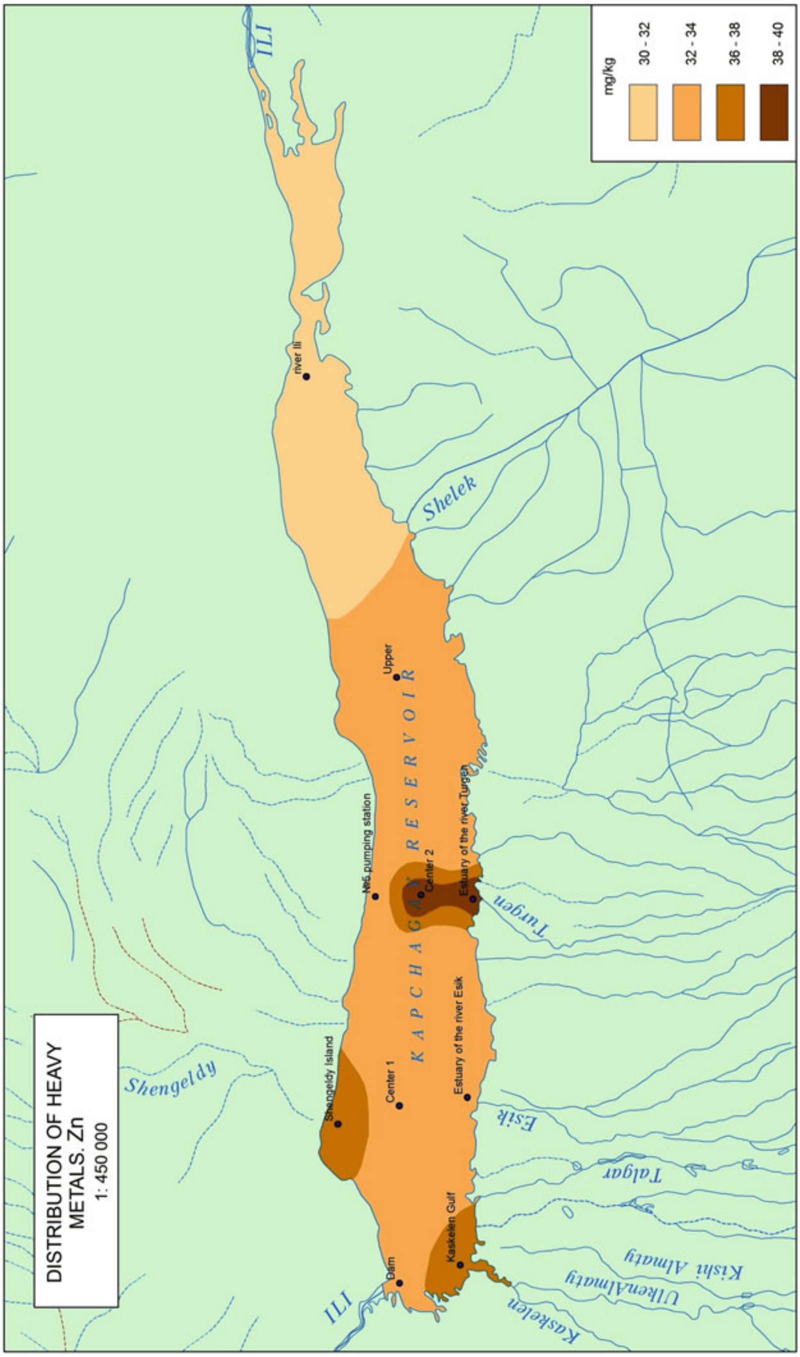

Fig. 7 Spatial distribution of zinc in the bottom sediments of the Kapshagay Reservoir

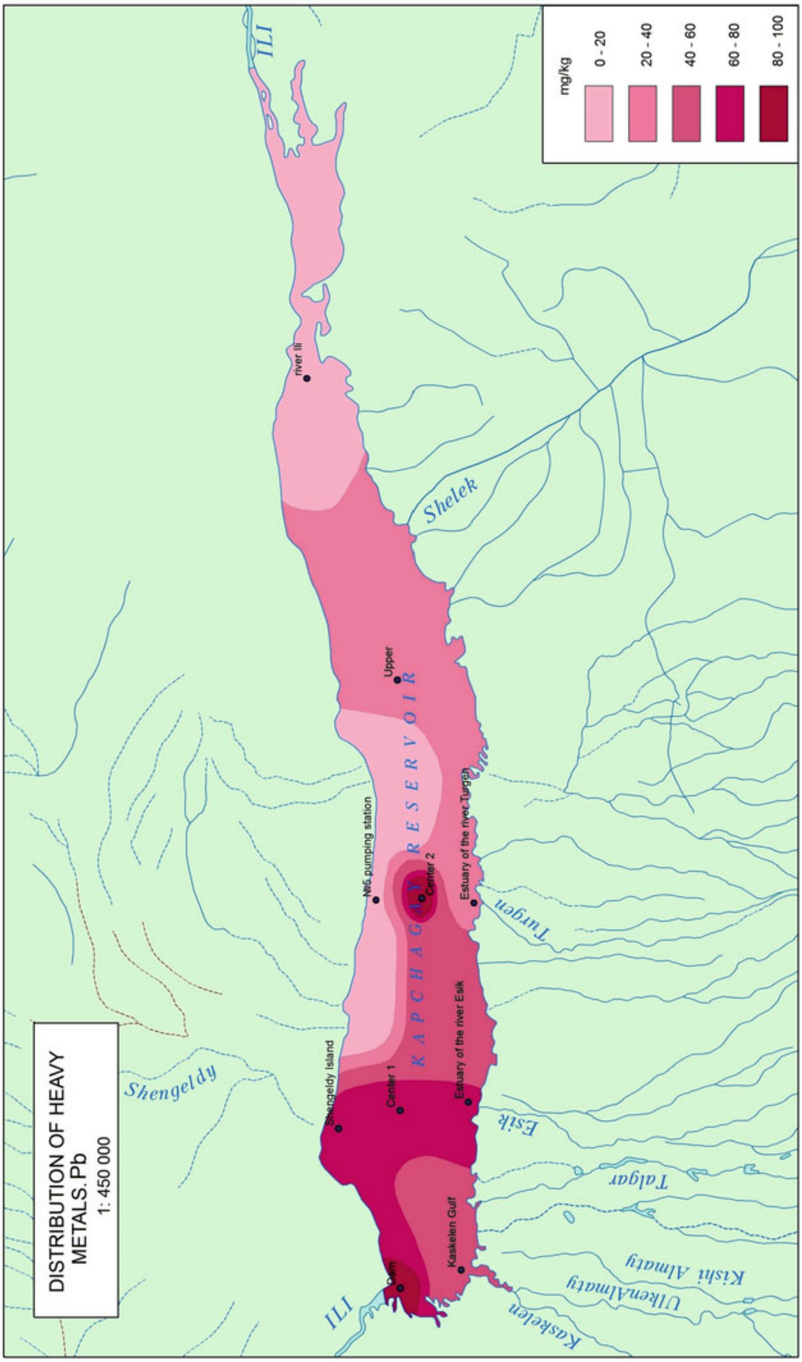

Fig. 8 Spatial distribution of lead in the bottom sediments of the Kapshagay Reservoir

dam zone and the southern coast of the central part of the reservoir, obviously, is due to the influence of the flow of the rivers of Esik, Turgen, and Shengeldy, which flows into the northern coast of the dam area. Less polluted Pb bottom sediments are observed in the upper reaches of the reservoir and the northern coast of its central part. It is impossible, of course, to exclude the accumulation of lead in the water reservoir, brought by the transboundary runoff of the Ili River. The concentration of lead in the dam zone and in the center is from 80 to 100 mg/kg, while its Clarke in the lithosphere is 16 mg/kg, which indicates the accumulation of this element even in the surface layers of the bottom sediments of the reservoir.

The concentration of cadmium (Fig. 9) to 10.0 mg/kg and 8.0 mg/kg accumulates in the bottom sediments of the mouths of the Kaskelen and Turgen Rivers, respectively, which indicates the significance of the anthropogenic load created by these rivers on the ecological condition of the Kapshagay Reservoir.

Obviously, under the influence of these sources, as well as the drains of the Rivers Ili, Shelek, and Shengeldy, the bottom sediments of a rather large water area in the upper and dam parts of the reservoir are polluted with cadmium with a concentration of 4–8 mg/kg. Deep water zone of the central part of the reservoir, starting from the confluence area of the Esik River, is characterized by extremely low cadmium content in sediments.

Thus, in the illustrative materials presented above, the foci of contamination of the reservoir deposition with heavy metals and the general picture of the distribution of the highest priority for a given water basin of HM in the surface horizons of sediments are clearly visible. The obtained results indicate that the influence of small rivers on the ecological state of the Kapshagay Reservoir is very high. The data also allow preliminary assessment of the nature of water pollution of these watercourses entering the reservoir.

5 Sources of Anthropogenic Pollution of the Reservoir

The main pollutants of the investigated water body within Kazakhstan are industrial facilities; municipal economy of settlements (mainly cities) and agriculture, in particular irrigated agriculture; removal of pollutants by surface runoff from storm water; meltwater from irrigation and rainfed farmlands, and livestock runoff. Kapshagay Reservoir is not an exception. In this regard, the hydrochemical regime of the rivers flowing into the Kapshagay Reservoir does not meet sanitary and hygienic requirements and quality standards for fisheries and recreation, and their polluted runoff, in turn, worsens the ecological state of the reservoir. The main supplier of heavy metals and other toxic compounds is, as already noted above, the transboundary runoff of the Ili River. For the years 2001–2009, the transboundary inflow of metals into the reservoir amounted to 843 tons for copper and 1,580 tons for zinc, an average of 105 and 198 tons per year, respectively. Moreover, in the period 2001–2009, the actual inflow in certain years exceeded its permissible copper values by more than 10 times and by zinc up to 4 times, which is an indicator of the

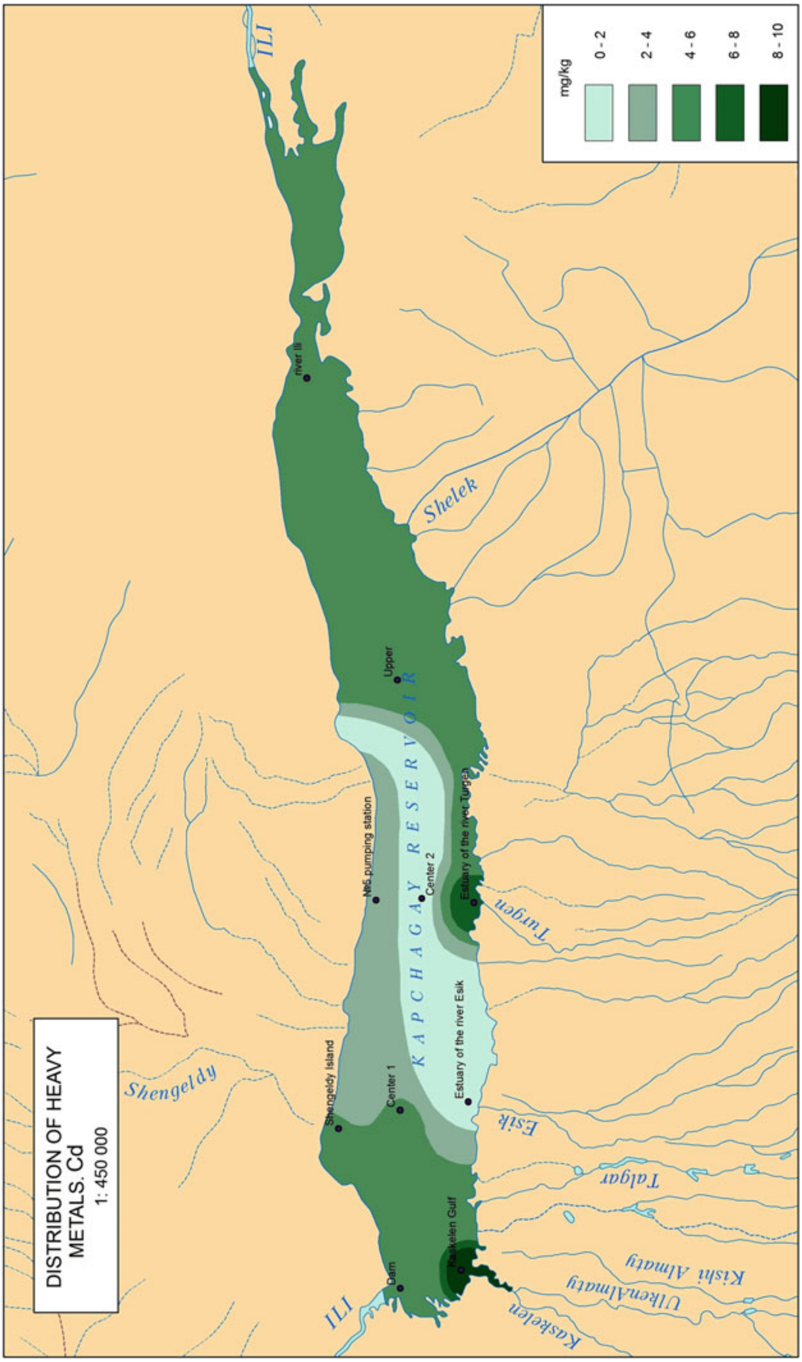

Fig. 9 Spatial distribution of cadmium in the bottom sediments of the Kapshagay Reservoir

Fig. 10 Land-based source of pollution of Kapshagay Reservoir (Photo by Nariman A. Amirgaliyev)

excess of the concentration of these elements in the transboundary runoff of the MPC river standards [35].

