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AND DISASTER RISK REDUCTION DIVISION]

The Aral Sea, Central Asian Countries and Climate Change in the 21st Century

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About the report

The Aral Sea, Central Asian Countries and Climate Change in the 21st Century is a research study that advocates joint solution of environmental and resource problems in transboundary river basins, implementation of multilateral investment projects, enrichment of latest scientific knowledge and upgradation of technical skills. The study argues that cooperation between water management bodies and water-using and water-consuming economic sectors (land-water-energy nexus) is the basis for integrated water resources management. It is important to strengthen cooperation between the hydrometeorological services of the region – at the local, national and regional levels. It argues full-fledged strengthening of the basin authority (at the national and regional level) to maintain sustainability of water resources management and to develop policy coherence to strengthen the national and regional basin authorities – Syr Darya Basin Water Management Associations (BWMA) and Amu Darya BWMA.

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Photo credits

Cover: the Aral Sea from a NASA Landsat 9 satellite imagery, accessed on 12 April 2022 at Landsatlook.usgs.gov.

Contents

Executive Summary

Water resource use in Central Asia is set to increase substantially due to demographic factors, industrial and agricultural development, mainly irrigation. Central Asian countries, primarily in the Aral Sea basin, are notable for their socio-economic development unfolding amidst complete depletion of their water resources, especially water use which exceeds available resources, and this trend will determine the nature of inter-State relations of the countries in the region. It should also be noted that by 2030-2050, the countries of the region will also reach the limits of irrigated land expansion due to limited availability. Despite the depletion of water and irrigation resources in the region, in their national strategies and programs, each country notes increased water use for irrigation and hydropower in the future. Hence, a coordinated regional water policy is required which must seek to balance the water resources use and improve the ecological situation in the region.

Large-scale development of irrigation and other uses of water, particularly hydropower, has changed the water cycle of transboundary rivers in the region and created serious socio-ecological problems such as the drying up of the Aral Sea and destruction of its ecosystem; desertification of vast areas around the Sea, deterioration of water quality and impact on public health; local climate change, etc. However, many aspects of socio-economic development across Central Asian countries are determined by the availability of water resources. Therefore, reaching consensus on inter-state water allocation in transboundary river basins is the overarching objective that requires political will and a comprehensive solution, considering socio-economic and environmental changes and the political situation in the neighboring countries of the region. Rapprochement among the key stakeholders on the joint use of transboundary water resources cannot be considered outside the economic development models of each country and economic cooperation in the region as a whole. Hence, strengthening the trade and economic ties among these countries along with close cooperation on water policy is an important factor for economic integration and should help solve the problem of joint use of transboundary water resources.

The Aral Sea basin countries lying in the arid zone are most exposed to high risks and threats as a result of global and local climate change. Climate warming can be observed throughout Central Asia, and long-term assessments on the basis of the climate scenarios project no increase in water resources in the region. Further, countries in the middle and lower reaches of transboundary rivers will face depletion of available water resources and increased water scarcity as water quality, including groundwater degrades. This will primarily affect the population's access to quality drinking water. Hydrographic regime of surface waters is expected to change significantly due to the accelerated glacier melting and reduced snow cover, accelerated desertification, land degradation and salinization, loss of biodiversity, and increased deforestation. The cumulative negative effects of climate change will increase competition for water among the countries in the region with long-lasting and significant implications for political, food, energy, sanitation, and environmental security in the region. With the increasing frequency of dangerous and extreme hydrometeorological phenomena, such as hail, drought, extremely high or low temperatures, etc., the frequency of natural emergencies is forecasted to rise. These include heavy showers, mudflows, landslides, avalanches, floods, and droughts. Climate change can also pose a threat to the existing ecosystems and biodiversity [Orlovsky N.S. and others, 2019].

Climate change impacts in the region are aggravated by the dried-out Aral Sea which, having lost its role as a climate and geochemical runoff regulator, has turned into a source of aeolian salt transport to the surrounding area. The resulting ecological, social, economic problems require new approaches to irrigation development and water management in the region, especially in the transboundary context [Pankova E.I., 2016]. Hence, practical adaptation measures must be put in place especially in large water-using and water-consuming sectors such as agriculture, hydropower, industry, and public utilities. In these sectors, step-by-step comprehensive reconstruction of water infrastructure is needed, with universal transition to water-saving technologies and waste-water reduction. In the agricultural sector, it is important to promote cultivation of more drought-resistant crop varieties on a larger scale, improve the technical level of engineering irrigation systems and equip them with automated means of water distribution and monitoring for condition of irrigated lands. In the industrial sector, low-water technologies and water recycling systems need to be implemented. In the public utilities sector, technical condition of water supply and sewerage systems should be improved while reducing their water losses, and new technologies for wastewater treatment should be adopted.

The future water needs of the countries in the region can only be met through a sustainable and efficient use of available water resources and implementation of integrated climate change adaptation measures, strengthening of regional cooperation for joint use and protection of transboundary river basins.

Central Asian states contribute greatly to the achievement of the Sustainable Development Goals (SDGs) in every dimension – environmental, social and economic: the SDG targets are integrated into strategies and policies of the government planning systems of countries in the region. Strengthening cooperation between the national authorities of Central Asian countries and international organizations in water management, water supply and sanitation is an important aspect of ensuring national water security.

Joint solution of environmental and resource problems in transboundary river basins, implementation of multilateral investment projects, development of scientific and technical base and personnel training must become important drivers of sustainable development and expansion of an integration cooperation. Coordination of regimes and rules of operation of hydropower plants with reservoirs, main channels and large pumping stations, construction plans of facilities for different types of transboundary river water resources use and protection, requires joint actions based on integrated water resources management. In doing so, it is fundamental for cooperation in transboundary river basins that water-using states observe the principles of reasonable and equitable use of international watercourses and avoid causing harm to other neighboring states.

Cooperation between water management bodies and water-using and water-consuming economic sectors (land-water-energy nexus) is the basis for integrated water resources management. It is important to strengthen cooperation between the hydrometeorological services of the region – at the local, national and regional levels. It should be noted that presently, an integral system of water resources management in the countries of the region is still nascent, and its legal development requires harmonization with multiple branches of law relating to environmental protection, economy and finance, construction, education, science, international relations, and national security.

The priority for water strategy and policy is to implement national actions to preserve the water and resource potential of the river systems and their environmental security. In order to implement the basin-wide principle of water resources management, the basin authority should be vested with sufficient powers and functions, have infrastructure to manage water assets (reservoirs, rivers, lakes, groundwater) and physical facilities, be able to automate collection and permanent storage of information base of basin data, etc. Strengthening of the basin authority (at the national and regional levels) will enable maintaining sustainability of water resources in the country irrespective of the multiple reorganizations of superior entities (ministries, committees). In this regard, it is necessary to develop a policy to strengthen the national and regional basin authorities, particularly Syr Darya Basin Water Management Associations (BWMA) and Amu Darya BWMA.

Introduction

In 1991, Central Asia emerged as a geopolitical space comprising Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan and Uzbekistan after the collapse of the Soviet Union. The historical and geographical name that formerly characterized these states, "Central Asia and Kazakhstan" or Turkestan, is also widely used in the academic world [USSR AS, 1968; Kastelskaya Z.D., 1980]. The modern designation of the region's post-Soviet states – Central Asia – has also become commonly used to refer to the region's role in international politics and the world economy. However, it is also necessary to distinguish, from the point of view of geographical science, another Central Asia – a broader region that includes, in addition to the above-mentioned states, Mongolia, the western part of China (Xinjiang), and Afghanistan [Zvyagelskaya I.D., 2009]. In this way, the notion of Central Asia and what states in the region it includes depends on the issue at hand and its subject matter. In our case, Central Asia refers to the region of former Turkestan, which means the post-Soviet states of Central Asia [Jandossova Z.K., 2005].

Figure 1-1

Source: World Atlas, 2017.
Disclaimer: The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations.
Dotted line represents approximately the Line of Control in Jammu and Kashmir agreed upon by India and Pakistan. The final status of Jammu and Kashmir has not yet been agreed upon by the parties.

The region occupies a vast undrained area within the confines of the closed Aral-Caspian basin, and this peculiarity predetermines a special regime of rivers, extremely susceptible to the impact of economic activity and climate change. Natural and geographical conditions of the region determine the special nature of formation of river flow within the river basin, while political and economic conditions determine its use [Volkhonsky B.M., 2014].

Until the 1960s, the condition of the Aral Sea and its feeding rivers Syr Darya and Amu Darya was characterized as stable. Then, over a very short period of time, the dramatically increasing anthropogenic impact on their condition caused by non-recoverable water diversion for irrigation purposes led to the exhaustion of the two rivers' compensating capacities and the drop of water level and volume in the Aral Sea. The desiccation of the Aral Sea, formerly one of the world's largest reservoirs, has reached such a degree of degradation extending far below the original level of the former sea – 53 m – and beyond, that led to catastrophic desertification of a huge area in the region. The deltas of the two great rivers of Central Asia have almost completely dried up [SIC ICWC, 2001; Dukhovny V.A., Joop de Schutter, 2003; Dukhovny V.A., 2020]. As a result, anthropogenic activity has led to a large-scale desiccation of the Aral Sea in just 30 years unparalleled in world history for a water body of this class.

In an arid climate, the consequences of non-recoverable diversion of the Syr Darya and Amu Darya river flow, extensive farming with high water consumption, had an extremely negative impact not only on the natural environment of the region, but also on the economy and living conditions of the population and their migration [Burnakov E., 2002; Ivanov D.V., 2013]. The impact of the drying sea has spread to all components of the natural environment and is increasingly shifting from downstream to midstream, manifesting itself in a sharp deterioration of irrigated land, swamping and salinization, declining crop yields and living standards of the population, and the quality of their drinking water supply. This poses a serious threat to public health not only in the lower reaches of the Amu Darya and Syr Darya rivers, but also in their middle and upper reaches [Elpiner L.I., 2002].

The social and environmental consequences of the extreme use of the water resources of the Aral Sea have been ignored [Kulpin E.S., 2007]. Poorly treated or untreated municipal and industrial wastewater, and drainage water often containing heavy metal salts and other highly toxic ingredients, is discharged into the Amu Darya and Syr Darya rivers and their tributaries because of the lack of any environmental and sanitary restrictions [Elpiner L.I., 2002].

Unfortunately, the problem of the Aral Sea is not the only one of its kind; it is part of the global process of desertification and loss of natural environment potential caused by anthropogenic factors, intensive use of natural resources and environmental pollution.

Changes in hydrological conditions of rivers and, consequently, water use conditions, and the resulting increased water competition in the region, underscore the importance of integrated land and water resource management strategies, water infrastructure development, and optimization of the required investments. Addressing the issues of cross-border water use and protection of river basins from pollution and depletion, and adaptation to climate change, and thus ensuring sustainable water use for the future and the economic development prospects of each country depends on the nature of regional cooperation [Sehring J., 2012].

After Central Asian countries gained independence and sovereignty, they faced serious environmental problems that required enormous efforts and resources to solve. These problems were difficult not only because they encompassed the entire country and neighboring states, but also because underlying causes were stonewalled for many years at the Soviet Union level, there was a lack of accessible and reliable information, many materials are still classified [Novikova, 2019].

After the collapse of the USSR, all decisions adopted at the Soviet Union level lost their force. The consequences of such a crisis could not be addressed by the country on its own so international assistance and joint efforts of the Central Asian states were required, first of all, to settle water relations problems in the region. In this regard, the Conference of Heads held on 26 March 1993 in Kyzylorda established such regional institutions as ICAS (Interstate Council for the Aral Sea) and IFAS (International Fund for Saving the Aral Sea) [Narbayev M.T., 2010; IFAS EC, 2021].

Transformation of the Aral Sea and the Aralkum desert that emerged in its place, as well as the natural environment of the Aral Sea region, due to the drop in sea level and contraction of its water surface, is characterized by changes in the Aral Sea region climate and defined as arid warming with the continuing probability of cold periods [Zavyalov P.O. and others, 2011]. However, the issues of climate change in the region related to the Aral Sea desiccation and adaptation to it still remain insufficiently addressed. This report proposes recommendations on adaptation measures for economic activities in the area and living conditions of the population in the area of the former Aral Sea, based on climate change models.

1. Socio-economic and climate profile of Central Asia

Central Asia is located deep inside the Eurasian continent occupying the seventh largest area in the world at over 4 million km2 and is bordered in the northwest by Russia, in the south by Iran and Afghanistan, and in the east by Russia and China. The region is almost equidistant from the Atlantic and Pacific Oceans (about 4,000 km). It reaches 47° l.d. in the north and 34° l.d. in the south, *i.e.* it occupies the southernmost latitudes of the temperate zone and wedges into the subtropical zone in the south [Alpatyev A.M. and others, 1976].

Geographical location of the region in the zone of inland deserts and its remoteness from the oceans and seas, the nature of the orographic structure determines the continental climate and related hydrographic network, and the river regime.

Figure 1-2

Source: Zoi Environment Network.

Disclaimer: The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations.
Dotted line represents approximately the Line of Control in Jammu and Kashmir agreed upon by India and Pakistan. The final status of Jammu and Kashmir has not yet been agreed upon by the parties.

In terms of orography, Central Asia is divided into two parts: the western part which occupies more than 71 percent of its territory, dominated by lowlands (the Turan Plain), and the eastern part (29 percent of the territory) with mountain systems. This is where the entire region's water resources are formed. In the northwest is the eastern part of the Caspian lowlands.

The main types of nature management activities affecting the condition of zonal (forest, steppe, desert) and intrazonal (water, marsh, floodplain-valley) ecosystems include mining, agriculture (pasture, farming), forestry, and nature conservation activities.

