Water Resources Development and Management

Jilili Abuduwaili · Gulnura Issanova
Galymzhan Saparov

Hydrology and Limnology of Central Asia

Springer

Water Resources Development and Management

More information about this series at http://www.springer.com/series/7009

Jilili Abuduwaili · Gulnura Issanova
Galymzhan Saparov

Hydrology and Limnology of Central Asia

Springer

Jilili Abuduwaili
State Key Laboratory of Desert and Oasis Ecology, Xinjiang Institute of Ecology and Geography, Chinese Academy of Sciences
Urumqi
China

and

Research Centre of Ecology and Environment of Central Asia (Almaty)
Almaty
Kazakhstan

Gulnura Issanova
State Key Laboratory of Desert and Oasis Ecology, Xinjiang Institute of Ecology and Geography, Chinese Academy of Sciences
Urumqi
China

and

Faculty of Geography and Environmental Sciences
Al-Farabi Kazakh National University
Almaty
Kazakhstan

and

Research Centre of Ecology and Environment of Central Asia (Almaty)
Almaty
Kazakhstan

Galymzhan Saparov
Research Centre of Ecology and Environment of Central Asia (Almaty)
U.U. Uspanov Kazakh Research Institute of Soil Science and Agrochemistry
Almaty
Kazakhstan

ISSN 1614-810X ISSN 2198-316X (electronic)
Water Resources Development and Management
ISBN 978-981-13-0928-1 ISBN 978-981-13-0929-8 (eBook)
https://doi.org/10.1007/978-981-13-0929-8

Library of Congress Control Number: 2018943710

Printed on acid-free paper

This Springer imprint is published by the registered company Springer Nature Singapore Pte Ltd.
The registered company address is: 152 Beach Road, #21-01/04 Gateway East, Singapore 189721, Singapore

Preface

Water resources of Central Asia are formed mainly in mountainous areas and occupied more than 20% of the Aral Sea basin area (3,50,000 km^2). About 90% of the surface runoff is formed in this area that is 115 billion m^3 of water (in the average water year). Mainly, they are located within two large river systems: Amudarya and Syrdarya rivers.

Lakes are a source of significant water resources, organic and mineral raw materials. Lakes are used for water supply, irrigation, watering of livestock, and for the development of fishing. Some salt lakes are deposits of valuable mineral raw materials for the chemical, food, and other industries (sodium and magnesium chlorides, sodium sulfates, etc.). In addition, most of the highly mineralized lakes contain significant reserves of medicinally valuable mud (mineral mud), and they have a great balneological significance. In addition, some lakes have a great recreational value.

Lakes are original water complexes and one of the most important elements of natural landscapes. They differ from the surrounding natural complexes of land. There are thousands of large and small lakes spread on the territory of Central Asia and Northwest China. They distributed on the plains and in the mountains as well. There are more than 51,000 lakes with a total area of 14,571 km^2 on the territory of Central Asia, including in the basins of the Amudarya, Syrdarya, Shu, Talas rivers, Issyk-Kul Lake, Eastern Pamir, and Tien Shan, as well as the drainless regions of Turkmenistan. There are 700 lakes in the arid regions of Northwest China, including 29 lakes in size more than 10 km^2.

Limnology is an independent complex science of continental water reservoirs with slow water exchange such as lakes, water reservoirs, ponds belonging to the family of geographical disciplines. This complex science studies the interaction of physical, chemical, and biological processes taking place in water reservoirs, as well as the history and evolution of lakes.

At present, the problem of integrated study of lakes is becoming increasingly important. Its correct solution is the study of the lakes in the arid regions of Central Asia and Northwest China. Since the Lobnor lake was dried up because of increasing anthropogenic factor, the same situation was observed in the Aral Sea

Basin. The basin is characterized by crisis level and became a catastrophical region. The rapid development of the economy requires the full utilization of all natural resources.

The main aim of this book is a comprehensive study of the development of lake systems and water reservoirs and impact of climate change on water resources in Central Asian countries. And this book provides information about genesis of lake basins, physical and chemical properties of water in lakes, hydrological regime (water balance and fluctuation levels) of lakes of Central Asia and Northwest China.

Study and research on lake systems are important and required in the background of climate change and sustainable development and use of natural resources in Central Asia. The study of the possible impact of climate change on water sources is very relevant, since the role of lakes in human life is determined primarily by large reserves of freshwater. Lakes are very sensitive in terms of climate change and anthropogenic factors, since lake sediments are the main parameter or source in climate change and anthropogenic factors. In addition, lakes are natural runoff regulators and the core of specially protected areas such as national parks, reserves of various levels. In modern conditions, the role of lakes is significantly increasing, because they remain custodians of clean freshwater in conditions of permanent anthropogenic factor and impact.

This book mainly addressed to scientists and researchers whose research has been focused on lakes and use of natural resources, irrigation, hydropower, and water supply as well as students and planners. We believe that our contribution on the study of lakes in Central Asia and in the arid regions of Northwest China will be a source of information and knowledge for all readers who feel responsible for the sustainable use and development of natural resources such as lakes and other water bodies.

Urumqi, China Jilili Abuduwaili
Urumqi, China/Almaty, Kazakhstan Gulnura Issanova
Almaty, Kazakhstan Galymzhan Saparov

Acknowledgements

Many scientists have contributed, supported and provided the basis for this book.

We sincerely thank all of the scientists: Dr. Ma Long and Dr. Yilinuer (Ilnur) Alifujiang from China and Dr. Salamat Abdyzhapar uulu, Burul Alymkulova and Talant Asankulov from Kyrgyzstan, who had provided help during the writing of this book by sharing their scientific publications, all of which became part of this book.

Separate thanks go to Dr. Azamat Kaldybayev from Kazakhstan and Dr. Kanat Samarkhanov, Dr. Alim Samat, and for technical support in GIS mapping for some chapters of this book.

We owe special thanks to Dr. Ge Yongxiao for his support and making comprehensive conditions to write this valuable book.

Thanks to library staffs in Kazakhstan and China, namely Wu Miao, for their help and assistance in gathering such base materials.