Data from the state monitoring at the Dobyn hydrological post for 2009–2011 show [36] an increased level of concentration of total iron and its oxides in water. The common form of iron in 91–97% of the analyzed samples exceeded the maximum permissible concentration by 10 times; in some cases it exceeds 10 MPC. On the whole, such a picture is also observed for ferric oxide.

At the same time, the tourist attractiveness and significance of the region is increasing, thanks to the natural and climatic conditions and close distance from the megalopolis City of Almaty.

Around the Kapshagay Reservoir, there are many hotels, resort complexes, and recreation areas. Already in 2014 there are about 150 recreation areas on the coast.

The use of recreational resources of the Kapshagay coast for the formation of tourism and recreation also leads to contamination of the reservoir (Fig. 10).

The sources of contamination of the reservoir mentioned above not only lead to a deterioration of the sanitary state of the water body but also to a decrease in water quality.

6 Conclusions

Contamination of the Kapshagay Reservoir with heavy metals continues. The concentration of a number of studied elements exceeds the MPC level due to their supply into the reservoir by the waters of Ili, Talgar, and Kaskelen and other rivers. The results of the analysis show that the level of the MPC is exceeded for some elements such as zinc to 27.8 μg/L and copper to 40.8 μg/L. The observed slight interannual difference in the copper and zinc content, and in recent years the lead in the water of the reservoir, is obviously associated with a marked fluctuation in the runoff of the Ili River in the annual and intra-annual aspects, as well as the influence of some anthropogenic factors.

In general, according to the results of the study, there is a reason to believe that in the bottom sediments of the Kapshagay Reservoir, there are mainly mobile forms of metals that are susceptible to leaching from the surface layers of the soil to the water mass. The significant spatial heterogeneity in the distribution of heavy metals in the sediments is the result of the influence of a number of factors of anthropogenic character on their regime.

Naturally, one of the significant natural factors regulating the spatial distribution of precipitation in basin is sedimentation processes that depend on the river runoff, the content of suspended sediments in them, their granulometric composition, the nature of the bottom of the reservoir, etc. The influence of these factors can be clearly seen in the distribution of the concentration of some elements in the bottom sediments of the reservoir.

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Current State of Water Resources and Problems of Their Use in Border Regions of Russia (The Ob-Irtysh Basin as a Case Study)

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Igor S. Zonn, Sergey S. Zhiltsov, Andrey G. Kostianoy, and Aleksandr V. Semenov (eds.), *Water Resources Management in Central Asia*, Hdb Env Chem (2020) 105: 163–188, DOI 10.1007/698_2020_604,
© Springer Nature Switzerland AG 2020, Published online: 18 July 2020

Abstract The water resources of Ob and Irtysh and water availability in the context of natural areas, landscape provinces, and river basins are considered. The information on extreme hydrological phenomena on water bodies of the Ob-Irtysh Basin has been analyzed and structured. Using the results of statistical analysis of data series of average annual discharges for major rivers in the south of West Siberia, the linear trends were calculated. The change in annual discharges for the last decades was estimated. The discharge forecast for the following 10–20 years was given, and the zones of its increase/decrease in the area under study were identified. The volume of abstraction and use of water intake and use and the share of withdrawal in landscape provinces and river basins of the region are estimated.

Keywords Average annual river flow, Climate change, Forecast, Ob-Irtysh Basin, River, Water resources

1 Water Resources and Water Availability in the Context of Natural Areas, Landscape Provinces, and Ob-Irtysh River Basins

In Russia, the Ob-Irtysh Basin – the largest catchment of the country – covers the area of 2,194.4 thousand km^2 (including drainage areas) [1]. It is almost entirely located within the West Siberian Lowland stretching far from north to south and from west to east. The basin is framed by the Altai-Sayan Mountains in the south and the Ural mountain ridge in the west. A wide range of climatic conditions accounts for the diversity in economic development and occupancy of the territories.

In the basin, along with industrial regions like Chelyabinsk, Sverdlovsk, Tyumen, and Kemerovo (coal, gas and petroleum production, ferrous metallurgy, mechanical engineering, and chemical industry), there are developed agricultural ones, i.e., Altai Krai, Omsk, Kurgan, and Novosibirsk oblasts and Republic of Altai, Altai Krai, Novosibirsk, Omsk, Tyumen, Kurgan, and Chelyabinsk oblasts (regions) border Kazakhstan, Mongolia, and China. These territories are fully or partially situated within the catchment area of major rivers of the basin. Some water bodies (e.g., rivers Irtysh, Ishim, and Tobol) are transboundary objects sharing their waters among the aforementioned countries.

The Ob-Irtysh Basin is rich in surface water (Fig. 1), average annual runoff of which, according to the State Hydrological Institute (SHI), is estimated as 405 km^3 [2]. In spite of water resources abundance, their distribution within the basin is extremely uneven. For instance, more than 68% of flow falls on the sparsely populated and unsuitable for agricultural development forest-tundra and taiga areas in the mid and low reaches of the Ob; at the same time agrarian and industrialized steppe and forest-steppe regions of the southern part of the basin are pressed for water resources (Table 1). The steppe zone of the closed drainage Ob-Irtysh

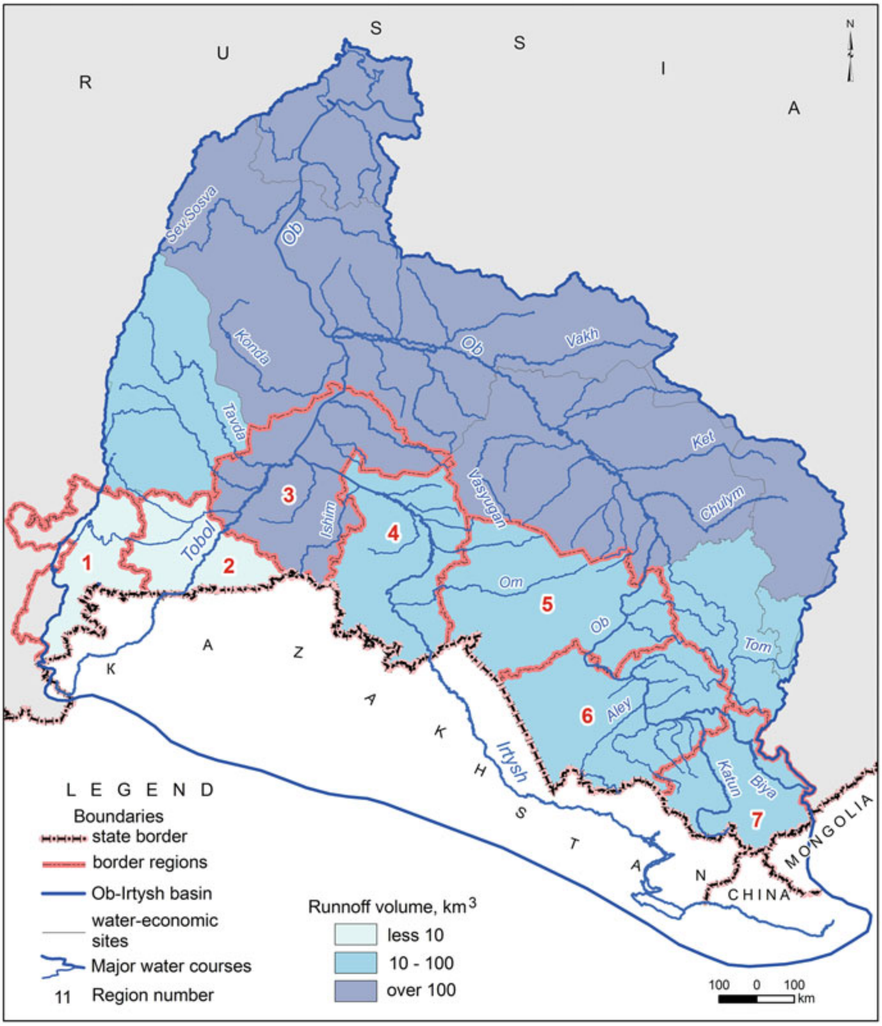

Fig. 1 Schematic map of river runoff distribution in the Ob-Irtysh Basin within the Russian Federation. 1 – Chelyabinsk, 2 – Kurgan, 3 – Tyumen (south), 4 – Omsk, 5 – Novosibirsk oblasts, 6 – Altai Krai, 7 – Republic of Altai, 8 – Republic of Khakassia, 9 – Kemerovo Oblast, 10 – Krasnoyarsk Krai, 11 – Tomsk Oblast, 12 – Khanty-Mansiysk Autonomous Okrug, 13 – Sverdlovsk Oblast, 14 – Yamalo-Nenets Autonomous Okrug

interfluve, which accounts for only 1.5% of the surface runoff of the basin as well as the southern and trans-Ural regions, i.e., Chelyabinsk, Kurgan, and the south of Sverdlovsk oblasts (<1%), experiences the greatest water deficit.

A specific water availability at the territory of the Ob-Irtysh Basin exceeds 18,000 m^3/(year/person) that is much lower than that for Russia and Siberian Federal Okrug (about 30 and 66.5 m^3/(year/person), respectively) [4]. On the other hand, it is

Table 1 Characteristics of water resources in the Ob-Irtysh Basin by natural zones [3]

Natural zones (mineralization*)	Water resource factors		
	Renewable water potential, m^3/km^2 per year	Probable water availability per capita, thousand m^3/year	Coefficient of renewable water withdrawal, %
Mountain tundra, high-mountain taiga, nival-glacial (0.02–0.10 g/l)	358	No consumers	<1
Tundra and forest-tundra (<0.1 g/l)	250	Up to 20,000	<1
Taiga (0.1–0.3 g/l)	225	600–800	<10
Mountain taiga (Altai) (0.1–0.3 g/l)	250	~500	<1
Forest-steppe and mountain-forest-steppe (0.2–0.5 g/l)	38	20–50	10–20
Steppe and mountain-meadow-steppe (0.5–1.0 g/l)	15	1–2	<10–20
Closed drainage area of steppe and forest-steppe (1–200 g/l)	10–15	1	<10–20

**Note:* salinity of natural drinking water is up to 1 g/l

several times higher than that in Federal Okrugs (regions) of the European part of Russia (i.e., in Central and Volga Okrugs, it exceeds 3 and 9 m^3/(year/person), respectively).

With water discharge increase and population density decrease, water availability in the basin grows from south to north. Its maximum of ≥22 mln m^3/(year/person) falls on sparsely populated forest-tundra regions in the low reaches of Ob River, while its minimum on the poorly moistened and most densely populated areas of the steppe and forest-steppe zones in the border regions of Russia. Thus, surface water availability does not exceed 1,700 m^3/(year/person) in the Tobol River Basin and 1,300 m^3/(year/person) in Lake Chany at average long-term annual discharge and 0.3 m^3/(year/person) at its minimum.

The most unfavorable situation is observed in the low mountain steppe, forest-steppe, and southern taiga landscapes of Chelyabinsk and Sverdlovsk oblasts due to high population density and shallow river sources. Here, water availability in the basins of Iset River makes up 0.5–1.0 and in Uvelka River – 0.8; in the most developed part of the Miass River Basin near the city of Chelyabinsk, it is 0.3 thousand m^3/(year/person).