Table 1-1 Demographic and nature and climate profile of Central Asia

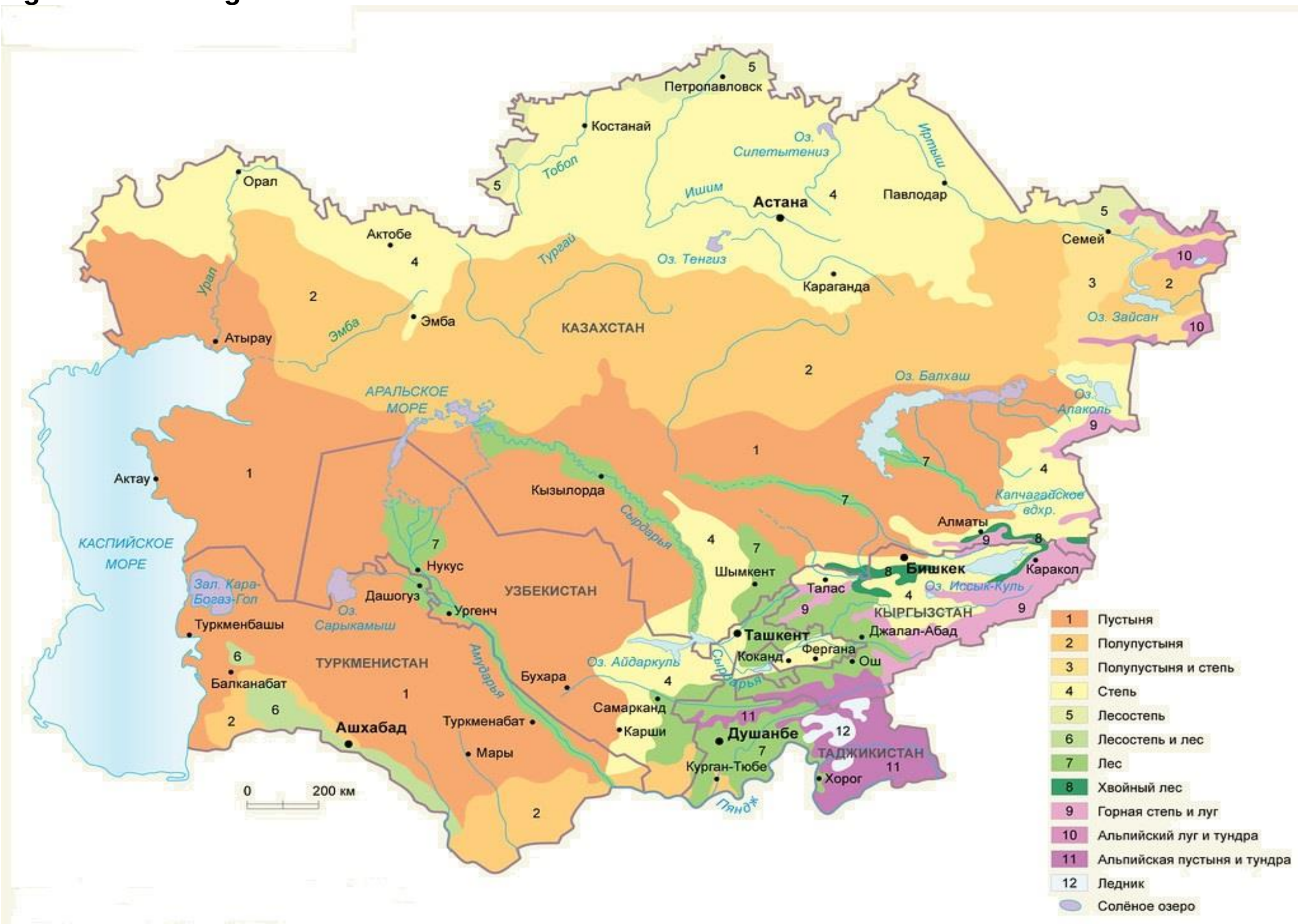
Profile	Kazakhstan	Kyrgyzstan	Tajikistan	Turkmenistan	Uzbekistan
Area, thousand km^2	2,724.9	187.5	142.6	491.2	448.9
Population, million people*	18.6	6.5	9.3	6.4	33.9
Population density, people per km^2	6.8	34.7	65.2	13.1	75.5
Share of flat area, %	deserts and semi-deserts	15%	7	deserts and semi-deserts	deserts and semi-deserts
Share of mountainous area, %	10	85	93	10	21,2
Share of agricultural land in the total area, %	23% farming, 70% livestock breeding	52%	53,6%	69.4% farmlands, 27.6% land reserve	46.1% farmlands, 20.1% land reserve
Maximum and minimum heights	7,010 m; -132 m	7,439 m 488 m	7,495 m, 300 m	3,139 m -81 m	4,643 m -12.8 m
Average temperature in January	-3ºC (S), -18°C (N)	-2.2°C (S), -29.1°C (mountains)	+2ºC in valleys -27ºC in mountains	+4°C (S), -5°C (NE)	+3ºC (S), -10ºC (Ustyurt Plateau)
Average temperature in July	S +29°C, N +19°C	+26.8°C (S), +4.1°C (mountains)	+30ºC in valleys +4ºC in mountains	+34°C (S), +28°C (NE)	+37ºC S, +33°C N
Maximum and minimum absolute temperatures	+49ºC (Kyzyl-Kum desert) -57ºC (N)	+43.6°C (Chu valley) -53.6°C (Aksay)	+47ºC (Lower Panj) -63ºC (Bulunkul lake)	+50°C Repetek -32.8°C Gusgy	+50ºC (S), -40ºC (Ustyurt Plateau)
Change in average annual precipitation across the territory, mm	< 100 in deserts, up to 500 in steppes, up to 1,600 in mountains	< 150 in deserts, 400-600 in valleys, up to 1,600 in mountains	from 70 in Eastern Pamir up to 1,800 in mountains	< 100 in deserts, up to 150 in plains, 350 in mountains	< 100 in deserts, up to 900 in mountains
Share of agriculture in GDP (%)	7	38	21	18	24

Source: CIS Statistical Committee; CESDRR, 2020.
Note: * as of early 2020.

In the vast plains of northwestern Central Asia, there are very few watercourses with rivers taking no tributaries all the way from their exit from the mountains to the mouth. Only the largest rivers, the Amu Darya, the Syr Darya and the Ili, are capable of crossing many hundreds of kilometers of desert stretches and reaching the most significant drainless reservoirs of Central Asia – the Aral Sea and Lake Balkhash. In contrast to the plains, the mountains of Central Asia are riddled with a highly extensive river network of over ten thousand streams [Schultz L.K., 1965; Domnitsky A.P. and others, 1971].

On average, a significant part of the plains with different topography lies at an altitude of 100-300 m above sea level. In the immediate vicinity of the Aral Sea, the absolute altitudes drop to 63 m. Plains and river valleys join the mountain zone, sometimes in the form of elongated strips.

Figure 1-3 Ecoregions of Central Asia



Source: ADB, 2010; GRID - A, 2016.
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Landlocked position of Central Asia and its vulnerability to the north contribute to a dry and harsh continental climate: dry, cloudless and hot summers are replaced by relatively wet winters, sometimes with severe frosts, especially in the north [Davydov L.K., 1947; Alpatyev A.M. and others, 1976].

In terms of hydrology, Central Asia can be divided into three areas: *mountainous, piedmont and plains*. Groundwater feeds in the mountainous areas, transits mainly in the piedmont areas, and dissipates and evaporates in the plains [Alpatyev A.M. and others, 1976]. For Central Asian rivers, glaciers account for no more than 10 percent of the annual runoff, with a maximum of 20 percent. Seasonal snow accounts for up to 50 percent, sometimes even more, in the mountain rivers feeding. Rainfall share in river feeding is insignificant, usually below 10 percent, rarely 20 percent even at elevations of 1,000-2,000 m, where its share in surface runoff is more noticeable. Groundwater contributes considerably (20-40 percent) to the feeding of mountain rivers in Central Asia, and its share increases noticeably at the foot of piedmont aprons, or the so-called alluvial cones. By water regime that is closely tied to the climate and altitude position of the belt, the rivers of the Aral Sea basin are classified as the Altaian and Tien Shan types [Alpatyev A.M. and others, 1976]. For them, the major determinant of average river flow capacity and annual flow fluctuations is the snow cover and year-to-year changes in its reserves. In turn, flow distribution throughout the year mainly depends on the thermal regime of the snow and ice reserves melting period, if we disregard the rivers fed from the lower zones of the mountain system where snow floods can be strongly distorted by liquid precipitation [Schultz L.K., 1965; Mikhailov V.N., 2017].

Figure 1-4

Source: Zoi Environment Network.

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Economic activity also has a great impact on the flow regime of the rivers. As soon as the river enters the plain, it begins to be taken apart for irrigation; it is especially intensive during the flood season, and the river's flow gradually decreases [Schultz L.K., 1965].

1.1 Socio-economic profile of Central Asian countries

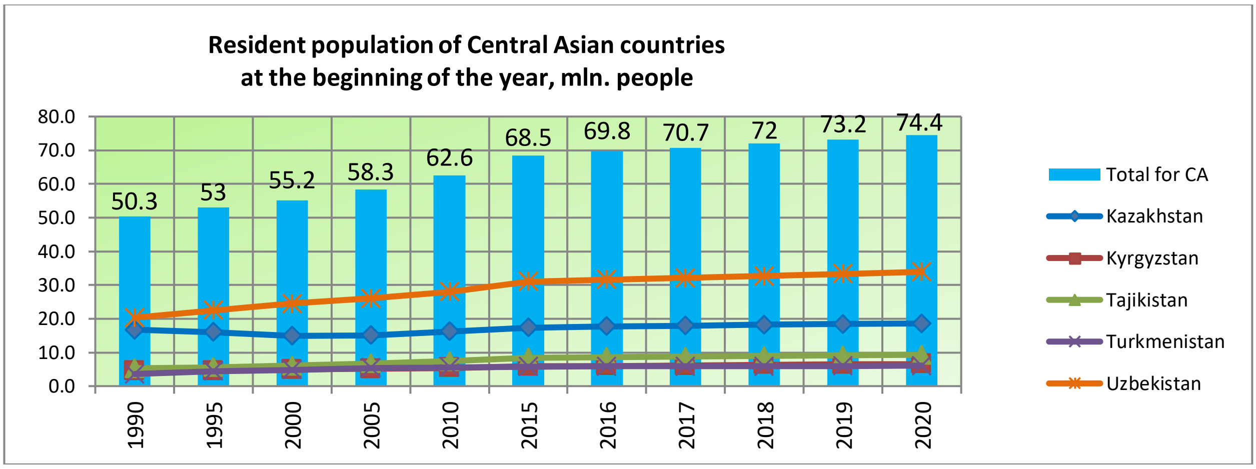
Demographic factors have a decisive influence on the socio-economic development of Central Asia and determine water use and energy supply strategies, as well as the *nature* of interstate relations in the region, both at present and in the future.

By early 2020, the total population of Central Asian states amounted to 74.4 million people with 80.6 percent of the population concentrated in the Aral Sea basin. The Kazakhstani part of the Syr Darya River basin is inhabited by more than 3.6 million people (South Kazakhstan oblast – 2.8 million people, Kyzylorda oblast – 777.1 thousand people).

Compared to 1990, an average annual population growth rate exceeded 3 percent. Conservative scenario projections show that the median population growth across Central Asia will be from the current 74.4 million to 90.0 million in 2050. Most of Kazakhstan's population (more than 61 percent) is concentrated in cities, towns and urban areas. Rural population prevails in Kyrgyzstan (64.1 percent), Tajikistan (72.8 percent), and Uzbekistan (63.3 percent). In Kazakhstan, female share in the total labor force makes 49.4 percent, in Kyrgyzstan –

42.75 percent, in Tajikistan – 45.2 percent, in Turkmenistan – 39.3 percent, in Uzbekistan – 39.8 percent.

Figure 1-5



Source: USSR national economy in 1990, CIS Statistical Committee, EEU, 2020.

Migration of the working-age population of Kyrgyzstan, Tajikistan and Uzbekistan who migrate both inside and outside their home countries due to socio-economic and environmental factors, has a significant impact on the changes in the size and structure of the population of these countries. The migration destinations are mainly Russia and Kazakhstan [Burnakova E., 2002; Ivanov D.V., 2013].

In terms of HDI, Central Asian countries rank relatively satisfactorily. In 2019, Kazakhstan ranked 51st in the world with HDI score of 0.825 and lists among the countries with a very high level of human development. The countries with high human development level include Uzbekistan with HDI of 0.720 (106th in the 2019 ranking) and Turkmenistan with HDI of 0.715 (111th in the 2019 ranking). Kyrgyzstan with HDI of 0.697 (120th in the 2019 ranking) and Tajikistan with HDI of 0.668 (125th in the 2019 ranking) are among the countries with medium level of human development [UNDP, 2020].

In virtually all countries, the share of fuel and energy mineral extraction and metallurgical production has increased. While relative importance of the agricultural sector has changed differently from country to country, in general the share of agriculture and other industries has declined relative to the extractive industries. At the same time, Central Asian countries, except Kazakhstan, have limited land resources suitable for expansion of irrigated areas (Table 1-2).