We thank Gulmira Nazanova, Shen Hao, Zhang Weiyan, Pu Jia, and Hua Yousheng for their contributions in the designing of tables and some illustrative materials.

We sincerely thank all of the colleagues from Xinjiang Institute of Ecology and Geography, Chinese Academy of Sciences, in particular Prof. Chen Xi and Prof. Lei Jiaqiang, and U.U. Uspanov Kazakh Research Institute of Soil Science and Agrochemistry, in particular professor and academician Saparov Abdulla.

Thanks to all the colleagues from Research Centres of Ecology and Environment of Central Asia, including the branches in Kazakhstan (Almaty), Kyrgyzstan (Bishkek), and Tajikistan (Dushanbe).

The authors thank all the contributors, colleagues, friends, and well-wishers for their support and engagement.

This research was funded and supported by the National Natural Science Foundation of China (U1603242), the Science and Technology Service Network Initiative (Y838031) and CAS "Light of West China" Program (2016-QNXZ-A-4), and the Strategic Priority Research Program of Chinese Academy of Sciences (Grant No. XDA2006030102).

Content and Structure of This Book

This book summarizes the outcomes of research results and studies on water resources and lakes and lake systems in Central Asian countries (Kazakhstan, Kyrgyzstan, Uzbekistan, and Tajikistan) and Northwest China. This book has twelve individual chapters. Studies and research results on lake systems and water resources were analyzed and overviewed within those chapters. Chapter 1, "Water Resources and Impact of Climate Change on Water Resources in Central Asia," provides an overview and analyzes the lakes in Central Asia and impact of climate change on water resources. Chapter 2, "Water Resources in Kazakhstan," contains three sections providing general information on water resources (water reservoirs, rivers, groundwater) in Kazakhstan, as well as water availability and state of water resources within water-economic basins in Kazakhstan. Chapter 3, "Lakes in Different Regions of Kazakhstan," considers a regional division of lakes within Kazakhstan. It describes regional distribution of lakes in different regions of Kazakhstan. Chapter 4, "Lakes in the Central Kazakhstan," contains three sections providing information on morphology and genetic types of the lakes in Central Kazakhstan, as well as hydrological and hydrochemical regimes of the lakes in Central Kazakhstan. Chapter 5, "Morphometry and Genesis of Lakes in Kazakhstan," provides and describes information about morphometry and genesis of lake basins in Kazakhstan. Chapter 6, "Water Balance and Physical and Chemical Properties of Water in Lakes of Kazakhstan," considers a water balance, fluctuation of levels in lakes, and physical and chemical properties of water in lakes of Kazakhstan. Chapter 7, "Lake and Sea Basins in Kazakhstan," provides an overall information (hydrography, water regime, hydrographic network, etc.) on water resources and water use and state of water resources in the Lake Basin, Lake System, and Sea basin such as Aral Sea and Balkash Lake, Alakol–Sasykkol and Tengiz-Korgalzhyn lake systems. In addition, environmental impact of the Aral Sea desiccation was discussed in the chapter. Chapter 8, "Water Resources and Lakes in Kyrgyzstan," contains five sections providing information on lakes, and water resources and hydrographic system in Kyrgyzstan, water balance of natural belts and artificial hydrological network, as well as water reservoirs, fresh groundwater, and wetlands in Kyrgyzstan. In addition, use of water resources in Kyrgyzstan was discussed and analyzed. Chapter 9, “Hydrographical and Physical–Geographical Characteristics of the Issyk-Kul Lake Basin and Use of Water Resources of the Basin, and Impact of Climate Change on it,” describes and considers physical–geographical characteristics of the Lake and provides information about hydrography and hydrochemistry of the Issyk-Kul lake, as well as use of water resources of the Lake in different sectors of economy and sustainable water management, and impact of climate change on the Lake basin was analyzed and discussed. Chapter 10, “Water Resources and Lakes in Uzbekistan,” offers a general information on water reservoirs as a source of manufacture, and management of lakes, as well as use of water resources in Uzbekistan, was considered. Chapter 11, “Water Resources in Tajikistan,” provides an overview on glaciers and rivers in Tajikistan. Chapter 12, “Lakes in Arid Regions of Northwest China,” contains three sections providing a general information on lake distribution and lake types in arid regions of China, as well as hydrographical characteristics of the Ebinur and Sayram Lakes and environmental issues in the region, and climate and environmental changes over the past 150 years in the Chaiwopu Lake were considered and discussed.

Contents

About the Authors

Jilili Abuduwaili is a professor and deputy director at the Xinjiang Institute of Ecology and Geography, Chinese Academy of Sciences, China, and co-director of the Research Center of Ecology and Environment of Central Asia, Almaty. He holds a doctoral degree from the Lomonosov Moscow State University, Russia.

He is a member of a council of the China Natural Resources Society and a deputy chairman of the Xinjiang Geographical Society as well as a deputy chairman of the Xinjiang Natural Resources Society.

He is an associate editor of the *Journal of Arid Land* and editor in chief of the journals *Arid Land Geography* and *Arid Land Research* (both in Uyghur language). He is also an editorial board member of the journals *Arid Ecosystems* (*Russia*) and *Soil Science and Agrochemistry* (*Kazakhstan*). He is a supervisor for postgraduate students.

Since 2015, he has been a foreign academician at the Academy of Agriculture of Kazakhstan. His main fields of work and expertise are in the areas of natural resources and environments, ecological safety, lake environments, disaster, and landscape changes in arid lands.

He has built international cooperation in research between Russia and Central Asian countries. He has published more than 200 papers in international and domestic journals and 7 books: *Lakes and Salt Dust Storms in Arid Lands* (in Chinese), *Overview of Central Asian Environments* (in Chinese), *Aeolian processes as dust storms in the deserts of Central Asia and Kazakhstan* (in English) *by Springer Nature, Salt Dust*

Storms: Special Disaster in Arid Lands (in Uyghur), *Climate Change Effects to the Ecological System in Tien Shan Mountains* (in Russian), *Physical Geography of Kyrgyzstan* (in Russian), *Arid Soil in Kazakhstan: Current States and Utilization* (in Russian).