Krasnoyarsk Krai, Tomsk, and Tyumen oblasts (including Okrugs), the Republic of Altai, and Khakassia are distinguished by the best water supply (116–190 m^3/(year/person)) within the territory of the Ob-Irtysh Basin. Minimal water availability (2–8 m^3/(year/person)) is in Chelyabinsk, Kurgan, and Sverdlovsk oblasts. Note, threshold exceedance here is of 1.7 thousand m^3/(year/person) that corresponds to the water crisis onset [5, 6].

The landscape-basin approach was proposed for the overall assessment of the water-resource potential of territories based on the uniform criteria [7]. The Institute for Water and Environmental Problems of the Siberian Branch of the Russian Academy of Sciences (IWEP SB RAS) has performed the in-depth analysis of the zonal and azonal factors of landscape differentiation for the territory nature management and developed a general scheme of physical-geographical zoning of Siberia [8]. The authors made an emphasis on the importance of zonal-provincial characteristics of the territory in water resources formation. A total of 83 landscape provinces with similar conditions of surface and underground runoff formation were identified within the territory of West Siberia and the Ob-Irtysh Basin.

Evaluation of current availability of surface water per capita was made according to the State Hydrological Institute data on average long-term annual discharge and using the map “Average long-term runoff of rivers” 1:24,000,000 [9]. To do that, the data from the nearest gaging stations for the entire observation period with reference to the sites of rivers crossing the borders of landscape provinces were used. In case of such station’s absence or their remoteness from the provinces border, we used the data on specific discharge.

Cartographic materials from “The Atlas of hydrogeological and engineering-geological maps of the USSR” [10] and evaluation of freshwater and slightly mineralized groundwater availability in the south of the West Siberian Artesian Basin [11] as well as the results of recent exploration works (if available) became the basis for the assessment of groundwater water availability. For its calculation the groundwater specific discharge was used in the zone of intensive water exchange.

The analysis of results showed that 3.3 million residents (15% of total population) of the Ob-Irtysh Basin live under conditions of extremely low (<1.0), very low (1.0–2.0), and low (2.0–5.0 thousand m^3/(year/person) potential water availability. The least water supply is in the area of internal drainage and in the southern part of the Ural Region, including the regions bordering Kazakhstan.

2 Surface Water Resources of the Ob-Irtysh Basin

The Ob River is one of the largest in the world; it ranks first in Russia by its catchment area and third – by its flow (after rivers Yenisei and Lena). The Ob-Irtysh Basin is drained by thousands of rivers, which total length exceeds 250,000 km [12]. The largest tributaries of Ob River are rivers Irtysh, Vasyugan, Bol, Yugan, Severnaya, and Sos’va (left) and Chulym, Ket’, Vakh, Tym, and Tom (right).

The source of Ob River is the confluence of rivers Biya and Katun springing from the Altai Mountains. Irtysh River, the largest tributary of Ob River, originates in Mongolia (short section of Irtysh River) and then crosses the territory of three countries, i.e., China, Kazakhstan, and Russia. In Russia, the river length makes up 48% of its total one. The largest Irtysh tributaries are rivers Ishim and Tobol, which originate in Kazakhstan.

The largest surface runoff in the Ob Basin is formed on the western (windward) slopes of the Kuznetsk Alatau and the Abakan range of the Western Sayan mountains; the annual precipitation here is about 1,000 mm. Runoff of small rivers is 600–1,000 mm. About 400 mm falls on Biya River, 335 mm on Katun River in Srostky, and 500–700 mm on Tom River. The river runoff from the eastern slopes of the Kuznetsk Alatau (upper reaches of Chulym River) is less than from the western ones.

River runoff from the Biya-Chumysh Upland, the Altai Plain, and the central part of the Kuznetsk Depression ranges from 100 to 400 mm depending on their location relative to moist-laden winds and the altitude. In the regions covered mostly by wetlands, there is no correlation between precipitation and runoff (main components of a hydrological cycle). Bogs are characterized by high moisture content; the difference “precipitation minus runoff” describes as evaporation as moisture accumulation in the marsh layer. The Ob tributaries running in the north and northeast direction annually bring around 108 mm of moisture to the zone of excessive moistening. From south to north, annual runoff and the territory moistening increase.

The Ob runoff grows by 34.7 km^3 (2,677 km from the Ob mouth) after the Tom confluence and by 86.4 km^3 after the Irtysh confluence nearby Khanty-Mansiysk [2]. Mean annual amount of the Ob runoff before the Irtysh confluence is 237 km^3, whereas near Belogorye Village (1,152 km from the Ob Mouth), a bit upstream, it is 327 km^3 [2]. The analysis of fluctuations in average long-term annual discharge of the Ob and its tributaries is evidence that after 1980 the river’s water content remains practically the same [13].

Despite big water resources in the Ob River Basin near Salekhard (405 km^3/year, [2]), their distribution within the catchment is very uneven. The most populated areas of the Ob-Irtysh Basin (Altai Krai, Kemerovo, Novosibirsk, Omsk, south of Tyumen Oblast) are not rich in considerable water resources. Uneven annual runoff aggravates the situation. When spring flood occurs, most surface waters flow down (May–June). During a winter low water period (November–March), volumes of minimum runoff cannot fully satisfy the Russian regions’ demand in water consumption.

By annual runoff distribution, the Irtysh Basin rivers belong to those with intensive spring floods, rainfall-induced floods in the warm period, and relatively low water flow in winter and summer, except for Irtysh River in its mouth and the Nizhny Irtysh tributaries, where the flood period lasts till summer due to zonal snow melting and lake-wetland regulation. Floods on Irtysh rivers lasts 3–5 months and even 6 on the Nizhny Irtysh during high water years; 60–90% of the annual runoff falls on a flood period.

In the areas of closed drain of the Ishim-Irtysh and Ishim-Tobol interfluve during a summer-autumn period of low water, runoff volume is negligible (5–6% of annual amount), while in the basins of the forest-swamp zone, it amounts 12–20%. There is no runoff from small rivers at this period in the southern part of the study area.

Minimum water runoff in the Irtysh Basin occurs in late summer (September–October) and winter (February–March) low water period that affects the water availability in the regions. On all rivers with natural flow regime, winter minimum discharge is 1.5–3 times less than that in summer-autumn. In summer, average minimum discharge of the Irtysh increases in the direction from the Kazakhstan-Russia border to the mouth (Khanty-Mansiysk) as 449–2,090 m^3/s and in winter – from 238 up to 660 m^3/s.

The analysis of the Irtysh runoff fluctuations for a long period with regard to economic activities shows insignificant changes in runoff volumes downstream the river and in the estuarine sites of its main tributaries.

3 Hazard Hydrological Events (HHE) on Rivers of the Ob-Irtysh Basin

In terms of water resources, the analysis and structuring of the data on extreme hydrological events (EHE) on water bodies of the Ob-Irtysh Basin allowed to identify their localization, time of probable occurrence, and their impact on lower river sections.

The rivers of the Ob-Irtysh Basin undergo the following negative hydrological and hydrogeological phenomena: floods (territory flooding and waterlogging), low water, bed deformations (river banks undermining, erosion of bottom and longitudinal profile, etc.), and marginal erosion.

The highest probability of occurrence of emergency situations, caused by ice jams resulting in floods, is characteristic of the rivers of Altai Krai and Kemerovo Oblast (80%). On rivers of Chelyabinsk, Sverdlovsk, and Tomsk oblasts including Yamalo-Nenets Autonomous Okrug (YANAO), such a probability is a bit lower (70%), and for rivers of Khanty-Mansi Autonomous Okrug (KHMAO) and Novosibirsk and Omsk oblasts as well as the Republics of Altai and Khakassia, it is 60%. The least probability of extreme situations' occurrence (below 30%) is typical for rivers of Tyumen (except for KHMAO and YANAO) and Kurgan regions.

The Irtysh Basin rivers frequently suffer from flooding caused by spring (or summer) floods, rainfalls, ice jams, and watercourses under snow [14, 15]. Despite a feasible control over spring-induced runoff going through the cascade of Nizhny-Irtysh reservoirs, there is a risk of Russian territory inundation because at energy production by HPPs allowances are not made for the interests of users living below.

The analysis of water level series is evidence of flood absence on the Irtysh for the first 10 years of the twenty-first century (2000–2010), whereas it occurred four times (in 2002, 2004, 2005, 2007) on the Ishim and three times (2002, 2003, 2005) on the Tobol over the last 10 years.

By June 2016, the water users from Kazakhstan had raised the questions on Irtysh River shallowing caused by operation of 11–12 reservoirs with the manifold irrigation network built on the Kara/Cherny Irtysh and its tributaries in the Xinjiang

Uighur Autonomous Region (XUAR), China. Here, because of rainfall-induced floods in June, the reservoirs implemented the intensive water discharge, and as a result, the Kara/Cherny Irtysh influx exceeded its multiyear maximum of 1,100 m^3/s for 20 days, reaching its peak of 3,600 m^3/s on 16 June 2016. In its turn, the cascade of the Irtysh hydropower plants (HPPs) had to start emergency water discharge. During the extreme situation, a powerful tidal wave moved from Zaisan up to the Bukhtarma HPP dam for 2 weeks [16].

The map of flood hazards in border territories of the Irtysh Basin (Fig. 2) represents two indicators: the excess (over the critical) of maximum recorded levels (m) and the probability of exceedance of flooding onset levels (%). Note: the level is considered to be critical when water enters the floodplain [14].

Another, more dangerous hydrological phenomenon, typical for the Ob-Irtysh Basin, is a low water level; it is an extreme hydrological event characterized by sharp decrease in river runoff. Very high probability of water shortage does exist for the rivers of the Ishim Plain, Kulunda Lowland, and the south of the Barabinsk Lowland. Here, the permanent drying out of small rivers and occasional one of some medium-sized rivers occurs.

The part of the Irtysh River Basin bordering Kazakhstan has a very high probability of a low water level. It is so-called Kazakh type of water regime with a very high wave of spring flood, critical water shortage, and drying up during other hydrological seasons.

The methodology on hazard and risk of river water shortage developed by N.I. Koronkevich, I.S. Zaitseva, L.K. Malik, and A.F. Bumakova was the basis for the risk assessment of low water and for the schematic map construction (Fig. 4) [15]. Sites with episodic freezing and drying of rivers are revealed due to the analysis of average monthly discharge for years with different water availability (dry, medium, and wet). Altogether 22 tributaries of rivers Irtysh, Ishim, and Tobol were studied to identify the sites of riverbed freezing and drying out during the years with maximum (1985), average (1970), and minimal (1968) water availability.

The schematic map (Fig. 3) shows the areas with different probability of rivers' freezing and drying up that results in cessation of surface water use. The abnormal runoff is marked by a quality background on the map. The legend is based on the matrix principle that allows to display different combinations of freezing and drying out events.