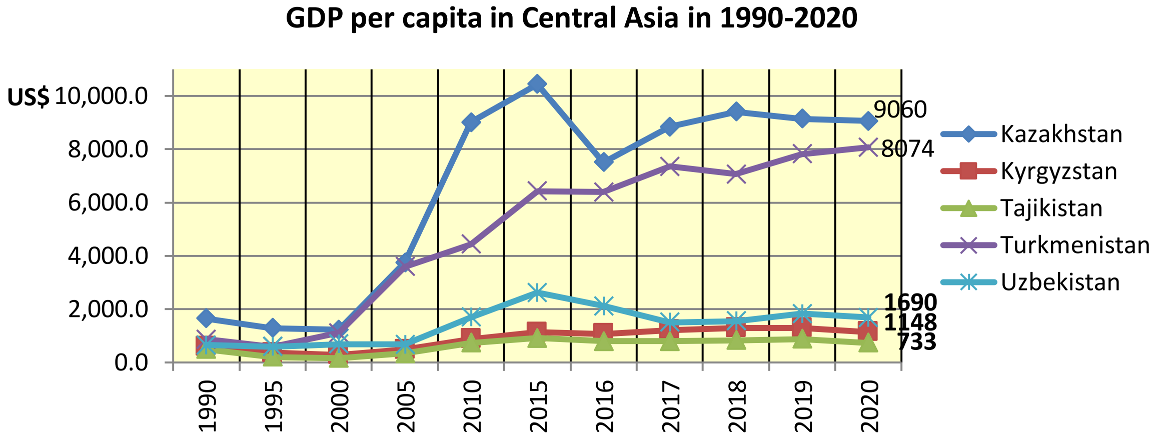
Table 1-2 Agricultural lands

Country	Total land area, million hectares	including: arable land, million hectares		
		rainfed land	irrigated land	range land
Kazakhstan	269.970	18.994	2.312	185.098
Kyrgyzstan	19.180	0.238	1.072	9.365
Tajikistan	13.996	0.208	0.722	3.198
Turkmenistan	46.993	0.400	1.800	30.700
Uzbekistan	42.540	0.419	4.281	22.219
Total for CA	392.679	20.259	10.187	250.58

Source: Gupta R. and others, 2009.

The economies of Kazakhstan and Turkmenistan are dominated by the export of hydrocarbons with deliveries mainly to the far abroad (European countries, China, Russia). Over the past 15 years, the specific value of GDP in these economies is significantly higher than that of the other economies in the region. Thus, in 2020, GDP per capita in Kazakhstan was US$ 9,060; in Turkmenistan – US$ 8,074; in Uzbekistan – US$ 1,690; in Kyrgyzstan – US$ 1,148; and in Tajikistan – US$ 733 (Figure 1-6).

Figure 1-6



Source: CIS Statistical Committee; EEU, 2020.

Availability and accessibility of various fuel and energy resources within the countries of the region determine the structure of their consumption. Thus, the fuel and energy balance of Kazakhstan relies on coal, in Uzbekistan and Turkmenistan on gas, and in Kyrgyzstan and Tajikistan on hydropower. The resource hydropower potential of Central Asian economies is shown in Figure 1-7.

Figure 1-7

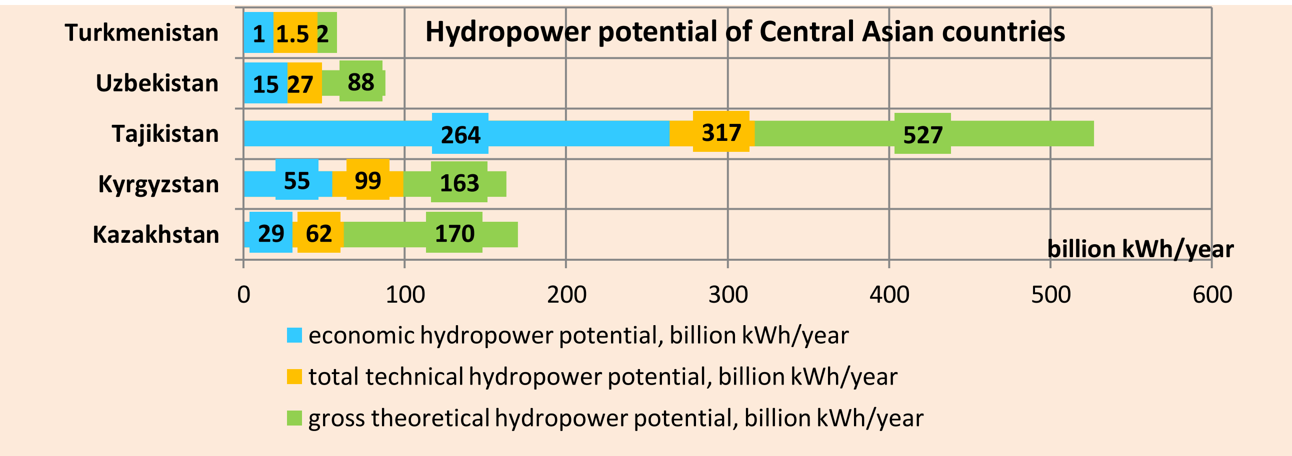


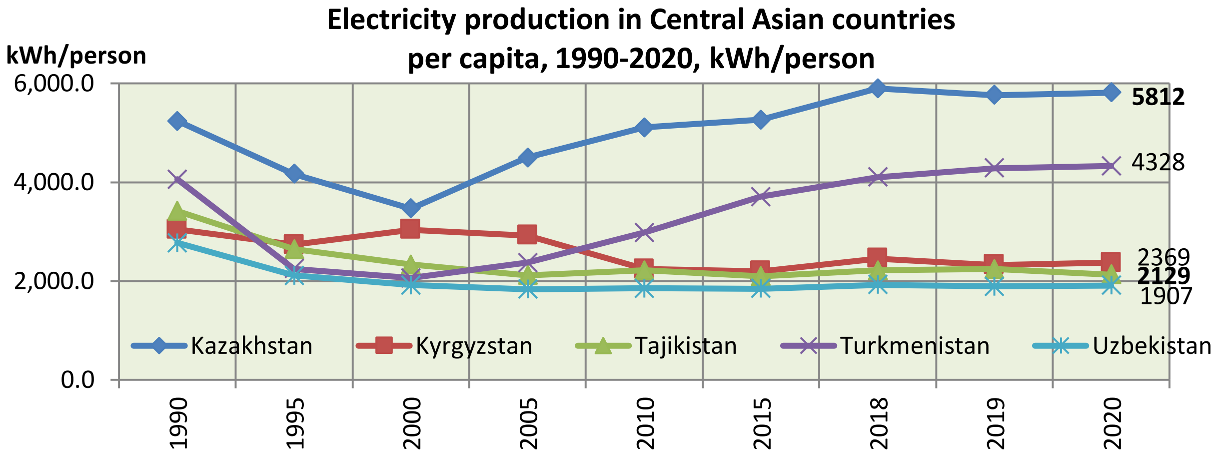
Table 1-3 Electricity sector profile in Central Asian countries (as of early 2020)

Country	Thermal and gas PP		HPP	Renewable power plants, MW				Total
	TPP	GTPP		WPP	SHPP	SPP	BPP	
Kazakhstan	17,389	1,999	2,666,	383.9	224.6	883.6	7.82	22,936
Kyrgyzstan	862	-	3,030	-	40	-	-	3,932
Tajikistan	598	-	5,748.3	-	60.2	-	-	6,406.5
Turkmenistan	-	6,510	1.2	-				6,511.2
Uzbekistan	3,054	9,989	1,682	-	247	-	-	15,044
Total								54,829.7

Source: CIS Statistical Committee; EEU, 2020; CIS EPC EC, 2020

Note: PP – power plant, TPP – coal-fired thermal power plant, GTPP – gas turbine power plant, WPP – wind power plant, SHPP – small hydro power plant, SPP – solar power plant, BPP – biogas-fired power plant.

Figure 1-8

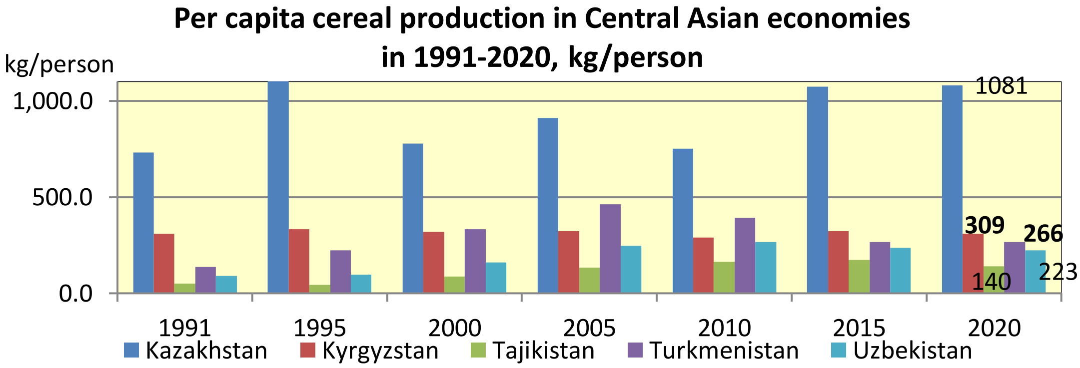


Source: CIS Statistical Committee; EEU, 2020.

Central Asian countries differ significantly in specific electric power production per capita: in 2020, it was 5,812 kWh per capita in Kazakhstan; 4,328 kWh per capita in Turkmenistan; 2,369 kWh per capita, 2,129 kWh per capita and 1,907 kWh per capita in Kyrgyzstan, Tajikistan and Uzbekistan, respectively (Figure 1-8). Hydropower use in CA countries faces a number of problems with one of the most significant being limitations of energy transportation infrastructure [Sarsembekov T.T. and others, 2004; Yassinsky V.A. and others, 2010].

Food security is another water-related problem for Central Asian economies. An important indicator of food security is per capita cereal production which varies considerably from country to country. In 2020, the highest production was in Kazakhstan (1,081 kg per capita) and the lowest was in Kyrgyzstan (140 kg per capita). In the rest of the region it is also relatively small, ranging from 223 to 309 kg per capita.

Figure 1-9



Source: CIS Statistical Committee; EEU, 2020

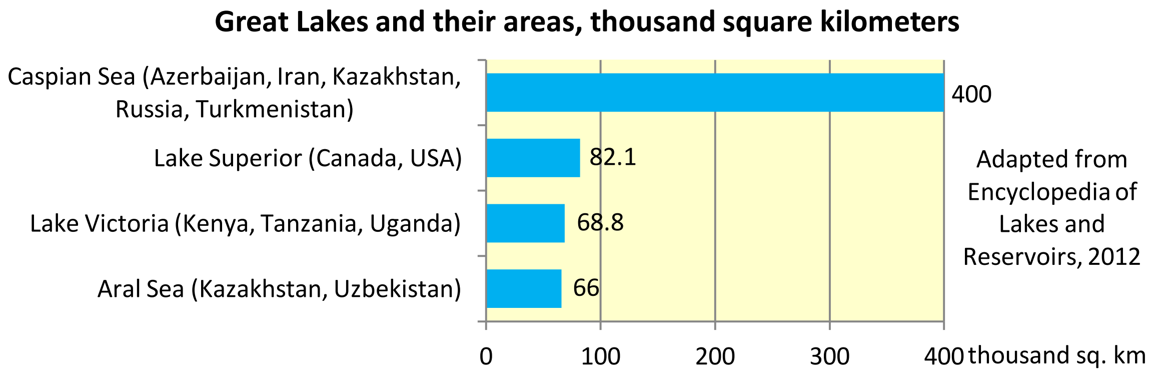
Due to the insufficient level of food security, crop distribution patterns in these countries are projected to be revised by expanding the area of irrigated land for food crops. Therefore, considering developments in irrigation and hydropower, we should expect a further increase in competition for water that will require new mechanisms and tools for cooperation in transboundary river basins, based primarily on a deeper economic integration of the economies across the region.

1.2 The Aral Sea basin

The Aral Sea basin encompasses a vast area in Central Asia spanning from the Caspian Sea in the west to the Sarykol and Kakshaal Too ridges, Kungei Alatau and Zailiski Alatau ridges in the east, from the watersheds of the Atrek, Tejen, Murgab rivers and the Hindukush mountain range in the south to the watersheds of the Turgai and Ubagan rivers and the Mugodzhar hills in the north. The basin's terrain is mostly a vast, sparsely dissected plain that descends from east to west toward the Aral and Caspian Seas, with mountains occupying only 20 percent of its area. The Aral Sea basin covers almost all of Tajikistan, Uzbekistan, most part of Turkmenistan, several provinces (oblasts) of Kyrgyzstan and Kazakhstan over an area of about 2.4 million sq km, and including the northern provinces of northern Afghanistan and northeastern Iran – a total of about 2.7 million sq km. The Aral Sea basin includes the basins of the rivers Amu Darya, Syr Darya, Chu, Talas, Assy, Sary-Su, Turgai and a number of small undrained rivers, as well as the basins of the Tejen and Atrek rivers [Baidal M.H., 1972]. However, the northern provinces of Afghanistan and Iran are still factored into the water balance of Central Asian countries in the long term only.

As of 2020, the Aral Sea basin, which covers 60 percent of Central Asia, was home to 60 million people, or nearly 80.7 percent of the region's population. In the recent past – as recently as the 1960s – the Aral Sea was one of the largest undrained reservoirs on Earth and ranked among the world's great lakes [Rumyantsev V.A. and others, 2014].

Figure 1-10



The Aral Sea basin is a region of sharp climatic contrasts: it combines extreme aridity and abundant moisture with snow fields often separated from hot deserts by a distance of no more than 100 km. The northwestern flat part of Central Asia has very hot summers. Average July temperatures here reach 25-30°, *i.e.* they exceed those in the tropics (where July temperatures are 24-28°). In summer, temperature differences between the north and south are minimal, with tropical air forming over the Central Asian plains and colder air masses flowing in from northern latitudes warming up quickly. Thus, almost the same high temperature prevails throughout the vast Central Asian plain during the summer which is a powerful factor of evaporation, hence are typical desert conditions [Zavyalov P.O. and others, 2011; Kolodin M.V., 1981; Babayev A.G., 1986].