Gulnura Issanova holds a doctorate degree in Natural Sciences and is an associate professor, scientist, and researcher at U.U. Uspanov Kazakh Research Institute of Soil Science and Agrochemistry and a scientific secretary at the Research Centre of Ecology and Environment of Central Asia, Almaty, Kazakhstan.

She studied at the Al-Farabi Kazakh National University for bachelor's degree (B.Sc.) and master's (M.Sc.) degree in Physical Geography and Xinjiang Institute of Ecology and Geography, Chinese Academy of Sciences, China, for her doctoral degree. She did a postdoc under the CAS President's (Bai Chunli) International Fellowship Initiative (PIFI) for 2017 at the Xinjiang Institute of Ecology and Geography, Chinese Academy of Sciences, China. She is a holder of the *Foreign Expert Certificate of the People's Republic of China.*

Her research interest was focused on problems of soil degradation and desertification, in particular the role of dust and sand storms in the processes of land and soil degradation and desertification during Ph.D. study. Currently, she is interesting and focusing on water resources and lakes (availability, state, and consumption/use) in Central Asian countries.

She participates regularly in the International Scientific Activities (Conference, Forum, and Symposium) on Environmental Problems as well as writes articles and monographs on the subject and takes part in local and international projects.

She has published many SCI papers in international peer-reviewed journals with high level and wrote a handbook, "How to Write Scientific Papers for International Peer-Reviewed Journals."

She is an author of the monograph *Aeolian processes as dust storms in the deserts of Central Asia and Kazakhstan* by Springer Nature (2017) and co-author of *Man-Made Ecology of East Kazakhstan* by Springer Nature (2017) and *Overview of Central Asian*

Environments (in Chinese) and the handbook *Methodical Handbook on Interpretation of Saline Soils* (in four languages: Kazakh, Russian, English, and Chinese).

She became a laureate of the International Award "Springer Top Author" and was awarded in the Nomination "Springer Young Scientist Awards-2016" for high publication activity in scientific journals published by Springer Nature. She was included to the list of "Top-8 Young Scientists and Top-18 leading Scientists from Kazakhstan," 2016.

Galymzhan Saparov is a Ph.D. candidate in Agricultural Sciences. He is a head of department of Soil Ecology at U.U. Uspanov Kazakh Research Institute of Soil Science and Agrochemistry as well as head of laboratory at the Research Centre of Ecology and Environment of Central Asia, Almaty, Kazakhstan.

He graduated from Kazakh Agricultural Institute in 1995 and holds a Ph.D. degree from U.U. Uspanov Kazakh Research Institute of Soil Science and Agrochemistry in 2004.

His research interest is focused on problems of soil degradation and remediation of disturbed lands.

He has published more than 45 scientific papers, including 2 recommendations in production and 3 innovative patents.

Chapter 1
Water Resources and Impact of Climate Change on Water Resources in Central Asia

1.1 Water Resources, Lakes and Water Reservoirs, and Glaciers in Central Asia

Central Asia covers the territory of five countries such as Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, and Uzbekistan. It is located in the center of the Eurasian continent with an area of 3,882,000 km^2 and with a population of about 55 million people. It borders on Afghanistan and Iran in the south, China in the east, and Russia in the west and north (Grinyayev and Fomin 2009).

The territory of Central Asia, with the exception of the highlands, is inadequate in humidification, and the humidification for the most part is extremely insufficient: The ratio of the average annual precipitation to the average annual evaporation is less than unity. This is connected with the great (in comparison with other CIS countries) sparseness of the hydrographic network. The density of the river network in the desert plains of Central Asia is about 2 m per 1 km^2, while in the northern half of the Russian Plain it reaches 300–350 m per 1 km^2 (Grinyayev and Fomin 2009).

Central Asian countries are located in the arid zone, where without irrigation it is impossible to cultivate crops and to obtain sustainable crops. Therefore, there is and prevails irrigation in almost all countries of the region, which requires large amount of water resources. Central Asia has approximately 170–180 km^3 of water resources, of which today more than 90% is used.

Water resources between the countries of the region are divided unevenly. More than 90% of Central Asia's water resources sources are concentrated in Kyrgyzstan and Tajikistan. At the same time, Uzbekistan and Kazakhstan are the main water users in the region. The share of Uzbekistan accounts for more than half of the water.

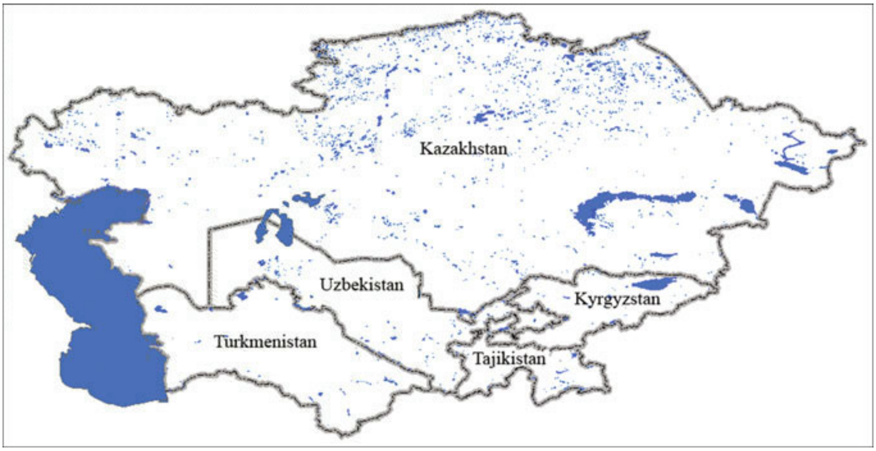
Syrdarya and Amudarya river flows are the main source of water in the region. They are formed in the mountains of the Pamir and Tien Shan. The Syrdarya river flows from Kyrgyzstan through Tajikistan to Uzbekistan and through the densely

J. Abuduwaili et al., *Hydrology and Limnology of Central Asia*, Water Resources Development and Management, https://doi.org/10.1007/978-981-13-0929-8_1

populated Ferghana Valley to Kazakhstan and the Amudarya river from Tajikistan to Turkmenistan and Uzbekistan.