4 Climate-Induced Changes in River Water of the Ob-Irtysh Basin

Secular and long-term variability of river runoff is mainly caused by long-term changes of climate and anthropogenic factors. Major causes of seasonal hydrological runoff variation are seasons change and synoptic fluctuations. Long-term climate

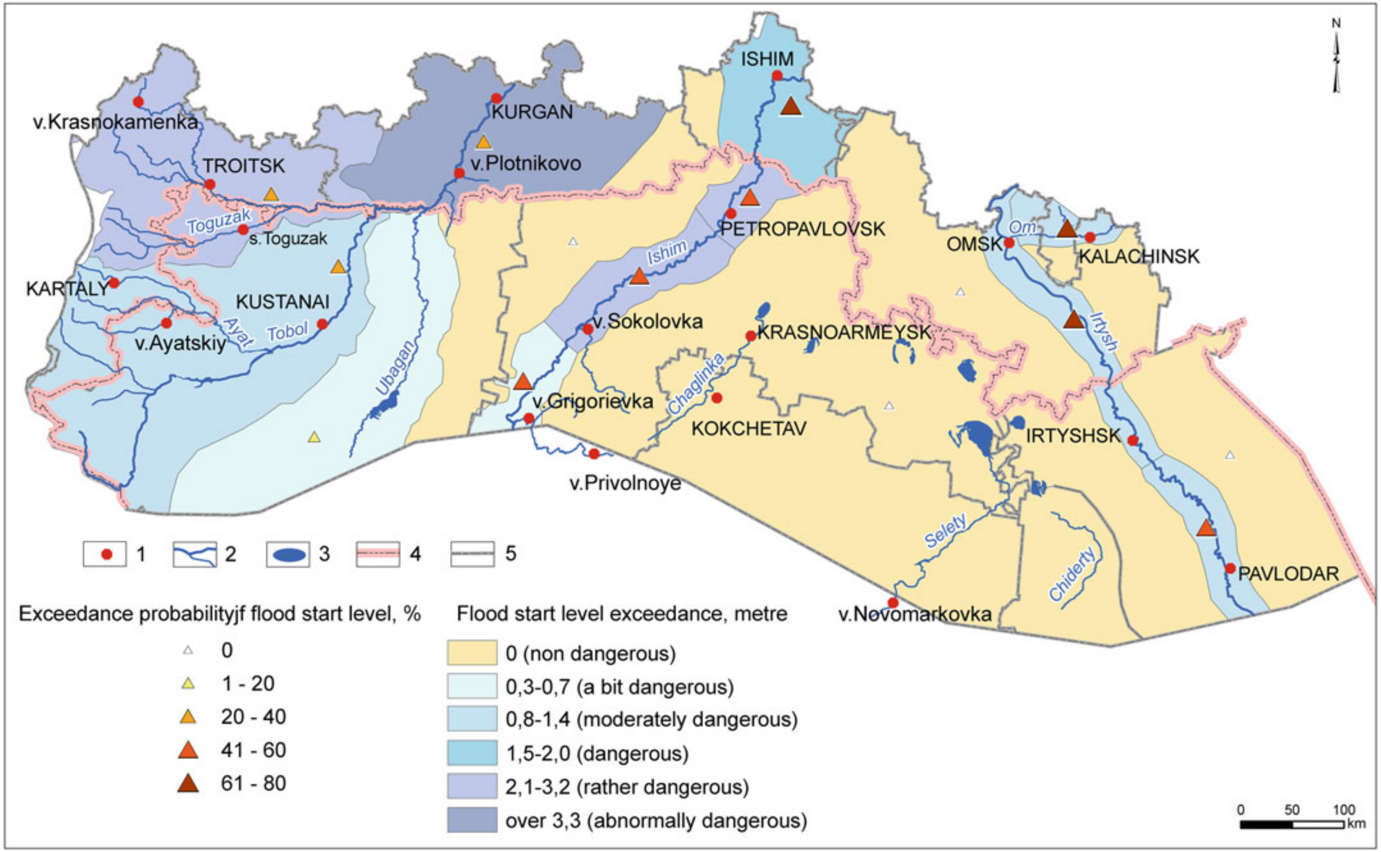

Fig. 2 Ranking of border areas of the Irtysh Basin by flood hazard [17]. 1 – settlements, 2 – rivers, 3 – lakes and reservoirs, 4 – states border, 5 – administrative subjects

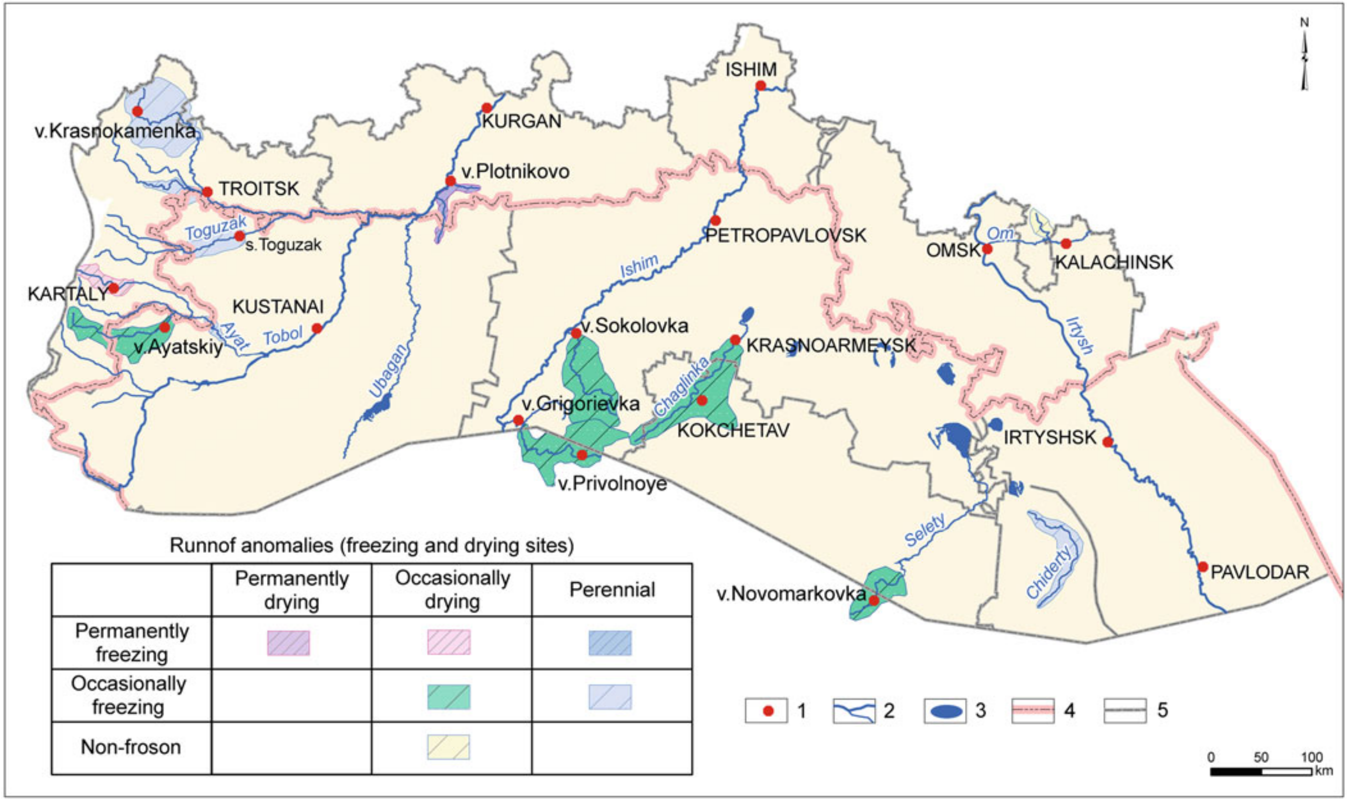

Fig. 3 Exposed to drying and freezing sites of rivers Irtysh, Ishim, and Tobol tributaries at the Russia-Kazakhstan border [17]. 1 – settlements, 2 – rivers, 3 – lakes and reservoirs, 4 – states border, 5 – administrative subjects

changes lead to an insignificant but steady trend in average annual discharge and runoff volumes.

The analysis of water content fluctuations in rivers of the Ob-Irtysh Basin was carried out based on the identified linear trends in series of average annual discharges [3, 13, 17–21]. For calculations we used the hydrological yearbooks' data on 35 rivers runoff and 69 hydrological gage sites in the upper and middle reaches of the Ob with the observation period of at least 50 years as well as the data of the Center of Register and Cadastre for the last 15 years [22–24]. Using the linear equations obtained from the trend, we calculated the normal runoff up to 2020 and 2030. Trends of average annual discharge are evidence of insignificant variations in normal runoff.

Using the established linear trends of average runoff in the study areas, the following zones of runoff change were identified (Fig. 4):

Zone 1 (−). By the year 2030, the decrease of discharges in rivers Anui (−2.2%/10 years), Katun (6.2%/10 years), and Biya (0.54%/10 years) will lead to a decrease in the discharges of Ob River at the Fominskoye water gage by 3.1% as compared to 2010.

Zone 2 (+). An increase in long-term annual mean discharge of the Ob left tributaries, in particular, rivers Aley and Charysh (at a rate of +0.40% and 85% over 10 years) provides the growth of that of the Ob river by the year 2030 by +1.1% (Barnaul) and +1.2% (Kamen-on-Ob) as compared to the year 2010.

Zone 3 (−). Right-bank tributaries of River Ob with decreasing normal runoff (rivers Chumysh, Berd, Tom, Chulym) produce the decrease in discharge of Ob River at Kolpashevo water gage by 3.1% as against 2010.

Zone 4 (+). Right-bank tributaries of Ob River, rivers Ket and Tym, show the increasing discharges. By the year 2030, the relative increase will make up 0.5% and 1.3%, respectively.

Zone 5 (−). The left tributary of Ob River, River Kasmala, and the rivers of the Ob-Irtysh interfluve (rivers Kulunda, Burla, and Kargat) will show the discharge decrease by 5.2%, 3.15, 0.85, and 3.9%, respectively, for 10 years.

Zone 6 (+). Within the Great Vasyugan Mire, a steady increase in the discharges takes place. This area demonstrates the maximum relative change of the discharge by the year 2030: River Om, 11.5% (southwest), and River Parabel 11.0% (east).

Zone 7 (−). Right tributaries of the Irtysh, rivers Shish and Tui, will reduce water content at a rate from −0.9 to – 3.1% for 10 years.

Zone 8 (+). The right tributary of River Irtysh – River Demyanka (its catchment area is a forested territory (50%) and wetlands (30%)) – has a 5.4% increase discharge every 10 years.

Zone 9 (+). Running through the Russian territory, River Ishim – the left tributary of River Irtysh – increases its water content by 6–7% every 10 years due to its forest-covered and wetland basin. From the Russian-Kazakhstan border up to Omsk and Tyumen Regions, forests cover 62% and bogs – 8% of the total basin area of 27,000 km^2. The river site from the Tyumen Region up to the river's mouth near village Orekhovo (the catchment area is of 20,000 km^2) is forested by 45% and waterlogged by 30%.

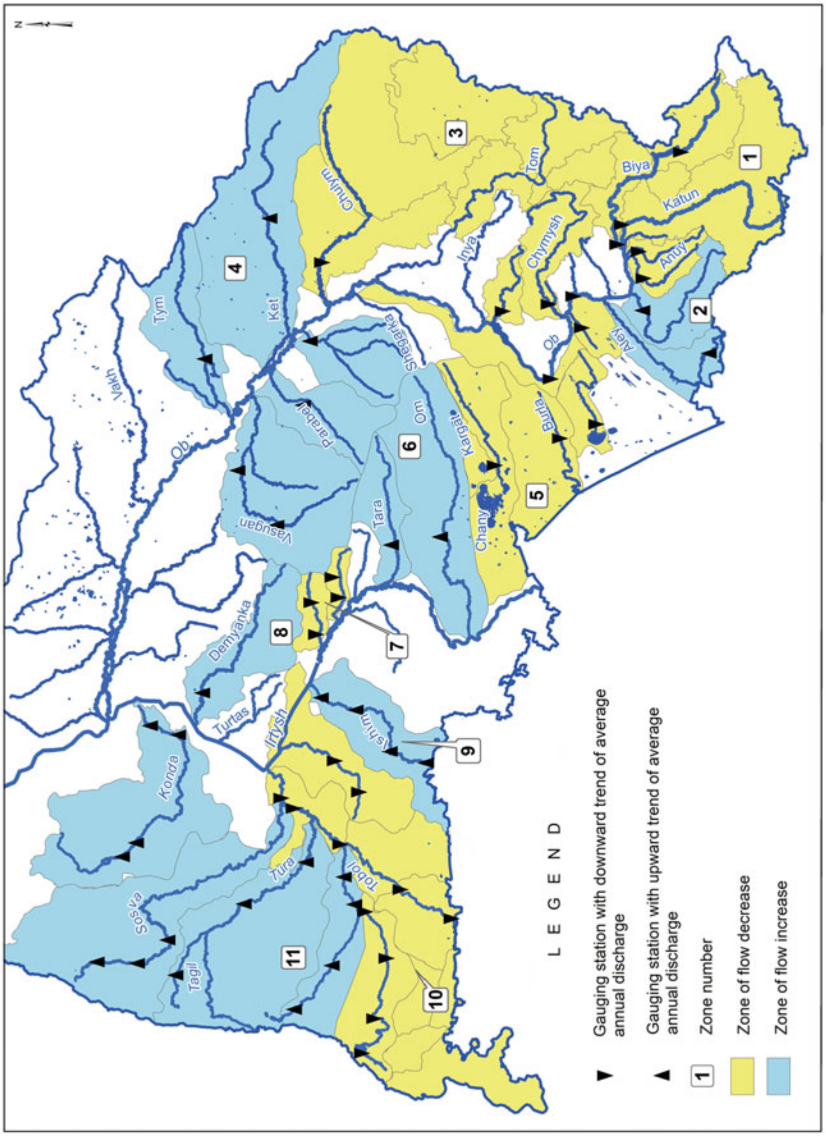

Fig. 4 Map of zones with changing Ob-Irtysh runoff induced by climate change in recent decades [18, 19]

Zone 10 (−). Left-bank tributaries of River Irtysh in the forest-steppe and steppe zones of River Miass (waterlogged by 5% or less), River Tobol (waterlogged in selected sites by 7–16%), and adjacent River Vagai running in the taiga zone will reduce their discharge.