Available water resources of the Aral Sea basin are made up of renewable surface water and groundwater of natural origin, and return water of anthropogenic origin. All sources – seasonal and eternal snow, glaciers, rainfall, and groundwater – take part in feeding the rivers in the Aral Sea basin, but the share of each of them varies according to the position of river basins in one or another altitudinal belt.

Table 1-4 Aggregate natural river discharge in the Aral Sea basin (long-time annual average discharge, km^3 per year)

Countries	River basin		Aral Sea basin	
	Syr Darya	Amu Darya	km^3	%
Kazakhstan	2.426	-	2.426	2.1
Kyrgyzstan	27.605	1.604	29.209	25.1
Tajikistan	1.005	59.578	60.583	43.4
Turkmenistan	-	1.549	1.549	1.2
Uzbekistan	6.167	5.056	11.223	9.6
Afghanistan and Iran	-	21.593	21.593	18.6
Total	37.203	79.280	116.483	100

Source: SPECA, 2004

The hydrographic network of the Aral Sea basin is characterized by an extremely uneven distribution of water bodies on its surface, including the river network [Sokolov A.A., 1964].

Table 1-5 Use of water and land resources in the Aral Sea basin

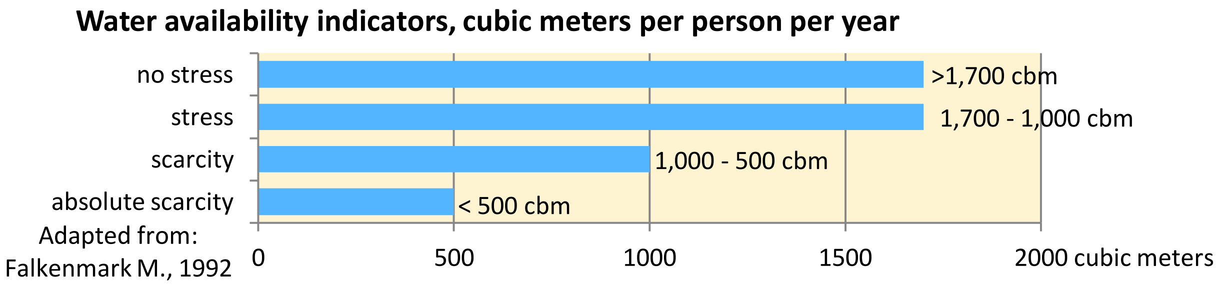
Indicator/ years	unit of meas.	1960	1970	1980	1990	2000	2020	2030*	2050*
Population	million people	15.8	21.3	28.8	36.4	43.7	60.0	67.8	75.6
Irrigated land: Total,	'000 hectares	4,510	5,150	6,183	7,421	8,038	8,040	8,100	8,200
per capita	ha/person	0.29	0.24	0.22	0.20	0.18	0.13	0.12	0.11
Water intake: Total including	km^3/year	60.61	94.56	120.69	116.27	105.0	104.6	107.5	106.3
for irrigation	km^3/year	56.15	86.84	106.79	106.4	94.66	94.1	87.5	79.72
per irrigated hectare	m^3/ha	12,450	16,862	17,272	14,338	11,777	11,704	10,802	9,722
per capita	km^3/psn a year	3,836	4,439	4,191	3,194	2,403	1,743	1,586	1,406

Source: Royal Haskoning (2003), CIS Statistical Committee, SIC ICWC

Note: * total water intake was calculated with account of reused discharge and drainage water, future urbanization level in the countries of the region and climate change.

Economies or regions with water resources of less than 500 m^3 per capita a year are known as countries with absolute water scarcity; between 500 and 1000 m^3 – countries with water scarcity; between 1,000 and 1,700 m^3 – countries with stressed water supply; and above 1,700 m^3 – countries with no water stress [Falkenmark M., 1992].

Figure 1-11



Based on a conservative scenario, Central Asian countries already experiencing water scarcity might be close to water scarcity by 2030. In case of inadequate regional economic cooperation and, in particular, water and energy integration, they can find themselves in a situation of absolute freshwater scarcity by 2050 (Table 1-5).

In the Aral Sea basin, over 80 reservoirs have been built with useful water volume of over 10 million m^3 each [WB, 1998]. The aggregate volume of these reservoirs is 64.5 km^3 including useful volume of 46.5 km^3, of which 20.2 km^3 is in the Amu Darya basin and 26.3 km^3 is in the Syr Darya basin. These rivers' flow is highly regulated by reservoirs, the level of regulation reaching 0.94 for the Syr Darya River (*i.e.* its natural flow is almost completely regulated) and 0.78 for the Amu Darya River (*i.e.* there is still room for further regulation, but available reserves will be exhausted in the coming years due to the extensive development of hydropower resources of the river and its tributaries) [Sarsembekov T.T. and others, 2004]. The flow of these rivers and their tributaries is expected to be fully regulated by 2030. Table 1-5 shows the dynamics of water use and irrigated land use in the Aral Sea basin since 1960, and projections for 2030 and 2050.

1.3 The Amu Darya River basin

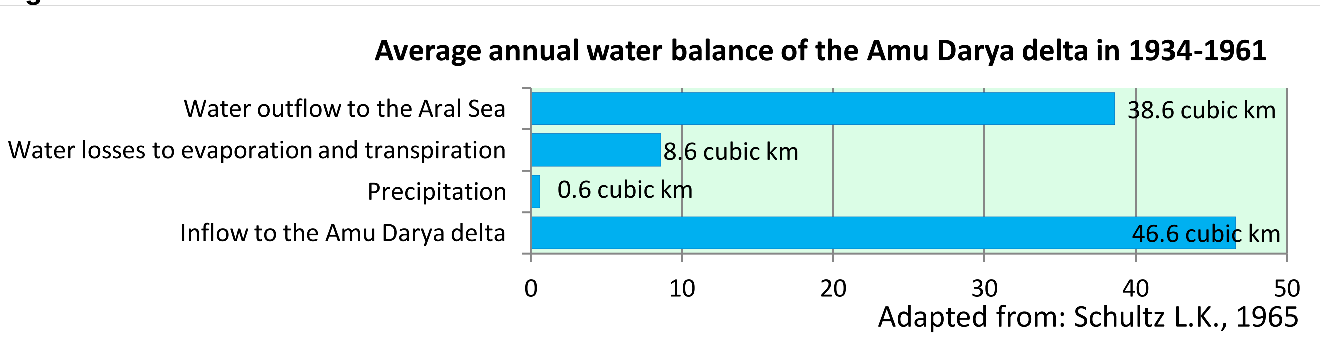
The Amu Darya River emerges through confluence of the Panj and Vakhsh Rivers and, flowing for 1,440 km mainly through desert areas, discharges into the Aral Sea. The Amu Darya receives tributaries only in the first 180 km but in the rest of its journey the river not only lacks any tributaries but, on the contrary, is used for irrigation, especially intensively in its lower reaches, loses water to evaporation and filtration, so its flow progressively reduces [Schultz L.K., 1965].

In terms of hydropower, the Amu Darya River basin is of great economic importance. The steep drop and considerable stream flow of its mountain rivers create enormous reserves of energy. Until relatively recently, it was believed that with sufficient long-term flow regulation, the Amu Darya basin rivers could enable using about 7 million hectares of irrigated land in the future. However, it was noted even then that the development of irrigation on such a scale would lead to a complete depletion of the Amu Darya basin's water resources, and the Aral Sea would be doomed to a gradual desiccation [Schultz L.K., 1965].

Another aspect of the Amu Darya basin is active denudation and erosion processes that contribute to the high sediment load of many rivers. Amu Darya is among top rivers on the globe in terms of suspended sediment discharge.

For example, the Vakhsh River annually discharges to the plains 2,680 tons of suspended sediment per 1 km^2 of its catchment area, while the Naryn River (the main source of the Syr Darya River) discharges only 290 tons per 1 km^2 of its catchment area, i.e. 9.2 times less than the Vakhsh [Sokolov A.A., 1964].

Figure 1-12



The delta channels feature extreme variability. The main reason for ceaseless and rapid changes of the delta channels is high turbidity of water. By depositing a huge mass of sediment (annual average of 86 million m^3) to its delta, the Amu Darya raises its surface over time (by 1.3 cm a year when the sediment is evenly distributed over the delta surface occupied by overflows). This results in a gradual advance of the delta into the sea. Therefore, the state of the delta's lakes and overflows which play the role of natural mud chambers largely determines the nature of the delta's changes [Schultz L.K., 1964; Mikhailov V.N., 2001].

1.4 The Syr Darya River basin

The Syr Darya River is formed by the confluence of the Naryn and Karadarya Rivers in the eastern part of the Fergana Valley at latitude 41° and longitude 72°. The effective active catchment area of the Syr Darya is located only in the mountainous region with an area of 219,000 km^2. The length of the river from the confluence of the Naryn and Karadarya Rivers to the mouth is 2,140 km; if the Naryn River is taken as the source, the length will be 2,660 km [Sokolov A.A., 1964]. The Syr Darya is the largest river in Central Asia by length and second only to the Amu Darya by water content. In its regime, the Syr Darya reflects, especially in its upper reaches, the main features of the Naryn and Karadarya Rivers' regime. Since the former gives about 78 percent of the Syr Darya flow, its regime is largely close to that of the Naryn River.

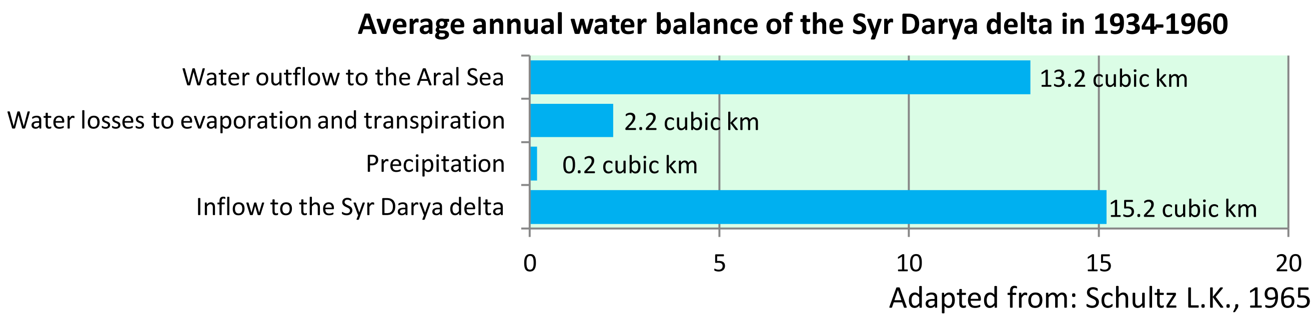
The Syr Darya River's headwaters originate in the Central (Inner) Tien Shan. The river becomes Syr Darya after the merger of the Naryn and Karadarya Rivers. It is fed by glacier and snow, with the latter predominating. The main flow of the Syr Darya is formed in Kyrgyzstan, thereafter crossing Uzbekistan and Tajikistan and further discharging into the Aral Sea in Kazakhstan.

Long-term observations of river flows show that low-water years alternate with high-water years, with low-water years occurring more often, by 2-3 in a row, and high-water years predominantly by ones. In years with different water levels, the surface flow of rivers varies considerably [FAO, 2003].

In the Syr Darya River basin, more than 5 million hectares can be irrigated, but developing such an area of irrigated land will completely deplete the water resources of the basin rivers, stopping water flow to the downstream, delta and the Aral Sea [Schultz V.L., 1975].

Elements of the Syr Darya delta water balance are shown in Figure 1-13.

Figure 1-13



The waters of the Syr Darya River are highly turbid, but to a lower degree than that of the Amu Darya River, at around 2,000 g/m^3. The total sediment load carried by the river to its mouth is 12 million tons per year, while the Amu Darya carries up to 100 million tons. The delta of the Syr Darya River annually advanced about 50 m into the sea; the area of the delta was then called *Kos-Aral* [Sokolov A.A., 1964]. After completion of construction of the Kayrakkum, Tokogul and other reservoirs, the flow of suspended sediments immediately downstream decreased dramatically.