Lakes in Central Asia are distributed unevenly (Fig. 1). There are many lakes in the mountainous area and plains of Central Asia.

Fig. 1.1 xxx



The lake is a natural pond with a slowed down water exchange. It is formed as a result of water filling with a deepening of the earth's surface. The size of the lake varies from very large, such as the Caspian Sea and the Great Lakes in North America, to tiny pools of several hundred square meters and even less. The lake water can be fresh as in the Baikal lake or salty as in the Dead Sea. Lakes are found at any altitude; from the lowest point on the Earth surface that is 408 m (Dead Sea) and high in the mountains (Lake Merzbacher on the glacier Engilchek, Kyrgyzstan). Many lakes exist permanently, while others are only occasionally filled with water. However, lakes of all types have a number of common physical, chemical, and biological characteristics and are subject to many general laws.

There are more than 51,245 lakes in Central Asia, namely in Kazakhstan more than 48,000 lakes, 1923 lakes in Kyrgyzstan, in Uzbekistan 22 lakes with size more than 1 km^2, and in Tajikistan more than 1300 lakes. The drying lake–sea Aral Sea and Lake Balkash with freshwater in western and salty eastern parts are the largest lakes and one of the deepest lakes in the world—Issyk-Kul Lake. The lakes in Kyrgyzstan (84%) and in Tajikistan (78%) are distributed in the mountains at an altitude of 3000–4000 m a.s.l and 3500 m a.s.l, respectively. Most mountain lakes are concentrated in modern glaciers and alpine zones. There are more than 3000 very small high-altitude glacial lakes, dozens of seasonal regulation reservoirs, thousands of ponds of decade-old and daily regulation (Gagloeva 2016). The plain lakes are mostly distributed in Kazakhstan and Uzbekistan. In Uzbekistan, plain lakes can be found in the Deltas of the Amudarya and Syrdarya rivers. There are many natural lakes in the mountainous areas and hollows of Central Asia. The mountainous or alpine lakes are mostly concentrated in Tajikistan and Kyrgyzstan. There are different types of the mountainous lakes. Most large lakes occupy basins of tectonic origin (Issyk-Kul, Chatyr-Kul, Karakul, Sarychelek). In addition, Sarez and Yashinkul in the Pamirs belong to the lagoon lakes.

There are numerous lakes of glacial origin. Lake Zorkul is one of the largest lakes, located at an altitude of 4125 m in the East Pamirs. Besides, there are karst lakes. The water in the lakes is usually fresh or brackish, depending on the quality of the inflow (Grinyayev and Fomin 2009).

Due to the discharge of drainage water into the drainless basins, many lakes of anthropogenic origin have arisen. Most of them are small. The largest lakes of this type are the Sarykamysh (in the lower reaches of the Amudarya river) and Arnasai (in the middle reaches of the Syrdarya river). Due to the low capacity of the Syrdarya river bed which is below the Shardara water reservoirs (on the border between Kazakhstan and Uzbekistan), in excessively large water years, excess water is discharged into Lake Arnasai. The volume of water in lakes of anthropogenic origin is estimated at 40 km^3. However, pumping is required to use this water. In addition, the water in the lakes is highly mineralized. In the future, this water can be best used for purposes in fisheries and biodiversity conservation (Grinyayev and Fomin 2009).

The total capacity of the water reservoirs in Central Asia is 176.9 km^3, of which 54% are in Kazakhstan (Table 1.1).

There are fifteen water reservoirs in the region, and each reservoir has a capacity of more than 1 km^3, of which six are in Uzbekistan, four in Kazakhstan, two in Turkmenistan, and two in Tajikistan. Most of them are multi-purpose, and they are used for the production of hydropower, irrigation, water supply, and flood control. The total capacity of these fifteen water reservoirs is 129.4 km^3 or 72% of the total capacity of all water reservoirs in Central Asia. The Bukhtyrma water reservoir in Kazakhstan has the largest capacity (50 km^3). The capacity of Toktogul water reservoir in Kyrgyzstan, Kapshagai water reservoir in Kazakhstan and Nurek water reservoir in Tajikistan is 20, 19 and 11 km^3, respectively. In Uzbekistan, a large water reservoir is the Tuyamuyun (8 km^3), the Zeid water reservoir (2 km^3) in Turkmenistan (FAO 2012) (Table 1.2).

Table 1.1 Water reservoirs in Central Asia (FAO 2012)

Country	Water reservoir capacity (m^3)	% from the region
Kazakhstan	95.5	54
Tajikistan	29.5	17
Kyrgyzstan	23.5	14
Uzbekistan	22.2	12
Turkmenistan	6.2	3
Central Asia	176.9	100

Table 1.2 Water reservoirs with capacity of more than 1 km^3 (FAO 2012)

Water reservoir	River	Basin	Exploitation year	Volume (m^3)	Surface area (km^2)	Reservoir function	Country
Bukhtyrma	Ertis	Ob	1960	49.6	5490	I, H, W, F	Kazakhstan
Toktogul	Naryn	Naryn	1974	19.5	–	H	Kyrgyzstan
Kapshagai	Ile	Balkash–Alakol	1970	18.6	1847	I, H, W	Kazakhstan
Nurek	Vakhsh	Amudarya	1980	10.5	98	I, H, W, F	Tajikistan
Tuyamuyun	Amudarya	Amudarya	1980	7.8	790	I, H, F	Uzbekistan
Shardara	Syrdarya	Syrdarya	1968	5.2	783	I, H, W, F	Kazakhstan
Kairakkum	Syrdarya	Syrdarya	1959	4.2	5450	I, H	Tajikistan
Shulba	Ertis	Ob	1988	2.4	255	I, H, W, F	Kazakhstan
Zeid	Karakum canal	Amudarya	1986	2.2	465	I, W	Turkmenistan
Charvak	Chirchik	Syrdarya	1977	2	22	I, H	Uzbekistan
Andizhan	Karadarya	Syrdarya	1978	1.9	55	I	Uzbekistan
Talimardzhan	Amudarya	Amudarya	1985	1.5	–	I	Uzbekistan
Pachkamar	Guzor	Amudarya	1961	1.5	–	I	Uzbekistan
Dostluk	Tedzhen	Tedzhen	2004	1.3	48	I, H, W, F	Turkmenistan
Tudakul	Tudakul	Amudarya	1953	1.2	–	I, H	Uzbekistan
Central Asia				129.4			

I irrigation, *H* hydropower, *W* water supply, *F* flood protection
Tuyamuyun water reservoirs consist of four reservoirs such as Ruslovoi, Sultansandzhar, Kapparas, and Koshbulak

1.2 Impact of Climate Change on Water Resources in Central Asia

Global climate change is one of the main issues among the major environmental problems facing the world community in recent decades. The issue of the impact of climate change on water resources in the Central Asian countries requires more detailed study from a regional perspective.