Zone *11 (+).* Tributaries of the left-bank Irtysh from the taiga zone will increase their water content (tributaries of River Tobol are rivers Iset, Sos'va, Tura, and Konda – a tributary of River Irtysh).

A trend for Ob River (Fominskoye) is negative; its runoff decreases every 10 years by 1.5%. Nearby Barnaul and Kamen-on-Ob, the Ob runoff increases by 0.5 and 0.6% per decade, respectively. Reduction in the Irtysh River runoff did not exceed 2% (Omsk), 0.1% (Tobolsk) for the last 10 years as compared to a preceding decade.

Comparison of hydrographs of average monthly discharge for the last 20 years of the twentieth century (1980–1999) with the previous two decades (1960–1979) allowed to identify changes in annual distribution of rivers' runoff in this region for the study period and to estimate them quantitatively.

The annual discharge of the Ob for the last 20 years of the twentieth century (W_2, km^3/year) decreased as compared to that for the previous two decades (W_1, km^3/year).

Runoff at sites Ob-Fominskoye ($F = 98{,}200$ km^2, $W_1 = 34$ km^3/year; $W_2 = 36$ km^3/year) decreased by 5.7%, Ob-Barnaul ($F = 169{,}000$ km^2, $W_1 = 47.7$ km^3/year; $W_2 = 45.6$ km^3/year) by 4.4%, Ob-Kolpashevo ($F = 486{,}000$ km^2, $W_1 = 120.8$ km^3/year; $W_2 = 106.3$ km^3/year) by 12%, and Ob-Salekhard ($F = 2{,}430{,}000$ km^2 $W_1 = 408.8$ km^3/year; $W_2 = 391.7$ km^3/year) by 4.2%. In summer, runoff decreased, while in winter and autumn, it increased. For instance, at Barnaul the monthly volume of runoff fell in spring and summer (March–July) by 12–16%; in a winter and autumn low water period (August–February), it increased by 3–11%. In the twenty-first century, annual average runoff of the Ob at Barnaul in 2000–2015 reached 50.3 km^3/year that is 8.85% more than in the last two decades of the twentieth century. This is due to the alternation of wet and dry periods. In the early twenty-first century, the Ob River runoff was the highest; the years 2009, 2014, and 2015 were distinguished by relatively high and the years 2010, 2011, and 2013 by high water content.

The Irtysh River runoff (Omsk) was regulated by the cascade of Upper-Irtysh water reservoirs built on the territory of Kazakhstan with weekly (1959), seasonal (1987), and long-term (since 1966) regulation. In the long-term hydrograph of the Irtysh (Omsk, 1923–2007), two periods of different water content were specified. In 1923–1962, average annual maximum was 41–47 km^3/year and annual average runoff remained as 29.2 km^3/year. In 1963–2007, the period of multiyear flow regulation, runoff maximum dropped to 35 km^3/year (1972, 1973) and later up to 31 km^3/year (1979, 1994, 1995, 2002). For this period, average annual runoff decreased by 3 km^3 and reached 26 km^3/year. Functioning from 1975 the K. Satpayev Canal with a capacity of 2.3 km^3/year has reduced the annual runoff of the Irtysh approximately by 1 km^3.

According to the Russian Water Cadastre, the volume of average annual runoff of the Irtysh in Omsk (2014) was estimated as 30.3 km^3/year [2]. The average long-term annual discharge of the entire series of observations, according to random processes hypothesis, does not depend on the series length. In fact, the average value of the average long-term annual discharge depends on the observation series length; furthermore, a linear trend is insignificant and, therefore, neglected. Runoff value for a decade or a year differs from the averaged of the whole series.

The year 1978 became the turning in estimating the climate change effect on annual runoff distribution in the rivers of the Irtysh basin due to the State Hydrological Institute research [25]. In the Irtysh tributaries at stable hydrographs during a flood phase, slightly increased runoff in the taiga, and slightly decreased in the forest-steppe zone were registered.

Runoff in the right-bank Irtysh increased in October–March minimum by 11% and maximum by 76%, while in April it fell by 5–40% (except for the Tui with runoff increase of 42%). In general, rivers' runoff in the taiga zone (rivers Tui and Shish) decreased in June–August by 30–40%, and in the forest-steppe zone, it increased by 10–25%.

In April, runoff of the left-bank Irtysh dropped or grew insignificantly. The increase in monthly runoff was largely recorded in rivers of left (not right)-bank rivers due to their larger catchment areas.

5 Water Intake and Use and the Share of Withdrawal in Landscape Provinces and River Basins

According to the upper and low Ob Basin Departments (BDs), a total of 9 km^3 of water (8.5 km^3 by the State Hydrological Institute data for 2014 [2]) are annually taken from the Ob-Irtysh Basin for economic needs.

In 1990–2007, the largest volumes of water intake fell on the basins of rivers Tom and Tobol (30% and 25% of total water withdrawal from the Ob-Irtysh catchment, respectively) [26]. In 2013, this indicator was in the lead in the basin of the Ob with its tributaries (35% of total water intake). Water withdrawal from rivers Tom and Irtysh including the Tobol was 29 and 28%, respectively, and from the Chulym – 8%. It should be noted that water withdrawal from all water bodies of the Ob-Irtysh Basin in 2013 dropped by 12% as compared to 2009. Water intake was reduced in the basins of rivers Tom, Chulym, Irtysh, and Tobol, except for the Ob and its tributaries (5% growth).

Sites of major water intake (and sites of wastewater discharge) are confined to cities and industrial centers located in the forest-steppe, southern taiga, and the northern steppe zones. Large water volumes are also taken in the mid and northern taiga areas due to oil and gas industry development in these regions. In the industrially developed regions of Russia, big intakes are mainly made by power engineering and metallurgical enterprises.

Table 2 Main indicators of water use, mln m^3 in regions of the Ob-Irtysh Basin for 2013

Indicators		Regions											
		1	2	3	4	5	6	7	8	9	10	11	12
Water intake from sources, total		8.53	438.60	649.41	2070.04	7.60	570.70	509.68	254.65	76.65	481.96	958.86	2101.32
Used	From surface	1.97	317.90	527.52	1568.29	1.96	532.58	354.98	191.51	45.62	309.11	648.72	1307.93
	From underground	5.73	86.79	41.28	161.49	1.04	15.49	70.12	9.13	13.16	34.13	126.17	728.86
Wastewater discharge of all categories, total		4.49	314.43	514.76	1763.49	5.88	473.96	372.32	171.70	42.49	303.82	937.40	1145.59

1 – Republic of Altai, 2 – Altai Krai, 3 – Novosibirsk Oblast, 4 – Kemerovo Oblast, 5 – Republic of Khakassia, 6 – Krasnoyarsk Krai, 7 – Tomsk Oblast, 8 – Omsk Oblast, 9 – Kurgan Oblast, 10 – Chelyabinsk Oblast, 11 – Sverdlovsk Oblast, 12 – Tyumen Oblast [data of the Federal Agency for Water Resources (FAWR) [Electronic resource http://www.gks.ru/wps/wcm/connect/rosstat_main/rosstat/ru/statistics/databases/emiss/]

The greatest amount of water withdrawal falls on Tyumen and Kemerovo regions (Table 2).

In the structure of freshwater, surface water sources are in the lead; their share in the Ob-Irtysh Basin accounts for 84%. The largest volumes fall on the Chulym (95%) and the least on the Ob with its tributaries (74%).

For the period 2009–2013, the share of surface water used in the Ob-Irtysh Basin dropped by 1.6%. Actually, the greater reduction in water intake from surface water sources (average 13%) was registered. In the basin of rivers Tom and Chulym, it was 19% and in the basin of the Irtysh with the Tobol, 15%, and only the basin of the Ob with its tributaries showed a small increase of 4%.

The share of the used underground water in the Ob-Irtysh Basin is negligible on average 16%; its maximum is marked in the basin of the Ob with its tributaries (26%) and minimum in the Chulym River basin (5%). In 2009–2013, the use of underground water dropped by 1% on average. The greatest reduction in groundwater use was noted in the Irtysh and Tobol basins (18%) and the lowest in the Tom basin (less than 1%). The growth of groundwater use by 8% was observed in the basin of the Ob with its tributaries.

The use factor of renewable water resources in the Ob-Irtysh Basin is generally insignificant – it makes up around 1.4%. However, in some landscape provinces (Kuznetsk Alatau, Trans-Ural, etc.), this indicator exceeds 3.0% reaching its maximum in Nazarovo and Ural mountain-forest-steppe provinces (9.5% and 16.2%, respectively).

The comparative analysis of groundwater volumes and use of their water resource potential shows that in the Kuznetsk Alatau, Tarko-Zalessk, Kuznetsk mountain depression, Kulunda, mountain-steppe Ural, Trans-Ural, Surgut, mountain-forest-steppe Ural, Ust-Nadym, Severopriangarsk, Tobol-Ubagan, and Verkhnenydsk provinces, the use factor is greater than 3%. Its maximum falls on the Kuznetsk-Alatau province (19.7%).

For the bordering provinces and regions of Russia, the use factor makes up 1–3% or even higher in Kulunda, mountain-steppe Ural, Tobol-Ubagan, Barabinsk, Yuznoprealeisk, Teke-Kyzylkak, Yuzhno-Barabinsk, and Ishim provinces, which are geographically confined to Chelyabinsk, Tyumen, Kurgan, Omsk, and Novosibirsk oblasts and Altai Krai.

As for some river basins and water sites (Fig. 5), minimum of surface water use (<0.01%) is registered in the Altai Mountains (the basin of Lake Teletskoye and Katun River) and in mid and low reaches of the Ob, free from oil and gas field development. In the areas where oil and gas extraction is implemented, use factor increases significantly (the Vah Basin −1.8%, in dry years – 4%), but it does not exceed a low water stress index (<10%).

During dry periods, light water shortage (10–20%) may occur in the basins of some steppe rivers, including the areas of internal drainage of the Ob-Irtysh interfluve. In two Ural water economic sites, it takes place in average water years: in the basins of Uvelka River, it makes up 11.1% and in Neiva River (from the source to the Neiva hydroelectric complex) – 12.8%.

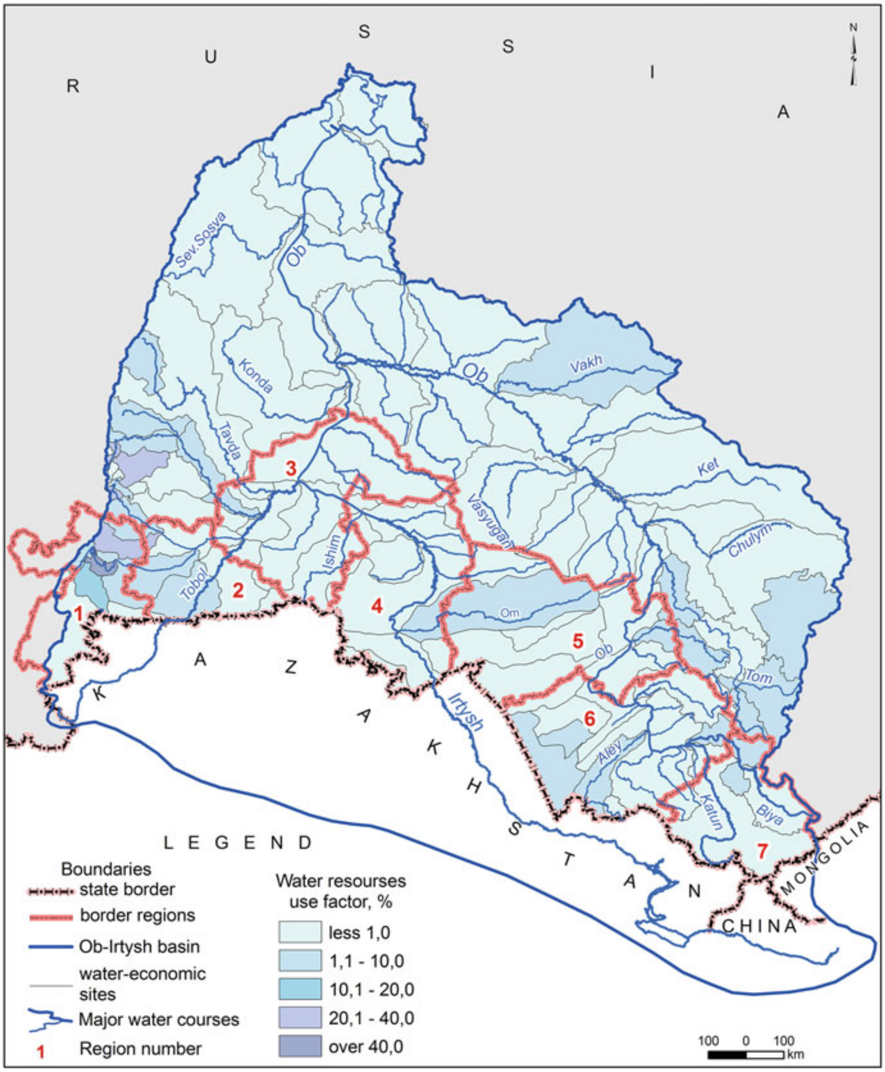

Fig. 5 A factor of water resources use in the basins and water-economic sites (2013)

Use factor of water resources in the Tom Basin varies from low (<10%) to medium and even high (20–40% and higher). For example, at town Myski total surface water withdrawal exceeds 20% of average annual runoff of Mrassu River.