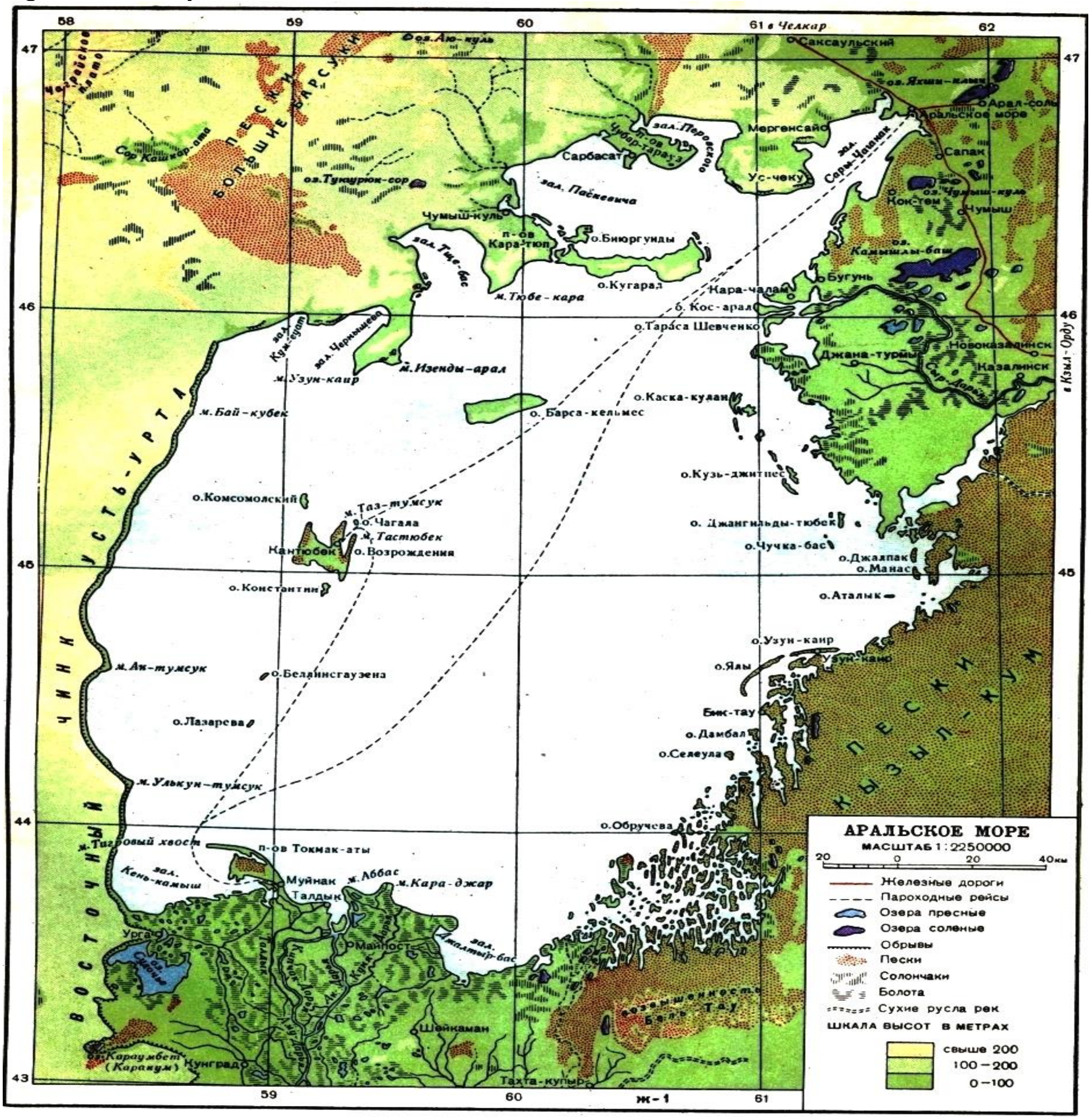
1.5 The Aral Sea problem

Historically, the Aral Sea and its basin have been very well studied. The works by Barthold V.V. [1964], Voyeikov A.I. [1884], Berg L.S. [1904] and others have contributed greatly to the methodological issues of studying the Aral Sea.

In his classical work on *Climates of the globe, especially of Russia* (1884), Voyeikov was one of the first to put forward the idea of interaction between waters and other elements of the geographical environment and to establish their dependence on climate. "Other things being equal, a country," points out Voyeikov, "will be the richer in flowing waters the more abundant the precipitation and the less evaporation from both soil and water surfaces and plants. Thus, rivers can be regarded as a product of climate."

In 1908, Berg L.S. published a monograph entitled *The Aral Sea: an Experience of a Physical and Geographical Monograph*. He disproved the hypothesis of sea desiccation by showing that there were only fluctuations in the water level due to temporary climate change. Berg believed that excessive use of the Syr Darya and Amu Darya waters for irrigation needs of the Central Asian soils could result in the disappearance of the water body.

Figure 1-14 Map of the Aral Sea in the 1950s



Source: GSE, 1950.

Disclaimer: The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations.

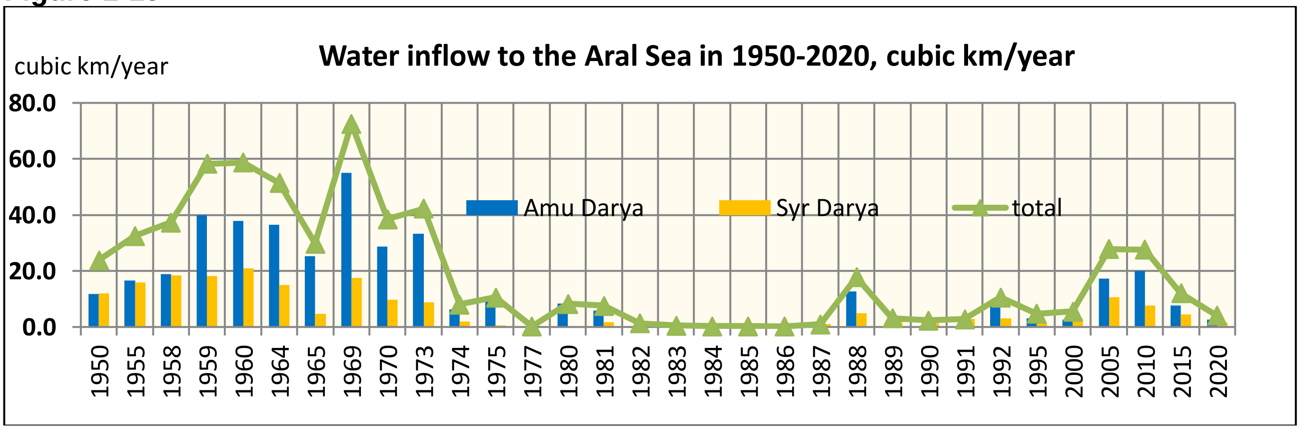
Berg explained the presence of ancient settlements, abandoned irrigation canals in deserts and other traces of material culture by the historical and social events that mankind experienced during the last millennia. He was convinced that the reason for their disappearance was not caused by desiccation but primarily by human activity. "*The withdrawal of water in the rivers as they emerge on the foothill plains is the cause of water disappearance in the lower reaches. Salinization as a corollary of irrigation has led to ruining of vast areas in the ancient civilization countries of the Middle East.*" [Berg L.S., 1908].

The present-day understanding of the Aral Sea and the problems resulting from its desiccation have been outlined in a number of works of the Soviet and post-Soviet periods [Glazovsky N.F., 1990; UNEP, 1993; Kuksa B.I., 1994; WB, 1998; Royal Haskoning, 2002; SPECA, 2004; Glantz Michael H., 2005; Zavyalov P.O. and others, 2011; Zavyalov P.O. and others, 2012; Pankova E.I. and others, 1996; Kipshakbayev N.K. and others, 2010; Novikova N.M., 2019; Novikova N.M., 2020; Dukhovny V.A., 2020].

Intensive development of irrigation in 1900-1913 began with the construction of new irrigation systems across the old irrigated oases (Tashkent, Bukhara, Khwarazm) and with the reclamation of the Mirzacho'l Steppe (*aka* the

Hunger Steppe). Irrigated areas in Central Asia during this period expanded from 2 to 3.2 million hectares. Further development of irrigation during 1925-1940 was associated with restoration of waterworks facilities destroyed during the war, irrigation and reclamation of new lands in all major regions of the Aral Sea basin: Fergana and Vakhsh valleys, Dalverzin Steppe, etc. Irrigated areas reached 4.3 million hectares [Dukhovny V.A., 1973]. By 1990, the total area of irrigated lands in Central Asia reached 7.2 million hectares, and expansion of irrigated areas in the Aral Sea Basin was stopped. The period of intensive irrigation development in the Aral Sea Basin ended due to complete exhaustion of resources and sharp deterioration of the environmental situation [Pankova E.I. and others, 1996]. In the 1930s, Central Asian agriculture was set the task of ensuring "cotton independence" for the country. Since then, the structure of irrigated land use began to shift towards increasing the share of cotton in crop rotations. The task of ensuring cotton independence for the country was largely solved by 1933 (share of domestic cotton fiber increased to 97 percent) [Tulepbayev B.A., 1966]. However, this task was achieved at the highest cost in the history of land reclamation in Central Asia – the area under cotton increased to 60-70 percent; raw cotton yields were not higher than 1-1.2 ton per hectare by 1933; water consumption to produce 100 kg of raw cotton increased to 1,800 m^3. It was in the 1930s that the basis was laid for the wasteful system of irrigated agriculture which depleted Central Asia's natural resources and caused the crisis in the Aral Sea basin [Pankova E.I. and others, 1996]. Thus, the cotton areas in the Central Asian republics (Central Asia and South Kazakhstan) grew at the expense of reclaiming unproductive lands which required large capital expenditures and more irrigation water. The withdrawal of huge volumes of water from the Syr Darya and Amu Darya and, accordingly, the share of their flow that fed the Aral Sea continued to grow. The necessity of applying drainage and leaching irrigation regime became evident. However, leaching irrigation regime against drainage failed to lead to the expected positive effect – salinized soils area in irrigated lands grew and reached 50 percent of irrigated lands area. Water intake from the Syr Darya and Amu Darya Rivers to leach saline lands sharply increased and further accelerated the water level decrease in the Aral Sea [Pankova V.I., 2016]. Discharge of drainage water into the rivers has sharply raised the mineralization of river water and increased its pollution by toxic chemicals. In lower reaches of the rivers, mineralization reached 2-3 g/L [Glazovsky N.F., 1990]. As the World Bank notes, salinization of irrigated land in the Aral Sea Basin poses a threat of a "fundamental and complex nature" to all aspects of security (food, water, environmental, social, etc.) of the countries in the region [WB, 1998].

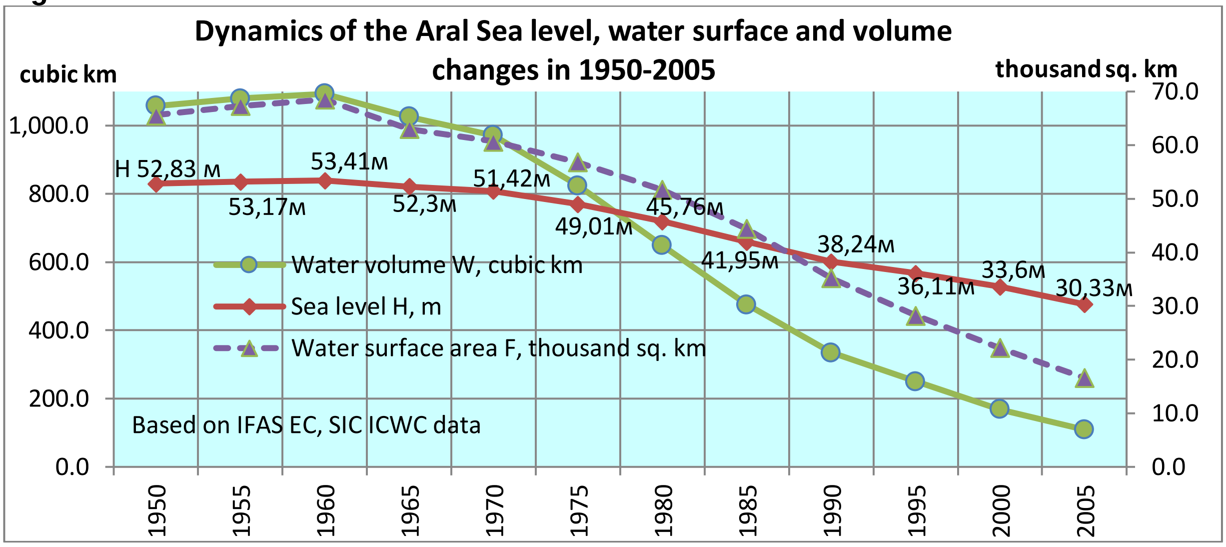
Figure 1-15



Source: Based on IFAS EC, SIC ICWC data.

In the 1950s, it was known that the sea would be lost [Schultz V.L., 1968; Schultz V.L., 1975]. In 1961, the sea level dropped sharply below its long-time annual average for the first time [Novikova N.M., p. 1, 2019]. Drainage water from irrigated lands has increased noticeably and, by flowing into downstream water sources, deteriorated the quality of irrigation water of other water users, which became a serious transboundary problem for Central Asian countries. In addition, horizontal drainage systems occupying large areas have not only increased the demand for irrigation water (because of filtration losses) but have also led to an increased discharge of drainage water into desert depressions [Gupta R. and others, 2009].