The arid and semi-arid climates are common for most part of Central Asia with minor precipitation during the year. Climate change created problems related to the ability of countries to meet the growing demand for water. As a result of a decrease in precipitation and a rise in temperature, the problem of water scarcity may worsen, especially in those parts of Asia where water resources are already stressed due to the growing water demand and inefficient water use.

There has been an inter-seasonal and spatial variability in rainfall throughout Asia over the past several decades. In general, the frequency of more intense precipitation events has increased in many parts of Asia, causing severe floods, landslides, and debris flows and mudflows, while the number of rainy days and total annual rainfall decreased. Nevertheless, there are reports that the frequency of extreme rainfall in some countries shows a decreasing tendency (UNEP 2006).

Global climate change affects processes occurring in the environment and changing the existing mechanism functions of the entire environmental system. Global climate warming will cause an increase in the melting intensity of glacial cover of the planet. Reducing the areas of arctic ice sheets can lead to significant changes in the water cycle in nature. The ice melting in the Arctic Ocean and the subsequent warming in the Arctic region can cause a change in the existing interaction between the underlying surface and the atmosphere of the entire Northern Hemisphere, and consequently the entire planet (Gagloeva 2016).

In general, the mechanism of moisture circulation between oceans and continents can change. The intensity of the zonal atmospheric circulation can decrease because of the decrease in the temperature gradient between the poles and the equator (WERCA 2008).

The role of the temperature difference between the sea and land will increase, and will enhance the monsoon circulation, especially on the coasts of Eurasia. The decrease in the rates of zonal transport of air masses and the intensity of cyclonic activity due to the decrease in the temperature gradient in the "pole–equator" system will cause an increase in atmospheric precipitation near the seas and it decreases within the continent, especially in winter.

The total water resources of Central Asia consist of river runoff formed from the water of precipitation, melted glacial water and underground feeding, and underground waters pumped by wells. The wide-scale impact of climate change on the globe, first of all, affects the state of glaciers, the seas of the World Ocean, and the snow cover of the Earth. In the period of cooling, the world water balance changes in the direction of increasing moistening of the continents and the mass of glaciers is increased. The water balance of the oceans is becoming negative, and their level is decreasing. In periods of warming, on the contrary, a negative water balance is established on the continents. The glaciers are melting, the flow from glaciers into the ocean increases, and the water balance becomes positive (Gagloeva 2016). The rapid melting of permafrost and the reduction of the depth of frozen soils are mainly due to warming process. It threatens many cities and settlements, causes more frequent landslides and the degeneration of some forest ecosystems, and leads to an increase in the water level of the lakes in the permafrost regions of Asia (Gagloeva 2016).

Changes in the quantity and regime of water resources in Central Asia are associated with both global climate warming and intensive irrigation in the river basins of the region (Alamanov et al. 2006). Over the past few years, these factors have led to the formation of a number of issues that most clearly manifested in the regime of the levels of inland water bodies such as the Aral Sea, the Issyk-Kul and Balkash lakes. Now practically all water resources in the territory of Central Asia are fully involved in economic circulation.

The increase in the frequency and intensity of droughts in many parts of Asia is mainly due to the increase in temperature, especially during summer and usually drier months. In this regard, the production of rice, maize, and wheat over the past few decades has declined in many parts of Asia due to increased water stress. The water stress was partly due to increased temperatures and a reduction of rainy days. These days all sources of water resources in Central Asia are fully used in different sectors of economy. The climatic conditions of Central Asia determine the development of intensive irrigated agriculture. Irrigated arable land, hayfields, and watered pastures provide human food, livestock feed, and raw materials for many industries. Therefore, changes in such major climatic characteristics as air temperature and atmospheric precipitation that affecting the thermal and water balance of the territory and the living conditions of the population. The population of Central Asia has increased over the past decades. In this regard, the problem of water scarcity becomes even more acute. Climate change is another factor that can lead to an increase in water scarcity. According to numerous studies, as a result of climate warming, changes in atmospheric circulation and redistribution of precipitation are expected. Owing to the increased transfer of water vapor from the subtropics toward the poles and the expansion of the subtropical high-pressure regions, the tendency toward aridity will be particularly pronounced at the higher latitude boundaries of the subtropics (Gagloeva 2016). According to some scenarios, by 2100, the amount of precipitation may decrease by almost 20% (Alamanov et al. 2006). In addition, the water scarcity in the region is related to the division of limited water resources from transboundary rivers such as Syrdarya and Amudarya. The water resources of these transboundary rivers are used for hydroenergy and irrigational purposes. Consequently, lack or scarcity of water in transboundary rivers and an imperfect system of its division can strengthen the conflict situation in the region. Additionally, the scarcity of water resources will lead to a weakening of the agricultural–industrial complex and socioeconomic conditions of the Central Asian countries.

Among the climatic factors, evaporation plays a leading role in the formation of water problems in Central Asia. It contributes to the expenditure of large quantities of water from the surfaces of natural and artificial water bodies and irrigated lands. Currently, the area of irrigated land in the region has reached almost 8–9 million hectares. The evaporation amount in the main irrigated fields/zones of Central Asia reaches 1500–2000 mm/year (Gagloeva 2016). Estimates of the effect of climate warming show that crop yields in Central Asia could be reduced by 30% by the middle of the twenty-first century. The demographic factor will affect the water resources and agricultural products. There is a prognosis on a shortage of agricultural products and an increase in social tensions in some of these countries (Gagloeva 2016). So, climate change, such as permafrost and glacier melting, increasing evaporation of water resources, and intensive use of water sources lead to water scarcity and consequently interstate conflicts.