Medium (20–40%) and high (>40%) level of water shortage is observed in highly industrialized and densely populated regions of the Urals. For instance, in the upper parts of the basins of rivers Tagil (near Nizhny Tagil City) and Miass, water intake reaches 50–70% or more of their average long-term annual discharge. In the upper reaches of the Miass, near Chelyabinsk, water intake is equal to the river discharge;

in other words, the river runoff is fully formed of wastewater discharged by urban enterprises. Maximum of water use factor was marked on some sections of rivers Miass, 57.6%, Iset, 36.0%, Techa, 31.2%, Reft, of 28.1%, and Tagil, 22.3%.

6 Wastewater Load in Landscape Provinces and River Basins

The volume of wastewater of all categories discharged in the Ob-Irtysh Basin amounted to 6.1 km^3 in 2013 that is less than in 2009 (16%). About 98% of wastewater is discharged directly to the surface water bodies. The share of treated waters in the total wastewater structure of the basin is only 9%, contaminated, 35.5% (including nearly 6% of untreated water), and clean waters, 55.5%.

The largest volumes of wastewater discharge were recorded in the basin of the Tom (over 32% of total volume of the Ob-Irtysh Basin) in 2013. Discharge of wastewater of all categories in the basins of rivers Ob and Irtysh with Tobol made up 29 and 30%, the Chulym – 9%.

In the territorial-administrative aspect, maximum amounts of wastewater of all categories are annually formed in Kemerovo and Tyumen regions. For example, in 2013 they reached 1,763.5 and 1,145.6 mln m^3, respectively. In Tyumen Oblast, the greatest sewage discharges fall on the enterprises of Khanty-Mansi Autonomous Okrug (KHMAO), 824.5 mln m^3, while minimum ones on the Republic of Altai (4.5 mln m^3).

Some regions discharge mainly untreated or undertreated sewage. Thus, most water discharged by large cities and industrial centers (up to 100–300 mln m^3) is classified as "polluted." These are industrial centers of the Urals (Chelyabinsk, Yekaterinburg, Nizhny Tagil, etc.) as well as cities Novokuznetsk, Omsk, Nazarovo, and Sharypovo [26].

Among water-economic sites, the greatest volume of wastewaters of all categories falls on Tom River (from its source to Novokuznetsk, except for Kondoma River), 1,154.5 mln m^3, that makes up approximately 19% of sewage of all categories discharged in the Ob-Irtysh Basin; the share of polluted sewage exceeds 25%. Almost 500 mln m^3 of wastewater is discharged from three sites, i.e., it is the section of the Ob from Vakh River confluence up to town Nefteyugansk, the Chulym from its source up to town Achinsk, and the Ob from Novosibirsk HPP up to the Chulym confluence, except for rivers Inya and Tom.

In 2013, dilution ratio of wastewater of all categories in the Ob-Irtysh Basin was 66.3, whereas in most provinces, this index exceeded 1,000.

However, for 11 out of 83 provinces, dilution of sewage by surface water was less than 100. In terms of location, these provinces correspond to the most loaded sites in the basin: Sverdlovsk, Chelyabinsk (mountain-taiga, forest-steppe, and steppe provinces of the Urals and Trans-Ural, including Turinsk), and Kemerovo (the Kuznetsk Alatau and the Kuznetsk depression) Oblast. In the Nazarovo Province of

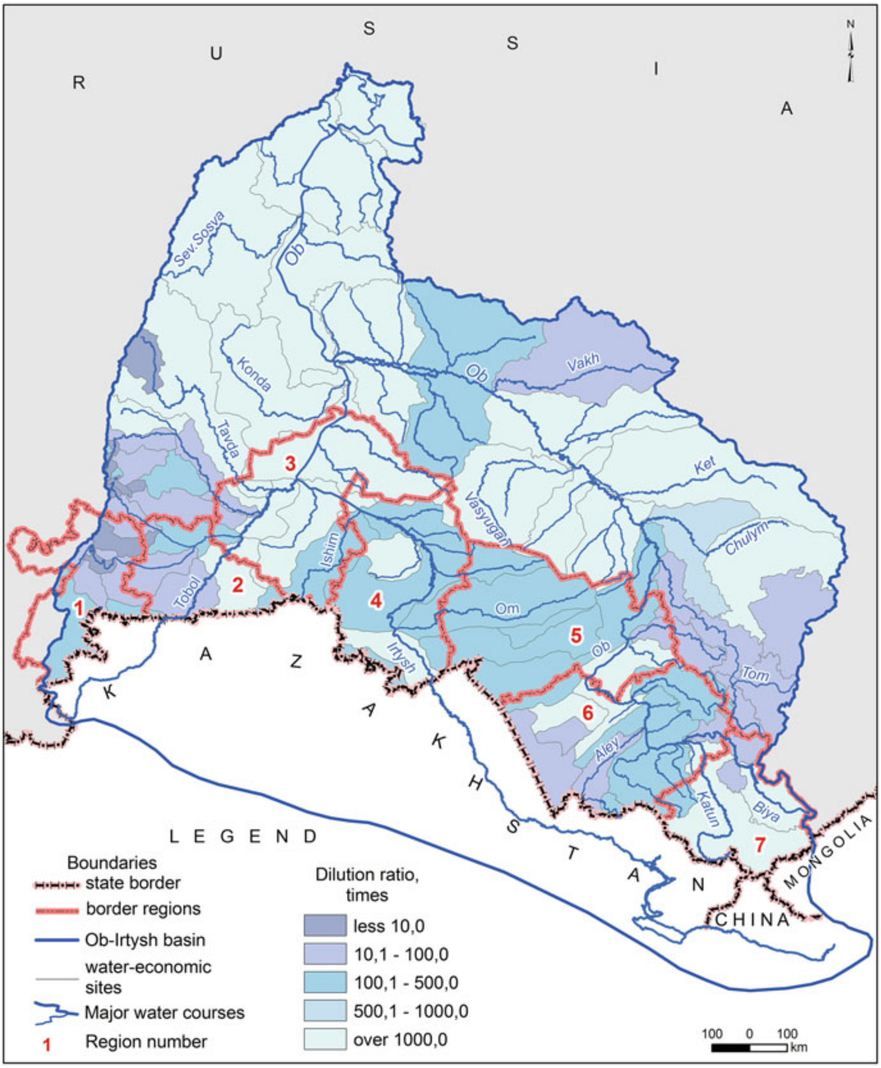

Fig. 6 Dilution ratio for wastewater of all categories (2013)

Krasnoyarsk Krai, the largest volume of wastewater discharge falls on Nazarovo and Sharypovo, in Severopriarginsk Region on Tomsk and Seversk, in the Upper Ob on cities Novosibirsk as well as Barnaul and Biysk (Altai Krai), and in the Vakh Province on Nizhnevartovsk HPP and KHMAO. Dilution ratio less than 10 is marked in two provinces, i.e., the mountain-forest-steppe province of the Urals and Nazarovo. Ratio of dilution by surface water does not exceed 100 in five studied provinces; in the mountain-forest-steppe province of the Urals, this index is 5.8.

As for river basins, the most loaded by wastewater of all categories was the Tom Basin (dilution ratio:16.8) and the Tobol (15.5). Some water bodies in the Tobol Basin (especially in its upper part) have a dilution ratio less than 10 (rivers Tagil, Miass, Iset, Pyshma, Reft, Neiva, Sos'va, Techa) (Fig. 6). Dilution ratio in the basins of rivers Irtysh (with Tobol) and Chulym equals 48.2 and 47.0, respectively. In the basin of Ob River with its tributaries, the load is minimal (229.0).

Dilution ratio under 100 is characteristic for another 21 sites. In addition to abovementioned Ural basins, these are upper reaches of rivers Tura, Rezh, Uvelka, and Tobol up to Tobolsk as well as all water-economic sites of rivers Tom and Aley below the Gilevo hydrosystem and rivers Vakh and Biya, including some closed areas of the Ob-Irtysh interfluve.

As for some water bodies, the lowest dilution ratio was recorded in the Tobol Basin, Nitsa, 0.59; Tagil, 0.78; Pyshma, 0.84; and Miass, 1.93, and in the Tom Basin, Bachat, 0.6, and Aba, 1.6.

7 Omsk Oblast as a Problem Region: Current State and Prospects for Water Availability

The territory of Omsk Oblast covers ten landscape provinces with different availability of surface and underground runoff that in turn has an effect on spatial differentiation of water use features.

The largest water withdrawal from the surface and groundwater sources (200.0 and 190.0 mln m^3/year that is about 75% of total water withdrawal and 90% of the water used in the region) occurs in the West Baraba Province, within which City of Omsk and almost the whole Omsk Oblast are located. In the structure of water supply sources, the surface water bodies dominate (99.1%). The share of water for drinking and economic purposes constitutes 50.3% of total water used in the province, for industrial, 45.6%, and for irrigation and agricultural ones, 4.1%.

The West Baraba Province is a home to 1.35 mln people that is 68.5% of population living in Omsk Oblast. The total volume of production is 583.8 mln Rub or 92.5% of gross regional product (GRP). The share of industrial production (mostly processing industry) makes up 565.8 mln Rub or 96.4% of GRP. Water capacity of GRP here is 0.34 m^3/1,000 Rub that is by 19% less than the average for the region. Industrial water consumption in this province is 0.15 m^3/1,000 Rub. In agriculture this indicator varies from 0.21 m^3/1,000 Rub in cattle breeding and up to 0.79 m^3/1,000 Rub in crop production that exceeds the average for this oblast by 25% and 88%, respectively.

Assessment of current water availability shows that most wealthy resources of surface water (including transit flow) are concentrated in North Baraba, Tobol, and Vasyugan provinces. However, with regard to local runoff, the largest specific water availability falls on Tobolsk (354.19 thousand m^3/(year/person)) and Vasyugan (267.31 thousand m^3/(year/person)) provinces. In the West Baraba Province, water availability consists of local runoff 0.15 and total runoff 20.52 thousand m^3/(year/person). Tobolsk and Vasyugan provinces possess considerable groundwater resources, i.e., 9,743 and 71.94 thousand m^3/(year/person), respectively, while the West Baraba Province has the least water resources – 0.12 thousand m^3/(year/person). Note that 130.5 thousand people live in Omsk Oblast under conditions of extremely poor water supply (<1.0 thousand m^3/(year/person).

Estimate of perspective water availability was carried out taking into account the peculiarities of water use and its efficiency (water capacity). Ongoing calculations will be illustrated on the example of the West Baraba area, where the central economic region of Omsk Oblast being industrially best developed one (over 90% of the region production) is situated. Here, the establishment of the industrial-production economic zone and the development of new high-tech industries, petrochemical, engineering, biotechnological, and other industrial complexes are expected.

According to the Strategy for the region development, the 2.7-fold increase in industrial production is expected by 2020 as compared to 2005 (mainly for 2015–2020, during the second stage of implementation of the Strategy 2025 called "Omsk Region – the industrial center of the south of West Siberia").