Figure 1-16



Source: Based on data from IFAS ED in Kazakhstan, 2021; IFAS EC, 2021

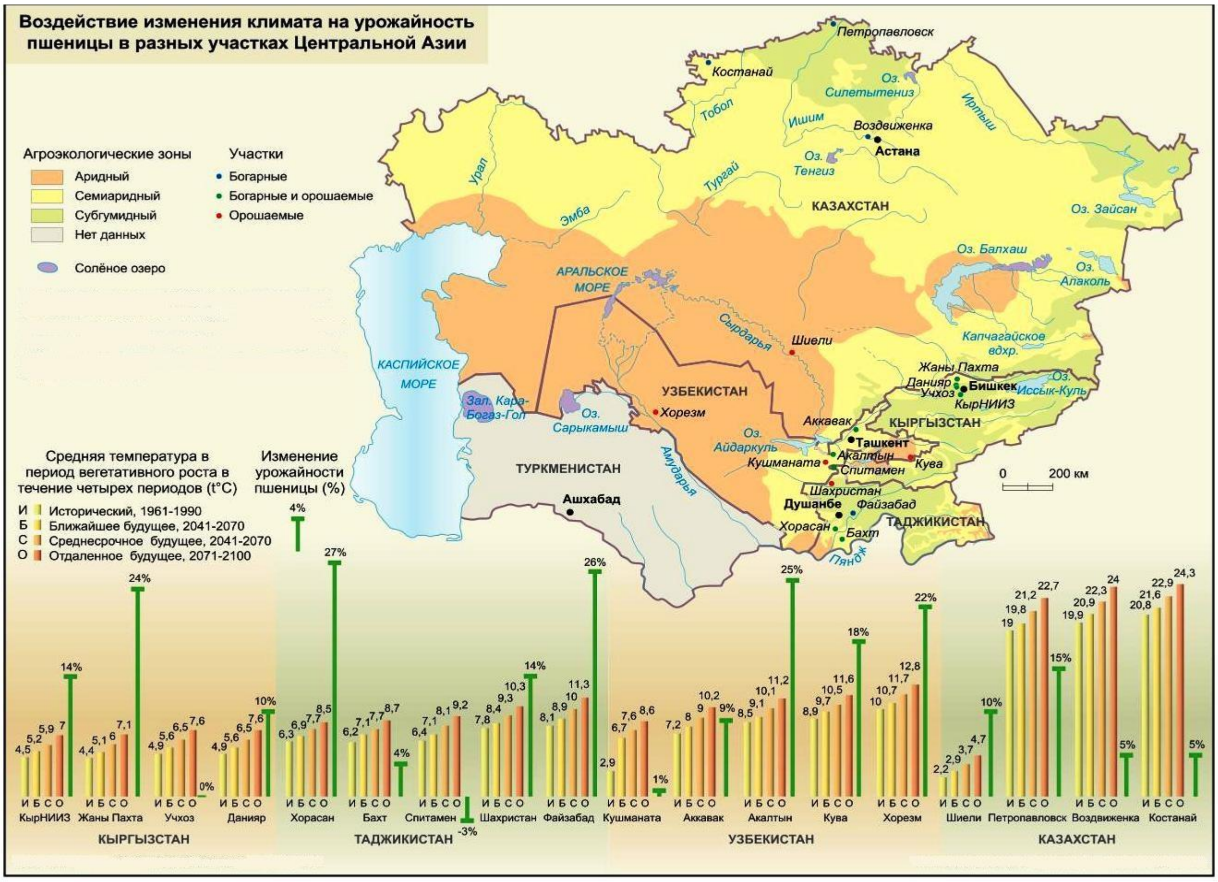
Note: Starting from 1990, when the Aral Sea began to break up into separate water bodies, water volume and levels are also shown for the Small Aral and the Large Aral which then broke up into the Western and Eastern Aral, etc.

The environmental disaster in the Aral Sea region and the desiccation of the Aral Sea attracted the attention of many countries and international organizations. In 1990 in Nairobi, its headquarters, UNEP gathered its member states for a special meeting on the Aral Sea problem which culminated in signing of a memorandum on preparation of an action plan for rehabilitation of the Aral Sea and approval of the Project on "Assistance in the Preparation of an Action Plan for Rehabilitation of the Aral Sea." []. Since 1990, the Global Infrastructure Fund Research Foundation Japan (GIFRFJ) has done extensive research on the Aral Sea Basin problem believing that "*the world must understand how the Aral Sea crisis began, and this is important in order to avoid similar occurrences in the future*" [GIFRFJ et al, 1992]. The cause of the Aral Sea crisis, according to GIF Japan, is the same one that destructed the Mesopotamia and Mohenjo-Daro civilizations. The same catastrophic phenomena experienced by mankind those days are reoccurring today. The Aral Sea disaster is the result of infrastructure development mistakes of the countries in the region. An ill-considered policy of large-scale conversion of barren desert lands into irrigated land by withdrawing water for this purpose from the Amu Darya and Syr Darya completely and irrecoverably. After articulating their understanding of the Aral Sea problem, GIFRFJ proposed ways to solve it, which boil down to the following. The way out of this large-scale crisis should be based on a regional infrastructure that would integrate all sectors of the economy on the principles of rational water use that would allow releasing water resources needed to restore the Aral Sea. This requires colossal funds which the Aral Sea Basin countries do not have, so it is necessary to form an infrastructure fund with participation of the industrially developed countries of the world [Takano Yoshihiro, 1994].

1.6 Climate impacts of the Aral Sea desiccation and their modeling

According to UNEP, over the last decades, the surface air temperature has increased by about 0.6 °C, and by 1.6 °C in the mountainous areas. While Central Asia has diverse climate conditions, its climate has one thing in common – it is highly continental and features a great amplitude of air temperature fluctuations throughout the year and low precipitation [Yassinsky V.A., 2010; UN, 2011].

Figure 1-17

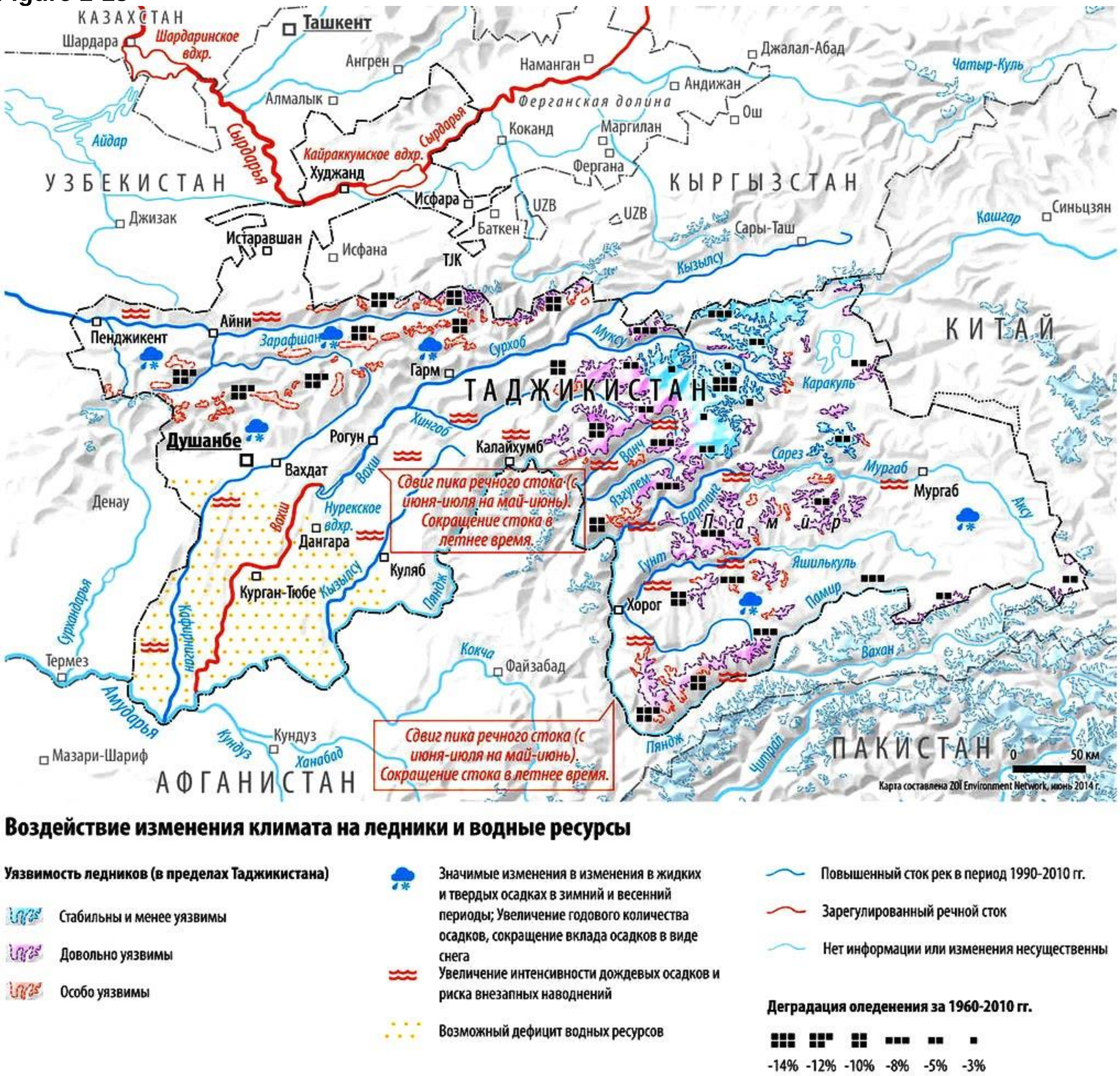


Source: Zoi Environment Network.
Disclaimer: The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations.

In many regions, rainfall variability and rates are growing. Precipitation changes are unevenly distributed over the area and seasons. Increasingly shifting rainfall patterns, when heavy rains alternate with periods of drought, have an adverse impact, affecting crop yields and intensifying soil erosion processes.

Warming in high mountain areas of the Pamirs, Tien Shan, Gissaro-Alai and other mountain systems reflects global and regional and climatic trends. Drying up of the Aral Sea and intensification of wind erosion of the dried bed surface has been regarded as one of important anthropogenic causes of local climate changes and glacier degradation in the region's mountainous areas, affecting generation of water resources and feeding regime of rivers. The key indicator of climate change in Central Asia is the state of glaciers and snow cover, as well as growing desertification in the region. The natural causes of glacier melting in Central Asia include dust pollution (with up to 20 g/m^2 of dust settling on glaciers every year) carried by dust storms from Iran, Afghanistan, China and other desert regions, and in recent years – from the dried up bed of the Aral Sea [EDB, 2009].

Figure 1-18



Source: Zoi Environment Network.

Disclaimer: The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations.
Dotted line represents approximately the Line of Control in Jammu and Kashmir agreed upon by India and Pakistan. The final status of Jammu and Kashmir has not yet been agreed upon by the parties.

Glaciers in the Central Asian mountains receive pollution throughout the year. Pollution of snow cover by aeolian fine soil (dust and salts) has been found to worsen in recent years, which will act as a catalyst for melting. Due to this process alone, snow melting rates increase by 20 percent [Alibekov L.A., 2007]. Widespread glacier recession has been registered, with small glaciers disappearing and large ones disintegrating. Between 1957 and 1980, the Aral Sea Basin glaciers lost 115.5 km^3 of ice (104 km^3 of water), nearly 20 percent of their 1957 ice reserves. An assessment of the global climate change impact on the Pamir-Alai glaciers has shown that over the whole period of observation since 1930, the total glaciation area has shrunk by about one-third [EDB, 2009].

As a result of expected anthropogenic climate change, water resources of the northern plains region in the first half of the 21st century will decrease at a rate of 6-10 percent by 2030, and 4-8 percent by 2050. This is because in the plain basins, the frost depth will decrease as the air temperature rises, resulting in increased infiltration losses of runoff, as well as a shortened period of snow accumulation before the spring floods. In mountainous areas, runoff will vary within the limits of natural variability until 2030, with a possible runoff reduction to 7-17 percent by 2050 [EDB, 2009].

Degradation of the mountain glaciation expected in the last decades of the 21st century will result in a 10-12 percent reduction of the mountain water resources. Such degradation will also increase the inter-annual flow variability and change its intra-annual distribution. As water storage in glaciers reduces, runoff will decrease in the summer period between July and September and will increase in the spring-summer period. **In the future, as water reserves in glaciers decline and water losses increase in the river basins surfaces freed from ice, water inflow to rivers through degradation of mountain glaciation will also decline** [EDB, 2009].

Climate change contributes to changes in the hydrological regime of the Aral Sea basin rivers. There is a significant natural climate change that increases climate aridification and evaporation from the daytime surface, especially in the spring-summer-autumn period. Transformation of hydrological regime of the rivers stems from the natural climate change and, first of all, from glacier melting as a result of climate warming. In addition, general changes in river flows come along with their intra-annual redistribution [Kuzmina J.V. and others, 2019]. Current and future climate change will be accompanied by an increase in inter-annual variability and will lead to increased frequency and depth of hydrological drought. Glacier melting and river flow changes, exacerbating many water and environmental problems, may also have a destabilizing effect on food security and quality drinking water supply to the population, as well as on the hydropower plants' operation regime [EDB, 2009].

1.7 Desertification and salinization

The falling level of the Aral Sea and contraction of its vast water surface, causing transformation of the natural environment in the Aral Sea region, have also been accompanied by climate change. This trend is characterized as arid warming that has a noticeable impact on the water resources of Central Asia [Kuzmina J.V., 2019; Kipshakbayev N.K. and others, 2010].

Climate change is closely associated with drought and desertification processes in the Aral Sea Basin countries, causing degradation of agricultural lands and worsening their reclamation status [UNCCD, 1994]. Within the vast limits of Central Asia lie deserts of various geological and landscape types such as sandy deserts [Babayev A.G., 1986]. Drought, desertification, and land degradation hinder sustainable development by reducing food security and increasing social tension and unemployment [Alibekov L.A., Alibekova S.L., 2007]. In this context, the General Assembly proclaimed 2010-2020 as the UN Decade for Deserts and the Fight Against Desertification [UN, 2010]. Notably, all Central Asian countries are parties to the Convention to Combat Desertification and have ratified the Convention.

Dramatic environmental deterioration in the Aral Sea region led to degradation of natural ecosystems, increased desertification, intensification of soil salinization processes. It should also be noted that the Aral Sea region is an ancient salt accumulation area where the process of secondary salt accumulation – anthropogenic salinization – has intensified in recent decades [Pankova E.I. and others, 1996]. Coastal salt marshes cover an area of about 2 thousand square kilometers [Kurbaniyazov A.K., 2017].