1.3 Impact of Climate Warming on Glacier and Permafrost Melting in Central Asian Mountains

The climatic conditions of the plains of Central Asia are characterized by low amount of precipitation with high evaporation and are not favorable for flow formation. The amount of precipitation increases noticeably only in mountainous areas, starting from 700 m and the river flow also increases accordingly. The density of the river network in some mountainous areas exceeds 600 m per 1 km^2. Most of the rivers in Central Asia have glacial–snow feeding. The rivers of glacier–snow feeding are characterized by small fluctuations in the annual runoff and a high flood (June– beginning August), which together with the steep fall of the channel makes them especially valuable for economic use—obtaining hydroelectric power and irrigation.

There are two large river basins: the Syrdarya river basin in the north and the Amudarya river basin in the south. Within the Aral Sea basin, between these major Rivers is the Zerafshan River, a former tributary of the Amudarya river. The average annual flow of all rivers to the Aral Sea basin is 116 km^3. This volume includes 79.4 km^3 of the Amudarya river flow and 36.6 km^3 Syrdarya river flow (Grinyayev and Fomin 2009).

Glaciers represent the most important source of river flow in the warm season. The glaciers of Central Asia are occupied an area of 17,950 km^2 and represent the most important source of river flow in the warm season. They are distributed unevenly on the territories of the Central Asian countries. There are 8200 glaciers in Kyrgyzstan and occupied 4.2% of the country's territory. The water reserve of glaciers in Kyrgyzstan is estimated at 650 km^3. The number of glaciers in Tajikistan is 8492 they occupy about 6% of the country's territory. The rest of the glaciers is concentrated in Kazakhstan (UN 2002).

The wide-scale impact of climate change on the globe affects the state of its glaciers, the seas of the World Ocean, and the snow cover of the Earth. As a result of climate warming, the glaciers started to melt. Asian glaciers are melting since the 1960s and in a constant rate. However, individual glaciers may fall out of this list, and some of them actually come in, their thickness increases and it is possibly due to increased precipitation. As a result of the continuing melting of glaciers, the glacial runoff and the frequency of breakthrough of glacial lakes that cause mudflows and avalanches increases. So, the current climate warming leads to a steady reduction of the glaciers in the Tien Shan and a reduction in their glacial coefficients which show the ratio of the areas of glacial accumulation to the entire area of glaciers (Gagloeva 2016).

As is known, small glacial coefficients are characteristic for degrading glaciers, where the arrival of ice matter does not compensate for its consumption. Thus, there is a deepening process of the decay of glaciation in the basins of the Kichi Naryn, Talas, and Assa rivers and on the southern slope of Kungei Alatau, where the glacial coefficients remained 0.45 (Gagloeva 2016).

Hydrometeorological observations showed that the asynchronous nature of atmospheric precipitation and air temperature in the high-mountain zone of the Tien Shan negatively affects the balance of glaciers and affects the total water content of rivers with a significant glacier catchment.

Past and future changes in water resources of Tajikistan are also associated with climate change: a decrease in precipitation and an increase in air temperature. At that time, according to the most conservative estimates, the glaciers of Tajikistan lost more than 20 km^3 of ice only in the twentieth century. Intensively degrading small glaciers with areas less than 1 km^2, which account for 80% of all glaciers. The average annual river runoff of Tajikistan over the last 30 years has decreased annually by 110 million m^3 per year (Gagloeva 2016). The forecasts of Tajik specialists and scientists show that thousands of small glaciers will disappear in Tajikistan until 2050. Therefore, the area of its glaciation will be reduced by 20%, and the volume of ice will decrease by 25%. Consequently, this will lead to a reduction in glacial feeding of rivers by 20–40%. At the same time, there is a prediction that on increasing in the amount of atmospheric precipitation by 14–18% will not have a significant effect on the runoff, since most of the precipitation will be spent for evaporation from watershed surfaces.

In the mountain systems of Kazakhstan, there is also a reduction in the number and size of glaciers. According to forecasts, due to global warming the water resources of the main rivers of Kazakhstan can decrease by 20–40% in the next decades.

According to studies and researches, since the middle of the twentieth century, the glaciation in Central Asia has decreased so much that by the middle of the twenty-first century the revealed trend may lead to the disappearance of many glaciers (IPCC 2007).

Changes in the quantity and regime of water resources in Central Asia are associated with global climate warming, and with intensive development of irrigation in the river basins of the region. Studies also show that intensive melting of glaciers continues in the formation zone of the Syrdarya and Amudarya river flows. For 50 years, the volume of glaciers has decreased by 20–40%, and in recent years, the rate of reduction is about 1% per year (UN 2002).

References

Alamanov SK, Lelevkin VM, Podrezov OA (2006) Climate change and water problems in Central Asia: A training course for students of natural and humanitarian specialties. Bishkek (in Russian)

FAO (2012) Irrigation in Central Asia in numbers. In: Frenken K (ed) Review AQUASTAT, water reports (in Russian)

Gagloeva AE (2016) The climate change impact on water resources of Central Asia. J Water Econ Kaz 3(71):49–54 (in Russian)

Grinyayev SN, Fomin AN (2009) Actual issues of application of the mechanism of exchange trade for solving water and energy problems of the Central Asia countries, Analytical report. Moscow, 52 p (in Russian)

IPCC (2007) Climate change. The fourth assessment report of the intergovernmental panel on climate change. Summary for Policymakers. The physical science basis, vol 1, p 18. Impacts, Adaptation and Vulnerability, Mitigation, vol 2, pp 24–26

UN (2002) A diagnostic report for the preparation of a regional strategy for the rational and efficient use of water resources. Project working group on energy and water resources, 83 p (in Russian)

UNEP (2006) Climate change and water problems in Central Asia. In: World wildlife fund of Russia, Moscow-Bishkek (in Russian)

WERCA (2008) Water-energy resources of Central Asia: problems in use and development. Branch survey of the Eurasian Development Bank, Almaty (in Russian)

Chapter 2
Water Resources in Kazakhstan

2.1 General Characteristics of Water Resources in Kazakhstan

The territory of Kazakhstan is 2717.3 thousand km^2 and ninth biggest country in the world. It extends from west to east by 2995 km and from north to south by 1600 km. Kazakhstan borders with Russia in the north and west; in the south with Turkmenistan, Uzbekistan, and Kyrgyz Republics; and with the People's Republic of China in the southeast (Dzhanalieva et al. 1998).