At a current rate of industrial growth, the load on water resources in the West Baraba Province will exceed permissible limits, since the present level of local water withdrawal reaches almost 100%. Note: if volumes of water intake are over 40%, it means a high level of water shortage or water stress [6]. However, according to other estimates, this index is considered to be "critically high" at 60% and higher [25]. The State Hydrological Institute data are evidence that in average water years the load on local runoff in Omsk Oblast does not exceed 5%, and with the least values for low water periods, it equals 18.3%.

When calculating perspective water availability, the previously obtained estimates of water consumption by enterprises were taken into consideration. In the West Baraba Province, by 2020, such a capacity under the inertial variant of development will be 0.15 m^3/1,000 Rub (i.e., will remain the same), and under the innovation one, it will fall to 0.14 m^3/1,000 Rub (10% less than in 2012). Thus, industrial water consumption by 2020 will increase for the inertial variant by 28.43 and for the innovation one – 20.73 mln m^3/year (note: in 2012, it was 86.95 mln m^3/year).

Experts believe [4, 27] that in the coming decade the river runoff will tend to increase in West Siberia. Probably, the resources of local and transit flow will not decrease by 2020, and according to the Rosstat demographic forecast, prospective water availability by this time in the region will be as follows: 0.16 including local runoff, 21.85 with transit flow, and 0.13 thousand m^3/(year/person) with groundwater flow.

8 Problems of Water Use and Water Resources Protection in Transboundary Basins of Rivers Irtysh, Ishim, and Tobol

Most problems of water use in the Irtysh Basin are typical for almost all transboundary water objects. One of major problems – water allocation – results from water shortage caused by natural and anthropogenic factors [28].

Natural factors are related to the upper and middle parts of the Irtysh River Basin situated in the arid inland areas of China and Kazakhstan. Main river flow is formed in the mountains of the Mongolian and Ore (Rudny) Altai; in the middle part of the basin (at the section below Semipalatinsk up to Omsk), it takes almost no tributaries. As a result, downstream runoff does not increase; on the contrary, it falls by 4.5% – from 30.3 to 28.9 km^3.

High anthropogenic load on the basin aggravates the situation. Within the territory of Kazakhstan and the Altai Region of Xinjiang Uyghur Autonomous Region (XUAR) of China, Irtysh River is the major waterway and the source of water supply to population and various sectors of the economy; in the river valley, most settlements as well as developed industrial and agricultural centers are concentrated.

In the upper reaches of the river, in the territory of China, the most developing economic part of the Irtysh basin (Kara-Irtysh River) is located. Water consumption here is mostly related to oil field development in Karamay-Urumqi water supply and irrigation of rapidly increasing cultivation areas. In addition, future water consumption will be associated with water supply to the Tarim Basin, where large deposits of oil and gas have been prospected.

To meet the increasing needs in water resources of China, two canals (i.e., Kara-Irtysh-Karamay and Kara-Irtysh-Urumqi) were built. In 2012, about 1.8 km^3/year of water (20% of average long-term annual discharge at the site of China-Kazakhstan border) were taken from Kara-Irtysh; in the immediate future, these volumes will increase for sure. By experts calculations made in the Institute "Kazgiprovodhoz," technical capabilities of canals can provide water transfer to Karamay and Urumqi at most up to 6.3 km^3/year [http://www.group-global.org/storage_manage/download_file/2029]. The coming years may witness water withdrawal of 40–70% (9.0 km^3/year) of the Irtysh average long-term annual discharge at the site of China-Kazakhstan border [29, 30]. All of this can present a considerable challenge to the states located downstream the river, especially for Kazakhstan.

In Kazakhstan, the Irtysh Basin is one of the most industrialized regions due to its enterprises of mining and metallurgical complexes. Recently, in the south of Eastern-Kazakhstan Oblast (EKO), oil production has been started. For river flow regulation, three large cascade reservoirs (Bukhtarma, Shulbino, and Ust-Kamenogorsk) were built.

Nearby Pavlodar, the Irtysh water is delivered to the central part of the Republic of Kazakhstan (RK) via the Irtysh-Karaganda Canal to provide growing needs of Astana, the capital of RK, and agriculture. The Irtysh-Karaganda Canal (the Kanysh

Satpayev Canal) has a capacity of 2.0 km^3/year (actually it is 1.0 km^3/year; in 2011 water intake was less than 0.5 km^3/year [ecocenter.kz/sites/default/files/]); it transfers some runoff of Irtysh River into the basins of rivers Nur, Kengir, Sary-Su, and Shiderty [3].

With annual water intake of about 3 km^3 at average long-term annual discharge of 27.9 km^3 (village Ekaterininskoye, a border with Russia), the Irtysh has a very high level of water withdrawal (about 12%) that corresponds to water shortage state.

Kazakhstan, like China, plans to increase water intake from the Irtysh significantly, and to do that is by using the Canal Irtysh-Karaganda (up to 1.5 km^3) for purposes of irrigation and water supply to Astana. Moreover, to solve the problems of water deficit, a large number of projects on the river runoff redistribution are being developed, for example, the project on partial withdrawal of water from Katun River (Republic of Altai, Russia) by transferring its tributary (Tikhaya River) and by bending rivers Ak-Kaby and Kara-Kaby originating from East Kazakhstan Oblast and then flowing into Kara-Irtysh River on the territory of China.

In the Russian territory, Irtysh River is the major source of water supply to enterprises of Omsk Oblast and a city-millionaire Omsk; the total annual water intake here amounts to 230–260 mln m^3, and the region does not experience water stress in average water years (<10%). Nevertheless, in the short water years and the periods of autumn and winter, low water withdrawal can reach 20% or more. In this case, water stress is considered to be moderate, and water (as a resource) is a factor limiting the region's development [28].

To provide a stable water supply to population and economy of Omsk, to avoid water deficit peaks in dry years and periods, as well as to improve the environmental and sanitary state of the Irtysh, the construction of the Krasnogorsk water-retaining structure and the reservoir with a capacity of 123 mln m^3 [http://invest.arvd.ru/project] is being implemented.

Water resources of Ishim River are formed mainly in Kazakhstan. With an average annual runoff of 2.2 km^3 and water intake over 200 mln m^3, water stress here is under 10%. Meanwhile, in dry years, when the river runoff is reduced in the tens and hundreds of times [25], withdrawal coefficient can reach 20–40% and even more, thus causing serious water problems, including those in the border areas of the Russian Federation (Tyumen Oblast) [17]. Until recently, on the Russian territory, the river runoff exceeded 65%. Nowadays, the problem becomes critical because the apportionment structure has been changed mainly due to the growing water demands of Astana, the capital of Kazakhstan.

The Astana (Vyacheslav) reservoir is the key source of water supply to Astana, but it does not cover the growing needs of the city. In 2001, hydraulic facilities (with a capacity of 288 thousand m^3/day) to transfer water from the Irtysh-Karaganda Canal to the upper reaches of Ishim River were put into operation [31]. Partially, Nura River runoff is also transferred to the Ishim via the Nura-Ishim Canal (255 mln m^3/year).

The draft on the transfer of some flood runoff of the Ishim to the south (into the Turgay and then to the drying up in summer Lake Shalkar-Teniz) does exist. Some experts believe that the river's water runs through the Russian territory, rivers Irtysh and Ob, and finally falls into the Arctic Ocean "in vain" [http://www.proza.ru/2009/01/06/536].

The Ishim Basin within the Russian territory is the least loaded part of the basin. According to Russian Hydrometeoservice data, the average annual runoff of the river at the Russia-Kazakhstan border (Ilyinka River) is 1.5 km^3 and at the site of Ishim River, 1.75 km^3. In dry years, runoff is reduced 10–20-fold or more, accounting at the head section only 0.06 km^3/year. The river with six small reservoirs is the source of water supply to the population and economy of Ishim City and the Ust-Ishimsky Region. At withdrawal rate over 10 mln m^3, water stress can reach 17% and even more in dry years.

Tobol River flows from the Russian territory, crosses Kostanay Oblast, Kazakhstan, and comes back to Russia. The total volume of surface water resources in the Kazakh part of the basin is of 0.78 km^3/year at an average annual runoff of the Tobol of 0.55 km^3/year at the site of the Kazakhstan-Russian border. If water withdrawal exceeds 100 mln m^3/year, water stress in the basin is around 20–25%.

In Kazakhstan, the river's runoff is well-regulated; a strong tear and wear of the existing hydraulic structures built in the second half of the last century is observed. In order to ensure the water supply to mining and ore-dressing plants including towns and settlements, the Tobol flow was regulated due to seven reservoirs (total volume of 1.5 km^3), the largest of which are Verkhnetobolsk and Karatomarsk ones [32].

In Russia, the Tobol Basin is the most problem in the Irtysh basin, especially its tributaries, i.e., rivers Iset and Miass, where large industrial centers of the Urals (cities Yekaterinburg, Chelyabinsk, Nizhny Tagil, etc.) are situated. In some sections of rivers Tagil and Miass, water stress is up to 50–70% or even more; in the upper reaches of the Miass, the volume of water intake is equal to river discharge [26]. This occurs because largest cities (including cities-millionaires) and water-intensive industries were built at river sources distinguished by water deficit.

To improve water supply of large cities and industrial centers, in the basin over 600 reservoirs were constructed. Moreover, basin and interbasin (from basins of rivers Ufa and Chusovaya) redistribution of river flow is carried out.

Hot problems of water allocation in the Irtysh transboundary basin require making national and international decisions on water management regulation. Though transboundary Irtysh River crosses the territory of three countries, a trilateral agreement on its joint water use and its protection has not reached yet. Currently, only bilateral agreements have been concluded (between and by Russia-Kazakhstan, Kazakhstan-China) that hamper sustainable water resource management in the regions of the basin.

Acknowledgments The research was carried out within the framework of the scientific project N 0383-2016-0002 "Study of hydrological and hydrophysical processes in water bodies and catchments of Siberia and their mathematical modeling for water management and conservation strategy."

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Conclusions

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Igor S. Zonn, Sergey S. Zhiltsov, Andrey G. Kostianoy, and Aleksandr V. Semenov (eds.), *Water Resources Management in Central Asia*, Hdb Env Chem (2020) 105: 189–198, DOI 10.1007/698_2020_605,
© Springer Nature Switzerland AG 2020, Published online: 7 July 2020

Abstract Water management remains one of key issues in Central Asia. The second volume on Water Resources in Central Asia addresses this issue and studies in-depth the legal regulations in water management that have been the basis for the regional countries after breakup of the single system of management that existed in the Soviet Union. The current approaches of the Central Asian countries to potential mechanisms of water management in the future are investigated. Regardless of introduction of the new paradigm of integrated water management, it is impossible so far to speak about its efficiency, and this is due to tough positions of the regional countries in the water-energy sphere and non-readiness to take into account the interests of their neighbors.

Keywords Central Asia, Conflicts, Management, Water resources

1 Introduction

The issue of water management has come to the fore due to nearly complete development of water resources in many world countries. This is true, at least, of the easily accessible water resources, and in the foreseeable future, no alternative ways for obtaining water resources are visible, more precisely, the economically validated ways. At the same time, the requirements in water are growing with every passing year. According to experts from the regional countries, the modern tendencies of climate changes and their effect on water resources, the growing water needs in view of the growing population and economic development, the economic and financial difficulties impeding implementation of projects, the regional threats, and other challenges aggravate still more the situation with water management in the Central Asian countries [1].

The persisting water deficit increases the probability of water conflicts enhancing at the same time their likelihood. Water similar to hydrocarbons is the basis of national security of each state because power generation by thermal, nuclear, and hydraulic plants depends on water. According to Zonn et al. [2], the conflicts in water resources management occur mostly not due to uneven distribution and absolute deficit of water, but due to endeavors of individual states possessing these resources to establish the absolute national sovereignty over them. Not only oil and natural gas but also water becomes the serious factor of interstate relations, the mechanism of influence. In the future the significance of this factor will only grow.

After disintegration of the USSR, the Central Asian countries faced for the first time the need to manage their sovereign power networks and national water economy. The matter is that the economy of this region was built-in and developed on the basis of the unified energy system of the Soviet Union and the “water quotas” policy of Moscow. After becoming independent the Central Asian countries broke up into two groups: hydrocarbon abundant (Kazakhstan, Uzbekistan and Turkmenistan) and water-abundant (Kyrgyzstan and Tajikistan) states. The management system, in particular in the first years of their development, was based on approaches used in the times of the Soviet Union.