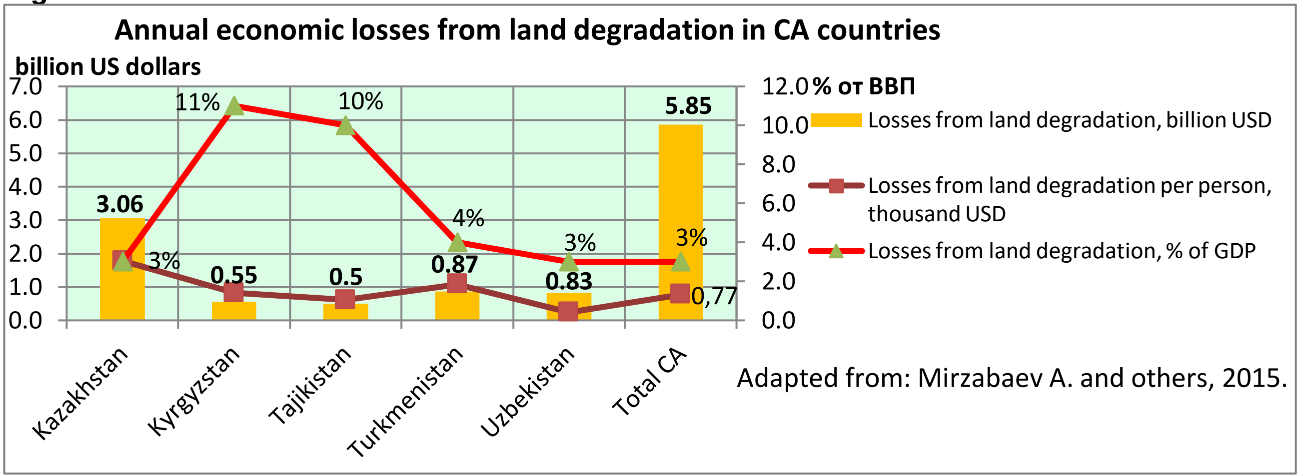
Table 1-6 Degraded lands and their areas in Central Asia

Countries	Land degradation, million hectares, due to:			
	salinization	alkalinity	eutrophication and improved water table	erosion
Kazakhstan	21.5	107.1	38.6	7.8
Kyrgyzstan	0.1	-	10.7	5.6
Tajikistan	0.7	-	6.8	3.7
Turkmenistan	7.3	1.7	3.5	0.7
Uzbekistan	6.3	4.6	3.9	1.3

Source: Gupta R.I. et al, 2009

In 2001-2009, land degradation caused by unsustainable land use and deterioration of the cropland and pasture areas cost the region a total of about US$ 5.85 billion annually. These costs exceeded US$ 3.06 billion in Kazakhstan; US$ 0.87 billion in Turkmenistan; US$ 0.83 billion in Uzbekistan; US$ 0.55 billion in Kyrgyzstan and US$ 0.5 billion in Tajikistan (Figure 1-19). Meanwhile, losses from the land degradation in the region as a whole reach 3 percent of GDP.

Figure 1-19



In Tajikistan and Kyrgyzstan, the region's mountainous countries with extremely limited land resources, economic losses approach 11 percent of GDP and 10 percent of GDP, respectively. In Turkmenistan, degradation cost reaches 4 percent of GDP, and 3 percent of GDP in each of Kazakhstan and Uzbekistan. Most of the costs – about US$ 4.6 billion – come from the loss of pasture productivity and its ecological functions with conversion to less valuable and infertile lands. In this period, the area of such degraded pastures reached 14 million hectares.

Costs of soil devegetation, *i.e.* loss of productive vegetation and development of infertile land, especially in areas near the Aral Sea, equal US$ 0.75 billion. The annual deforestation costs reach US$ 0.32 billion, and costs of arable lands withdrawal from economic turnover exceed US$ 110 million. Per capita costs of land degradation vary across the region, with the highest in Kazakhstan at US$ 1,782; Turkmenistan at US$ 1,083; Kyrgyzstan at US$ 822; Tajikistan at US$ 609; and the lowest in Uzbekistan at US$ 237 per year. Studies show that the costs associated with action to combat land degradation represent only a fraction of the costs of inaction. It is estimated that the cost of land degradation control would be about US$ 53 billion over a 30-year horizon, whereas doing nothing could cost nearly US$ 288 billion over the same period. This means that every dollar invested to combat land degradation can get about US$ 5 in return. Consequently, given the market economy realities in the countries of the region and inability and lack of motivation of private landowners and small farmers to combat desertification, Governments of the region should make provisions to allocate public funding to combating desertification and land degradation [Mirzabaev A. and others, 2015].

Desertification processes in the region are caused by unsustainable water use in irrigation systems [UN, 2011]. Aerospace data shows that virtually all drainless depressions are filled by drainage water. In Central Asia, such water has flooded about 800 thousand hectares of lands and affected more than 930 thousand hectares where pasture fodder plants have lost their value. The desiccation of the Aral Sea led to the exposure of vast areas of the seabed rich in salts, fertilizers and pesticides, representing a potent mixture that is dangerous for humans and the environment. Each year, an estimated 70 million tons of salts escape the Aral Sea basin and settle on an area of 1.5-2 million km^2. Sandy and saline deserts formed as a result of the desiccation have turned into one of the major sources of dust and mineral salts which are transported to the area around the Aral Sea and contribute to further desertification processes [Alibekov L.A., 2007].

2. Agroclimatic resources of Central Asian countries in the changing climate

Assessment of the global climate change impact on the environmental and economic potential, condition and productivity of the agriculture is one of the priority scientific problems of our time. The warming trend and related climatic and agroclimatic changes are expected to continue in the future [IPCC, 2013, 2014]. Studies related to assessment of the climate change impacts on agriculture in the Central Asian region are important primarily because the majority of arable land masses in this area lie in the areas of risky and critical farming. Achieving sustainable yields in this area is a major challenge. Devastating droughts, heavy and prolonged rainfall, and other hazards are the main reason for wide inter-annual variability in crop yields in this region, and worldwide [IPCC, 2014]. Rising food prices in the world are increasing the countries' income so the positions of the region's countries on domestic crop consumption and exports need to be maintained.

The project investigated agroclimatic resources of the Central Asian region, including the territories of Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan and Uzbekistan, using data from reference books under the general title "Agroclimatic Resources" [Agroclimatic Resources Handbook...].

2.1 Climate change mapping methodology

The principal methodological approach of the project employs a technology of climate and agroclimatic resources monitoring that is based on the Climate-Soil-Harvest simulation model [Pavlova and others, 2020; Sirotenko and others, 1997]. At the core of the Climate-Soil-Harvest computational system is a dynamic model of production process and Weather-Harvest agrocenosis water-heat regime [Sirotenko, 1981]. Input for the system is data from weather and agrometeorological network observations, as well as data on hydro-physical properties of soil and its fertility level. The model allows calculating/projecting dynamics of standing biomass accumulation including its productive part (crop) and main components of soil water balance and soil moisture reserves. Computations have been made with daily increments throughout the growing season of an agricultural crop.

Bioclimatic potential of the area in the CSH system.

The regional agroclimatic monitoring system that uses the Climate-Soil-Harvest model includes a set of agroclimatic and bioclimatic indicators including climate-driven crop yields and bioclimatic potential.

The aggregate biological productivity of crops during the warm period of the year can be used as one of indicators for agroclimatic zoning of the area. For this purpose, an "indicative" crop is selected that can grow at any spot within the assessed area throughout the warm period of the year. No single crop fully meets these requirements though some multiple harvest grasses seem to come close to doing so. The Weather-Harvest dynamic model for grain crops served as the basis for the "indicative" crop model.

One of the productivity indicators in the CSH system is bioclimatic potential (BCP) which is defined as the total dry mass produced during the warm period of the year starting on the date the air temperature goes higher than 5ºC in spring. Growth simulation continues until the crop's leaf area index (LAI) reaches 5 when the crop is "cut", then its growth resumes and continues until LAI reaches 5 again. The biomass accumulation stops when air temperature drops below 5ºC in autumn. The total dry biomass yield over the period with temperatures above 5ºC is the target value of bioclimatic potential (cwt/ha). Thus, the proposed approach allows to measure the bioclimatic potential (net primary biological productivity of agrocenosis) in yield units for the entire vegetation period.

2.2 Trends in agroclimatic performance changes in Central Asian areas

Agroclimatic resources performance and trends have been measured on the basis of the weather stations network observations within the target area (Figure 2-1, Table 2-1).

Figure 2-1 Schematic map of weather stations in Kyrgyzstan, Tajikistan, Turkmenistan and Uzbekistan for the CSH model calculations

Disclaimer: The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations.

The information database includes:

Time series of observations representing monthly averages of air temperature and precipitation January to December for 32 weather stations (WS) in Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, and Uzbekistan. The observation period runs from 1976 to 2020. These data represent a subset of the "Climate" Database developed by Roshydromet's (Russian Federal Service for Hydrometeorology and Environmental Monitoring) Global Climate and Ecology Institute and the Russian Academy of Sciences. The "Climate" Database is used as part of ongoing surface climate monitoring in Russia [Gruza G.V., Rankova E.Y., 2012; Gruza G.V. and others, 2016].

The current data provide the basis for annual agroclimatic monitoring conducted using the Climate-Soil-Harvest (CSH) simulation model across Russia [Climate Specifics Report.., 2020]. Mean weather data for the baseline period of 1961-1990 are taken as the climate normal and the period of 1976-2020 is taken as the global warming period.

To assess agroclimatic resources variations due to climate change in the nearest and medium-term future, the data from the climate scenario were used which were calculated using GFDL global atmosphere and ocean circulation model under RCP2.6 and RCP4.5 CO_2 emission scenarios for 2034-2053.

Data from the reference books under the general title "Agroclimatic Resources" [Agroclimatic Resources Handbook...] were also used in this project.

Table 2-1 List of weather stations in Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan and Uzbekistan

Weather station (WS)					Regular grid node coordinates, deg. (climatic scenarios)	
synoptic index	coordinates, deg.		altitude above sea level, m	name (former name)		
	latitude	longitude			latitude	longitude
Kazakhstan						
35229	50.3	57.2	219	Aktobe (Aktyubinsk)	50.5	57.5
36208	50.3	83.6	809	Ridder (Leninogorsk)	50.5	83.5
35394	49.8	73.1	555	Karaganda	49.5	73.5
28952	53.2	63.6	171	Kostanai	53.5	63.5
36003	52.3	77.0	124	Pavlodar	52.5	77.5
28679	54.8	69.2	136	Petropavlovsk	54.5	69.5
35108	51.2	51.4	36	Uralsk	51.5	51.5
35188	51.1	71.4	347	Nur-Sultan (Astana)	51.5	71.5
Kyrgyzstan						
36927	42.5	76.2	1658	Balykchy (Rybachye)	42.5	76.5
36938	42.2	77.6	1690	Tamga	42.5	77.5
36948	42.5	78.4	1718	Karakol (Przhevalsk)	42.5	78.5
36974	41.4	76.0	2041	Naryn	41.5	76.5
36982	41.9	78.2	3614	Tien Shan	41.5	78.5
38345	42.5	72.3	1218	Talas	42.5	72.5
38353	42.8	74.6	756	Bishkek (Frunze)	42.5	74.5
38615	40.5	72.8	887	Osh	40.5	72.5
Tajikistan						
38599	40.2	69.7	410	Khujand (Leninabad)	40.5	69.5
38836	38.6	68.7	803	Dushanbe	38.5	68.5
38954	37.5	71.5	2077	Khorog	37.5	71.5
Turkmenistan						
38507	40.0	53.0	89	Turkmenbashy (Krasnovodsk)	40.5	53.5
38687	39.1	63.6	193	Turkmenabat (Chardzhou)	39.5	63.5
38750	37.5	54.0	23	Esenguly (Gazan-Kuli)	37.5	54.5
38763	39.0	56.3	97	Serdar (Kzyl-Orda)	38.5	56.5
38880	38.0	58.3	227	Ashgabat	38.5	58.5
38895	37.6	62.2	241	Bayramaly	37.5	62.5
38974	36.5	61.2	276	Sarakhs	36.5	61.5
Uzbekistan						
38262	42.9	59.8	66	Chimboy	42.5	59.5
38413	41.7	64.6	238	Tamdy	41.5	64.5
38457	41.3	69.3	472	Tashkent	41.5	69.5
38618	40.4	71.8	577	Fergana	40.5	71.5
38696	39.7	67.0	675	Samarqand	39.5	66.5
38927	37.2	67.3	311	Termez	37.5	67.5

Evaluation of heat supply and moisture availability trends

The heat supply of the region is characterized by the following parameters:
average air temperature by calendar seasons, °C;
average air temperature of the coldest month (January) as an integral indicator of crop overwintering conditions, °C;
average air temperature of the warmest month (July) as a thermal stress indicator, °C;
climate continentality as the difference between air temperatures of the warmest and coldest months of the year (yearly temperature variation range), °C;
sum of temperatures for the period with air temperatures above 5 and 10 °C, °C;
growing season duration (number of days with air temperatures above 5 or 10 °C), days;
dates of vegetation resumption in spring and cessation in autumn.

The evaluation of linear trend coefficients for the above indicators are based on the station time series of annual and seasonal anomalies between 1976 and 2020.

Heat supply trend evaluation for Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, and Uzbekistan are shown in Table 2-2.