Intra-continental location in the center of the Eurasian continent is a characteristic feature of Kazakhstan, which affects the entire physical–geographical conditions: climate, hydrography, soil, and vegetation covers and fauna. There are four main hydrological regions in Kazakhstan: the Basin of Ob river, which flows into the Arctic Ocean; the Caspian Sea basin; the Aral Sea basin; and basin of inland lakes, depressions, or deserts. Surface water resources are distributed over the country is extremely uneven and characterized by significant long-term and seasonal dynamics. Only 3% of the total water resources is formed in Central Kazakhstan. The western and southwestern regions (Atyrau, Kyzylorda and, in particular, Mangystau) suffer from a significant deficit of water, and there is almost no freshwater. Almost 75% of the surface water resources generated within the country belong to the Balkash–Alakol and Ertis water-economic basins in the east and northeast parts of Kazakhstan. About 90% of the surface runoff is formed in spring, exceeding the capacity of existing water reservoirs (FAO 2012).

Kazakhstan is located in four natural climate zones: forest steppe, steppe, semidesert, and desert. In Kazakhstan, severe Siberia and sultry Central Asia, mountainous taiga and desert, vast plain steppes and mountains covered with eternal snows come together. The diversity of the terrain or relief and climatic conditions of Kazakhstan causes the uneven distribution of surface waters over its area.

J. Abuduwaili et al., *Hydrology and Limnology of Central Asia*, Water Resources Development and Management, https://doi.org/10.1007/978-981-13-0929-8_2

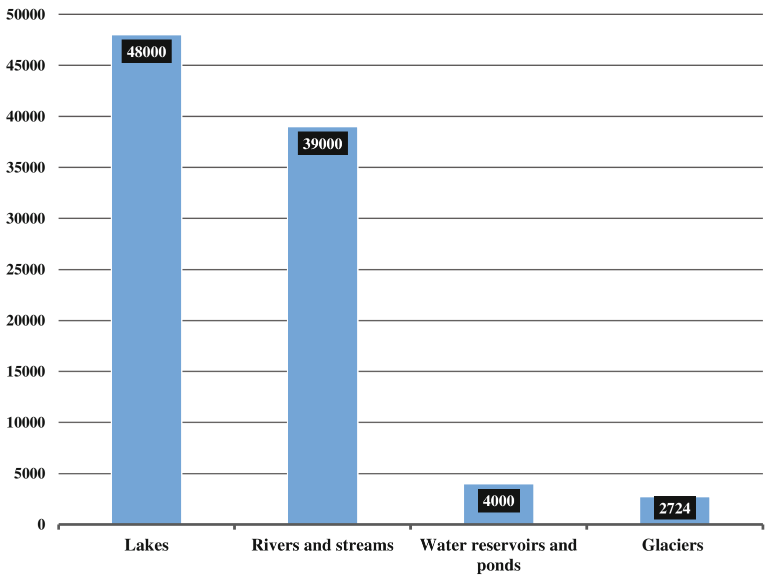


Fig. 2.1 Water resources of Kazakhstan

There are 48,000 lakes, 39,000 rivers and streams, 4000 water reservoirs and 2724 glaciers in Kazakhstan (Fig. 2.1) (FAO 2012). There are very few lakes and rivers in desert regions; it is much larger in the north part of Kazakhstan and in the mountains (Philonets and Omarov 1974).

Lakes play a significant role in providing the national economy with certain types of industrial raw materials. They have such important resources as water, fish, various salts, building materials (gravel, gravel, sand, and mud), reed beds, and other aquatic vegetation, sapropels, peat deposits, therapeutic mud, and brine. Some lakes can be breed a waterfowl and muskrat and create hunting farms and nature reserves. In addition, lakes can serve as rest or tourism places.

2.2 Water Reservoirs, Glaciers, Rivers, and Groundwaters in Kazakhstan

Water reservoirs There are more than 200 water reservoirs within Kazakhstan with a total capacity of more than 95.5 km^3 (excluding ponds and small reservoirs designed to contain spring runoff) (UNDP 2003; Riabtsev et al. 2004).

The water reservoirs are distributed according to their volume as follows: More than 50% of the reservoirs have a volume of 1–5 million m^3 of water (Fig. 2.2). Most of the reservoirs are designed for seasonal regulation of wastewater. The volume of annual runoff is affected by water reservoirs with a regime of long-term

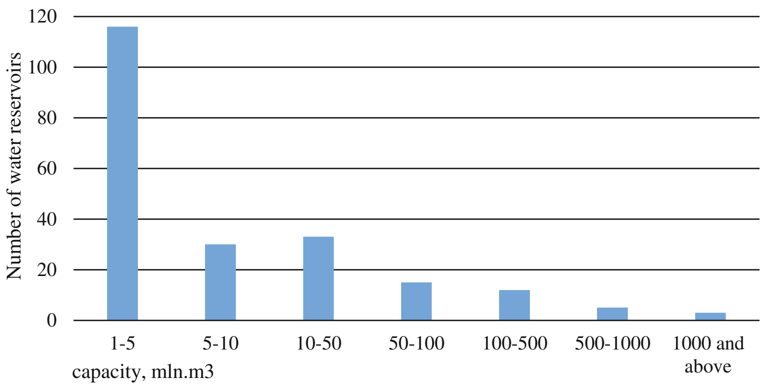


Fig. 2.2 Water reservoirs in Kazakhstan

regulation of sewage, of which about 20. Reservoirs with a capacity of more than 1 km^3 are considered as the largest ones. The largest water reservoirs are Bukhtyrma (on the Ertis River) with a total volume of 49.6 km^3, Kapshagay (on the Ile River) with a volume of 18.6 km^3, Shardara (on the Syrdarya river)—5.2 km^3 (UNDP 2003), the Verkhne–Tobol and the Karatomar (on the Tobyl River)—0.82 and 0.59 km^3, respectively, Vyacheslav and Sergeev water reservoirs (on the Esil River)—0.4 and 0.7 km^3, respectively (Philonets 1981).