The economic growth in the Central Asian states will require more water and energy. With the demographic growth and inflow of the agricultural population into cities and also in view of continuing climate changes, the water demand will be spurred, i.e., any development of the region will entail aggravation of the water-energy problem.

Active use of water in industry, agriculture, as well as in the housing and utilities sector will gradually deplete the world resources and make the countries dependent on water resources. This, first of all, refers to the developed and developing countries. According to UN estimates, by 2025, the world community will need 22% more water than in the recent years [3]. In water-based industries, the production growth may be held up.

In this context the interest to water resources management is growing. In the recent decades, considerable experience was amassed in this area. However, the absence of explicit legal norms and the conflict of interests prevent to implement in full the models of water resources management.

2 Central Asia

In 1998 Kazakhstan, Kyrgyzstan, Tajikistan, and Uzbekistan signed the framework agreement on joint use of water and energy resources of the Syr Darya River basin. It envisaged regulation of exchange of energy resources in the autumn-winter and spring-summer seasons and compensational measures. However, this agreement is not working, primarily, due to unpreparedness of some regional countries to adjust their national legislations to the water-energy realities that have been established in Central Asia in the recent decades.

For water-abundant countries, the issue of water sharing with neighbor states acquires the political dimensions, and this is demonstrated by the present-day relationships among the Central Asian countries. Some countries possessing sufficient water resources treat water as a commodity requiring pay for its use from their neighbors.

The uneven distribution of water resources in the Central Asian countries brings to the fore the need of more in-depth interaction in the water sector and introduction of the adequate system of water management. In the face of the sharply growing demographic, social, and economic pressure on natural resources, the issue of joint use and protection of water resources has become more complicated. The countries of the region make attempts to find the mutually acceptable ways of water management, but so far they have been not very successful as there are no effective mechanisms that are capable to regulate the relationships among the states in water management.

The Central Asian countries have tried more than once to develop the legal norms regulating the water management. As it is stressed in Zhiltsov et al. [4], such steps were taken at the national and regional levels, but the prepared documents are mostly declarative and do not address all difficulties of relationships among the regional countries and do not give appropriate considerations to water use issues.

The lack of effective mechanism of water sharing, water use management and settlement of conflicts, the poor exchange of information on water quality, and its use are the main obstacles for regional cooperation in water use. Moreover, the littoral states are trying to divide the benefits from the access to water rather than the water proper which aggravates the joint use of transboundary water.

The countries consider the possibilities to improve transboundary water management by applying the norms of international law. But so far each country of this region continues developing its own strategy of water use which boosts up the rivalry in Central Asia.

The policy of the Central Asian countries is based on the centralized approach of governmental bodies to water management which reflects not only the established system of state administration but also the importance of water resources for economic development of these countries.

The water management on the national level is determined by the state of the social, economic, and ecological areas. The legislation reflects the problem of water deficit that is growing with every passing year. For this very reason, the growing concern is witnessed with respect to the legal aspects of water management.

3 Russia and Central Asia

Obviously the experience of the Soviet Union in water management may be applied, but only partially. It should be adapted to the realities of modern development of Central Asia. Well-known Soviet expert in water management S.L. Vendrov, considering the reconstruction of rivers in the USSR, noted that “in the future the use of the northern rivers’ flow remote from the places of consumption will be required, but we think that the urgent need to do this will appear . . . mostly in the 21st century” [5]. This was said in 1970; however, this idea of the Soviet scientist is quite relevant at present.

For this reason Russia follows closely the problem of water distribution and management in Central Asia. In the future the Central Asian countries together with Russia may start addressing the water and energy issues of this region on the integration basis. Development of hydropower engineering has led to considerable reduction of the use of coal, oil, and wood as well as to significant cutting of hazardous emissions into the atmosphere.

According to Zonn et al. [6], in any case Russia will have to address the water issues in Central Asia as it is one of the world’s top countries by the river flow. Quite unlikely that the balance between the population growth and distribution, on the one part, and natural water reserves, on the other, will be attained only through water saving in the Central Asian countries that suffer permanently from water deficit. Accordingly, the natural regimes of the existing river network should be transformed.

One of the perspective ways of addressing the water issues here is deemed to be international maneuvering of the river flow which will require long and serious scientific and engineering investigations of either previously abandoned projects or consideration of the new projects, but not their implementation in the nearest future.

4 New Technologies

The principally new technologies and territorial redistribution of river flow are the two ways that will be in the focus of studies in the future. With regard to the geography of the region, they may complement each other. But it should be mentioned here that the principally new technologies appear quite rarely; therefore, the more in-depth and intensive study of both ways should be conducted to resolve the water availability problem. But before choosing any scheme of river flow redistribution, the measures to improve the water use efficiency in the existing water conveyance and irrigation systems must be taken.

At present there is only one not large country in the arid zone – Israel – that combines successfully these two ways creating a special natural and technogenic structure as a basis for development of highly productive agrotechnologies. In Israel water is a strategy, security, and independence. In this country the Central Asian slogan "A drop of water – a grain of gold" is realized not in words but in deeds [7].

The river flow transfer projects reflect, to a certain extent, the endeavors to find a new model of international cooperation and worldwide management in the conditions of the emerging multipolar world. This new approach is perhaps a key to resolving the water problems in Central Asia.

But so far some one-sided approach is observed in this region to water flow regulation and management. Flow regulation also supposes implementation of actions for efficient water use in land areas along the whole length of rivers. In the downstream countries, the overuse of water is enormous: only in Uzbekistan it amounts to 7–8 km^3. The construction of large HPP and reservoirs in the region may alleviate the water deficit in the downstream areas, but only if irrigation water is used with due care.

5 Negotiations on the Use of Water Resources

However, in the Central Asian countries, the one-sided approach to the water use and management prevails. According to Alamanov et al. [8], Kyrgyzstan should include in its water policy; some measures the key issues of which should be the following international legal initiatives. First of all, it is necessary to continue initiating the development and adoption of the multisided regional document on water relations. The regular negotiations on the rational distribution of water resources on the mutually beneficial basis are required. The negotiations should be aimed at development and adoption by the Central Asian countries of the basic document equal to the Convention on the Use of Water Resources in the Central Asian Countries that is called to implement the potentials of the following principles of cooperation in the water area already acknowledged by the Aral Sea states: "The member states recognize as general objectives the regulation of the system and better discipline of water use in the basin, development of the relevant interstate legal and regulatory documents identifying the common for the region principles of repayment of losses and damages" (Article 1 of the Agreement on "Joint Actions Towards Solving the Aral Sea and Priaralie Problems, Environmental Improvement and Provision of the Socioeconomic Development of the Aral Region" (Kyzyl-Orda, 26 March 1993) [9]. It stressed the idea to renounce the 1992 Alma-Ata Agreement that simply confirmed the scheme existed in the Soviet time and to continue negotiations on revision of the conditions or about development of a new agreement [10].

Similar ideas are suggested by other Kyrgyz experts. Thus, Kyrgyzstan developed the Draft Concept of the National Policy in the Use of Transboundary Water. It assumes the need to ensure the state interests of Kyrgyzstan in the conditions of market relations with the all-round cooperation with the Central Asian countries. This Concept suggests introduction of economic mechanisms in water use, thus, recognizing water as a special commodity. In addition, this Concept proposes to assume that in the water policy, all regional states should obtain the mutually beneficial conditions, which conduct the joint monitoring of transboundary rivers to establish more effective control of formation and use of water resources and to prevent and alleviate the damage incurred by hazardous hydrological events and their consequences at the interstate level and should establish the governmental systems for surveillance of security of hydraulic facilities. Kyrgyzstan proceeds from the fact that only after recognizing and adoption of the basic provisions of this Concept by the governments of all regional states, it will be possible to go over to the concept of Integrated Water Resources Management (IWRM) [11].

Tajikistan focuses on the issues of water management, too. Mukhabbatov and authors [12] note that the complexity of water management is the main obstacle for settlement of numerous regional, internal, and local conflicts. It seems insoluble for the engaged parties. Among five Central Asian states (Tajikistan, Kyrgyzstan, Turkmenistan, Uzbekistan, and Kazakhstan), there are two groups: water-abundant countries (Tajikistan and Kyrgyzstan) located in the upstream of the Amu Darya and Syr Darya rivers and the downstream water deficit countries (Turkmenistan, Uzbekistan, and Kazakhstan). While speaking about difficulties with water management, Tajikistan pursues its own policy aimed at construction of large hydropower plants.

The downstream countries do not possess adequate water resources. In addition, the surface water resources are distributed unevenly and subject to considerable variations in time. According to Parkhomchik [13], the water deficit is observed here because nearly the half of the river flow is formed in the territories of neighbor countries. But still within the framework of the green economy strategy, Kazakhstan concentrates its efforts on commissioning of not large hydropower facilities being environmentally friendly and not costly [13].

The strategy of construction of small power plants being implemented in Kazakhstan does not solve the regional problems of water management. More likely these measures are aimed at enhancing the water security inside the country and are called to make the issue of water deficit less acute.

6 Integrated Water Resources Management

The Central Asian countries do their best to follow the world trends in water management, although these problems were recognized at the international level only in the early twenty-first century. The World Summit on Sustainable Development held in Johannesburg in 2002 acknowledged that the concept and principles of the Integrated Water Resources Management were crucial for sustainable development.

The Integrated Water Resources Management (IWRM) is called to balance water resources for all respective sectors, political courses, and institutions to attain the national water, food, and energy security. Such management requires simultaneous assessment of various water use alternatives and provides the structure including the interested strategies for addressing future problems and uncertainties. IWRM engages many stakeholders to develop rules of water management which with respect to transboundary waterways supposes international cooperation [14, 15].

A failure in the past to recognize the economic value of water has led to wasteful and environmentally hazardous use of water resources. Management of water as an economic commodity is a very important method to attain the effective and just use of water and also to promote economic development and protection of water resources. The integrated management assumes that all kinds of water use should be considered in their totality and interrelation. Therefore, IWRM represents a systemic process of sustainable development, sharing and monitoring of water resources in the context of social, economic, and environmental goals.

In the recent time, the Central Asian countries have been introducing a new paradigm of integrated management into water planning and management. The existing administrative-territorial management system in the market economy conditions demonstrates its ineffectiveness.

In the present-day conditions, the basin system of management which is a part of IWRM is most potent. It allows for application of the better systems for management of water, accounting and collection of water pay, and control of its rational use. This is most important as the water use efficiency should be calculated as the quantity of water used per unit of produce.

The reforms in the water sector on the IWRM principle are supported by governments, governmental bodies, parliaments, and public associations. The main requirements of IWRM are outlined in water codes. However, the distribution of responsibility and reporting of the obtained results and indicators are far from the expected.

With the growth of water demand, the rivalry in transboundary river basins becomes more acute. Coping with this problem urges to change over from the former water use concepts to the Integrated Water Resources Management that will ensure the multipurpose and balanced achievement of the goals of economic development and environmental security of river ecosystems. Therefore, when speaking about hydropower engineering development, it should be considered in the context of the common goals of transboundary river use. In all likelihood this will be a reliable way to avoid monopoly in international relations concerning any kind of water use.

7 Conclusions

The issue of water resources management stirs great interest, and many publications study different aspects of and approaches to management. Among such publications are the following: Integrated Water Resources Management in Central Asia: the Challenges of Managing Large Transboundary Rivers. Global Water Partnership. 2014; Hudgson S. Strategic Water Resources in Central Asia: in Search of a New International Legal Order. EUCAM Policy Brief. 2014. №14; Implementing Integrated Water Resources Management in Central Asia. Ed. Wouters P., Dukhovny V. and Allan A. Springer. 2007. These and other books made their contribution into study of the problem related to water resources management in Central Asia.

Management of flow of river basins is deemed to have good prospects in addressing the water problems. This will require long scientific and engineering studies of either abandoned projects or consideration of the new ones. But as this will require significant financial inputs, their implementation in the nearest future is quite problematic.

As renowned US geographers P. James and J. Martin wrote, “we should move forward not repeating the mistakes of the past, but always with the bold drive to develop new hypotheses and, at the same time, not to be fearful to assess critically the existing hypotheses and may be even to abandon them” [16].

Acknowledgments A.G. Kostianoy was partially supported in the framework of the P.P. Shirshov Institute of Oceanology RAS budgetary financing (Project N 149-2019-0004).

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