The water reservoirs can be classified by their area. Small water reservoirs with area of up to 50 km^2; up to 250 km^2 is medium; up to 1000 km^2 is large, and over 1000 km^2 are the largest ones (Philonets 1981). According to the economic use, they are divided into integrated (complex) and special purpose. Most water reservoirs are multi-purpose that providing hydropower generation, irrigation, and flood control. The largest and large water reservoirs and many of the medium reservoirs belong to complex reservoirs. They are designed to solve the problems of energy, transport, and irrigation. Small ones have a designated purpose. They are used mainly for irrigation in arid regions and in less arid region for small-scale energy, water supply, and fish farming (depends on the water needs). The water reservoirs in the eastern and southeastern regions of Kazakhstan are mainly used for agriculture, and in the central, northern, and western regions—for drinking and industrial needs. The Bukhtyrma, Kapshagay, Shardarya, and Shulbi water reservoirs are connected to HPPs for power generation.

The water reservoirs due to their nature of formation are divided into lake, river, watershed, and liquid types (Vikulina 1979).

The acute need of the national economy of Kazakhstan in water is partially ensured by the creation of water reservoirs on its territory. There are more than four thousand ponds and water reservoirs with different size in Kazakhstan. Their total area is about 10 thousand km^2, and with a freshwater volume is about 90 km^3 (Table 2.1). A big number of the water reservoirs concentrated in central, southern, and eastern parts of Kazakhstan. Such large water reservoirs Bukhtyrma,

Table 2.1 Main characteristics of large water reservoirs in Kazakhstan

No.	Water reservoir	Location	Area (km^2)	Length (km)	Width (km)	Depth (m)	Full volume (km^3)
1	Bukhtyrma	Ertis river, East Kazakhstan region	5500	600	40	80	53.1
2	Kapshagai	Ile river, Almaty region	1847	187	23	43	28.1
3	Shardara	Syrdarya river, South Kazakhstan region	900	48	20	26	5.7
4	Sergeev	Esil river, Akmola region	117	75	7	20	0.693
5	Karatomar	Tobyl river, Kostanay region	94	38	4	16	0.586
6	Samarkand	Nura river, Karagandy region	82	25	7	12	0.267
7	Bugun	Bugun River, South Kazakhstan region	63	13	6	15	0.37
8	Vyacheslav	Esil river, Akmola region	61				0.419
9	Akkol	Assy river, Zhambyl region	50	10	6	5	0.11
10	Kirov	Koshim river, West Kazakhstan region	42	132	1	7	0.063
11	Sherubai-Nura (Topar)	Nura river, Karagandy region	39	13	4.2	24	0.274
12	Kengir	Kengir river, Karagandy region	37	33	1.6	21	0.319
13	Oskemen	Ertis river, East Kazakhstan region	37	85	1.2	45	0.65
14	Seleti	Seleti river, Akmola region	34				0.222
15	Dunguliuk	Koshim river, West Kazakhstan region	32	105	0.5	8.5	0.057
16	Botakara	Otkelsiz river, Karagandy region	25	8	3.5	6	0.053
17	Teris-Ashybulak	Teris river, Zhambyl region	24	10	3	24	0.158
18	Zhezkazgan	Zhezdi river, Karagandy region	18				0.078
19	Saryagash	Ulken Ozen river, West Kazakhstan region	18	6	4	6	0.062
20	Kurti	Kurti river, Almaty region	9	24	0.3	38	0.12

(continued)

Table 2.1 (continued)

No.	Water reservoir	Location	Area (km^2)	Length (km)	Width (km)	Depth (m)	Full volume (km^3)
21	Zhartas	Sherubai-Nura river, Karagandy region	9				0.012
22	Piatimar	Koshim river, West Kazakhstan region	8	10	0.8		0.034
23	Zhylkuar	Zhylkuar river, Kostanay region	8				0.033
24	Tuzdy	Kokozek river, Karagandy region	8				0.01
25	Maloulbi	Maloulbi river, East Kazakhstan region	7	5	3	29	0.087
26	Shagly	Shagly river, Akmola region	7				0.028
27	Akzhar	Akzhar river, Kostanay region	6				0.017
28	Ekibastuz	Ertis–Karagandy channel, Pavlodar region	5				0.014
29	Esil	Esil river, Karagandy region	3.5				0.014
30	Trudovoe	Shiderti river, Karagandy region	3				0.015
31	Koksarai*	Syrdarya river, South Kazakhstan region	467.5	44.7			

Notice *seasonal water reservoir. It provides seasonal flow regulation for irrigation and flood protection

Kapshagai, Shardara, Samarkand, Bugun, Akkol, etc., are located in those economic regions of Kazakhstan. The useful volume of water in the reservoirs of the region is about 45 km^3. Only 20 water reservoirs of those economic regions have an area of 8.7 thousand km^2 (87%) with a water volume of more than 86 km^3 (95%). The mineralization of water in reservoirs varies from 0.13 to 1.7 g/kg (Philonets 1981). Water is mostly mild and moderately stiff with a neutral and slightly alkaline reaction. The water in the reservoirs belongs to three chemical classes: 92% of water is hydrocarbonate, more than 7% is sulfate, and 4% is chloride.

There are 30 large water reservoirs in the main river basins of Kazakhstan (Fig. 2.3). Eight of the large water reservoirs concentrated in the Nura–Sarysu RB, in the Esil RB is five and rest water reservoirs distributed in the rest river basins (Fig. 2.3).