Table 2-2 Evaluation of linear trend coefficients *b (y=b·x+c)* of thermal regime indicators for Central Asian regions during 1976-2020

Weather station	Air temperature, °C/10 years		Temperature sum, °C/10 years		Length of period, days/10 years		Air temperature, °C/10 years				Continentality, °C/10 years
	January	July	>5 °C	>10 °C	T>5 °C	T>10 °C	winter	spring	summer	fall	
Kazakhstan											
Aktobe	0.2	0.3	91*	84*	3.4*	2.3*	0.4	0.6*	0.4*	0.4*	−0.1
Ridder	−0.6	0.1	30	15	2.4*	0.0	−0.3	0.6*	−0.3	−0.1	−0.1
Karaganda	−0.1	−0.3*	15*	3	2.8*	1.1	0.1	0.6*	0.1	0.1	0.0
Kostanai	0.1	0.1	45	46	2.1*	1.9	0.2	0.6*	0.2	0.5*	0.0
Pavlodar	−0.5	−0.1	32	25	2.8*	1.8	−0.1	0.7*	−0.1	0.2	0.0
Petropavlovsk	−0.3	−0.1	25	25	1.6	1.7	0.1	0.5*	0.1	0.4*	0.0
Uralsk	0.4	0.5*	103*	90*	4.1*	2.2*	0.5*	0.6*	0.5*	0.4*	0.0
Nur-Sultan	0.0	0.0	76*	72*	4.0*	3.3*	0.4	0.9*	0.4	0.4*	0.0
Kyrgyzstan											
Balykchy	0.0	0.2	51*	55*	1.7	2.4	0.1	0.4*	0.1	0.1	0.1
Tamga	0.2*	0.2*	66*	73*	2.5*	3.5*	0.4*	0.4*	0.2*	0.2*	0.0
Karakol	0.3*	0.2*	65*	76*	2.3*	3.6*	0.4*	0.4*	0.3*	0.2*	−0.1
Naryn	0.0	0.1	43*	45*	2.1*	2.4	0.1	0.5*	0.1*	0.2	0.0
Tien Shan	0.8*	0.4*	47*	—	7.3*	—	0.8*	0.8*	0.3*	0.5*	−0.4
Talas	0.3	0.2*	80*	81*	2.7	3.1*	0.2	0.6*	0.3*	0.0	−0.1
Bishkek	0.3	0.3*	111*	114*	3.9*	4.4*	0.2*	0.6*	0.4*	0.2	0.1
Osh	0.5	0.3	105*	106*	3.3*	3.3*	0.4	0.5*	0.3*	0.3*	−0.2
Tajikistan											
Khujand	0.4	0.2	96*	97*	2.8	3.1*	0.3	0.4*	0.3*	0.2	−0.2
Dushanbe	0.0*	−0.1*	37	26	3.6	1.7	0.1	0.4*	−0.1	−0.1	−0.2
Khorog	0.4*	0.0*	23	24	0.6	0.8	0.3*	0.2	0.0	0.2*	−0.5
Turkmenistan											
Turkmenbashy	0.5	0.5	170*	130*	8.6*	2.3	0.4*	0.4*	0.6*	0.3*	0.0
Turkmenabat	0.5	0.2	124*	111*	−4.3	3.1*	0.4	0.5*	0.3*	0.2*	−0.2
Esenguly	0.5	0.6*	231*	202*	9.4*	6.3*	0.5*	0.6*	0.6*	0.5*	0.1
Serdar	0.7	0.2	151*	132*	7.6*	4.2*	0.6*	0.5*	0.4*	0.3*	−0.4
Ashgabat	0.4	0.1*	148*	22	3.5	1.0	0.3	0.2	0.0	−0.1	−0.5
Bayramaly	0.5	0.3*	127*	122*	2.3	2.8	0.4	0.5*	0.4*	0.3*	−0.2
Sarakhs	0.7	0.3*	165*	173*	4.7	7.1*	0.5*	0.6*	0.4*	0.3*	−0.4
Uzbekistan											
Chimboy	0.5	0.3	123*	120*	4.2*	4.4*	0.4	0.8*	0.4*	0.1	−0.2
Tamdy	0.4*	0.1*	108*	123*	2.9	4.9*	0.3	0.7*	0.3*	0.1	−0.3
Tashkent	0.5	0.3*	129*	127*	4.7	3.7*	0.3	0.5*	0.4*	0.2*	−0.2
Fergana	0.4	0.3*	103*	99*	3.2*	2.7*	0.4*	0.4*	0.3*	0.2*	−0.1
Samarqand	0.5	0.4*	133*	131*	5.6	3.9*	0.4	0.6*	0.4*	0.2*	−0.1
Termez	0.5	0.3*	99*	102*	2.3	2.9	0.2	0.4*	0.2*	0.2*	−0.2

Note: * 5 percent significance level.

Kazakhstan. In Kazakhstan, the warming rate is slower compared to other regions of Central Asia. In the northeast – WSs in Petropavlovsk, Pavlodar, Ridder – estimated linear trend coefficient for January and winter temperatures is generally negative, *i.e.* inclined to be colder. July temperature has a positive trend only in the westernmost regions – WSs in Aktobe and Uralsk. The temperature sum during the period with temperatures above 5 and 10 °C increases significantly at WSs in Aktobe, Kostanai, Uralsk and Nur-Sultan. However, the linear trend coefficient here is lower than in other regions of Central Asia. The highest warming rate is in the spring period – 0.6 to 0.9 °C/10 years.

Kyrgyzstan. The linear trend coefficient of temperature in January, the coldest month of the year, is positive and does not exceed 0.3 °C/10 years, except for the highest region of Tien Shan (WS Tien Shan, 0.8 °C/10 years) and Fergana Valley (WS Osh, 0.5 °C/10 years).

Estimated temperature trend of July, the warmest month of the year, is also positive and equals 0.3 °C/10 years in the western regions of Kyrgyzstan (WSs Talas, Bishkek, Osh) and 0.2 °C/10 years in the eastern regions (WSs Balykchy, Tamga, Karakol, Naryn). The highest trend is observed at WS Tien Shan (0.4 °C/10 years). Almost all estimates are statistically significant at the 5 percent level (p-level<0.5).

The growth of heat supply to crops was demonstrated by the positive trend in the air temperature sums for the period with temperatures above 5 and 10 °C, as observed across Kyrgyzstan. The variation ranges from 43 °C/10 years (WS Naryn) to 111 °C/10 years (WS Bishkek) for the period of T>5 °C and from 45 °C/10 years to 114 °C/10 years for the period of T>10 °C for the same weather stations. The highest trend estimates are based on WS Bishkek and Osh data and equal ~110 °C/10 years. All estimates are statistically significant.

Analysis of temperature trends by season (winter, spring, summer, autumn) has shown that the highest estimates of winter temperature trends are observed in Tien Shan (0.8 °C/10 years), and the lowest at WS Balykchy (0.08 °C/10 years). Ranking by the linear trend coefficient value by seasons shows that the temperature growth rate is the highest in spring and the lowest in autumn (by rank: spring-summer-winter-autumn).

Tajikistan. There is a positive trend of air temperature during the cold season in northern (WS Khujand) and southern (WS Khorog) parts of Tajikistan, which is ~0.3 °C/10 years. In the Gissar Valley (WS Dushanbe), a significant upward trend in temperature is observed only in spring (0.4 °C/10 years).

Summer temperature trend estimates are statistically significant only in the north of Tajikistan at 0.3 °C/10 years (WS Khujand). In the Gissar Valley (WS Dushanbe) and in the West Pamir region (WS Khorog), there are no trends of calendar summer temperature increase.

The estimated crop heat supply growth as calculated using the sum of air temperatures over 5 and 10 °C in the northern regions (WS Khujand) is positive, statistically significant, and equals ~100 °C/10 years. At the same time, according to WS Dushanbe and Khorog observations, estimated upward trend of this indicator over the past decades here is insignificant at only 20-30 °C/10 years.

A weak downward trend in the continentality degree measured as the difference between the temperature of the warmest and coldest months of the year (T_{VII}-T_{I}) can be observed, ranging between -0.1 and -0.5 °C/10 years or -0.3 and -1.7 percent of the mean annual values of this indicator (~30 °C).

Turkmenistan. In Turkmenistan, warming continues at the highest rate. The estimated linear trend coefficient of January temperature ranges from 0.4 (WS Ashgabat) to 0.7 °C/10 years (WS Serdar, Sarakhs) and July temperature ranges from 0.1 (WS Ashgabat) to 0.6 °C/10 years (WS Esenguly).

Analysis of the linear trend of the air temperature sum for the period with temperatures above 5 °C and 10 °C shows that the positive trend in the growth of this indicator over the past decades is the highest compared to the rest of Central Asia. Over the warming period since 1976, the growth rate of this indicator has ranged from ~120 °C/10 years in the area of WSs in Turkmenabad and Bayramaly to ~230 °C/10 years in the area of WS Esenguly. It is worth noting that the estimates are statistically significant for all of the points in question.

Uzbekistan. Assessment of linear trend coefficient of January temperature suggests quite high growth rate of this indicator as calculated using observation data in different agroclimatic zones of Uzbekistan at 0.4 to 0.5 °C/10 years. Warming trends are also observed in summer months: temperature trends vary from 0.2 °C/10 years (WS Termez) to 0.4 °C/10 years (WS Samarqand). This means that the upper limit of summer temperature increase for the period 1976-2020 was 1.8 °C (4.5×0.4) compared to the baseline period 1961-1990. The highest estimates of air temperature trends were observed for the calendar spring (0.4 to 0.8 °C) and the lowest for autumn (~0.2 °C).

There is a significant increase in temperature sums for the period with temperatures above 5 and 10 °C; they are growing at a rate of 100 to 130 °C/10 years. Thus, thermal resources of this area, which are very significant, have been growing at a fairly high rate over the past four decades.

Naturally, an increase in air temperature leads to an increase in the growing season duration. The growth rate of the duration of the growing season with temperatures above 5 °C is 2.3 to 5.6 days/10 years and with temperatures above 10 °C is 2.7 to 4.9 days/10 years. Compared to the initial warming period, the length of the growing season (T>5 °C) has increased by about 2 weeks and the length of the growing season with temperatures above 10 °C has increased by 2-3 weeks by now (2020), which is a statistically significant estimate.

The moisture availability of the region is characterized by the following parameters:
sum of calendar winter, spring, summer, autumn and annual precipitation, mm;
HTC (Selyaninov's hydrothermal coefficient) [Selyaninov G.T., 1958], units.

Numerical estimates of the linear trend coefficient (in mm/10 years and percent of normal/10 years) for individual weather stations are shown in Table 2-3.

Kazakhstan. Similarly to other regions of Central Asia, precipitation trends in Kazakhstan vary in sign and magnitude across all seasons due to considerable variability of this parameter. Statistically significant estimates constitute 20 percent of the total calculated estimates. The most significant upward trends in precipitation are observed in spring – from 3 percent in Aktobe to 15 percent in Kostanai.

Kyrgyzstan. In Kyrgyzstan, most of the annual rainfall falls in the warm period of the year. The rainfall is generally distributed unevenly across the country during the growing season. Most part of precipitation ~290 mm falls in spring and summer period on the eastern coast of Issyk-Kul depression (WS Karakol). Over the last decades, precipitation here has shown some growth in all seasons with rates of 3-5 percent per decade. However, despite the growing air temperature, the heat and moisture ratio remains virtually unchanged, as evidenced by the absence of the Selyaninov's HTC trend.

The western part of the Issyk-Kul depression (WS Balykchy) is the driest place in Kyrgyzstan. Spring-summer precipitation here is about 100 mm. The annual precipitation grows at a rate of 6 percent per 10 years; spring precipitation grows at a rate of 10 percent per 10 years.

The highest precipitation growth rate is observed in the WS Tien Shan area. Statistically significant estimates of the linear trend coefficient range from 9 to 14 percent per decade. The annual precipitation grows at a rate of 11 percent per 10 years.

Table 2-3 Estimates of linear trend coefficients of moisture regime parameters by regions of Central Asia during 1976-2020

Weather station	Rainfall										HTC, units/10 years
	winter		spring		summer		autumn		year		
	mm/10 years	%	mm/10 years	%	mm/10 years	%	mm/10 years	%	mm/10 years	%	
Kazakhstan											
Aktobe	0.2	0	2.0	3	−7.8	−9	−5.9*	−7	−11.5	0	−0.10
Ridder	6.1*	12	7.6	5	−4.1	−2	−5.0	−3	4.5	0	−0.10
Karaganda	5.8*	9	5.1	7	12.6*	11	2.8	3	26.4*	0	0.00
Kostanai	0.1	0	9.6*	15	−1.6	−1	0.9	1	9.0	0	0.00
Pavlodar	0.0	0	1.9	4	9.1	9	0.4	1	11.4	0	0.00
Petropavlovsk	−2.0	−4	6.7*	10	0.1	0	−2.3	−3	2.6	0	0.00
Uralsk	−2.3	−3	6.8*	11	−7.2	−7	−3.9	−4	−6.7	0	0.00
Nur-Sultan	5.1*	10	3.9	6	6.1	5	1.9	3	17.1*	0	0.00
Kyrgyzstan											
Balykchy	0.7*	44	3.2	10	2.0	3	2.0	14	8.0	6	0.01
Tamga	−0.7	−3	4.2	6	10.9*	9	3.7	8	18.0*	7	0.03
Karakol	1.2	3	6.6	5	6.8	4	2.8	3	17.3*	4	0.01
Naryn	0.3	1	1.8	2	8.2	7	3.0	7	13.3	4	0.01
Tien Shan	2.4*	12	11.1*	14	14.5*	9	6.6*	13	34.6*	11	—
Talas	−1.9	−3	4.2	3	2.3	4	−0.6	−1	4.1	1	−0.01
Bishkek	3.4	4	−2.0	−1	−0.8	−1	1.4	1	2.1	0	−0.07
Osh	−0.7	−1	5.4	4	3.9	16	−3.3	−5	5.2	2	0.02
Tajikistan											
Khujand	−0.7	−1	4.3	6	1.3	13	−2.7	−8	2.1	1	−0.01
Dushanbe	3.1	1	26.0	8	4.3*	47	3.4	4	36.7*	6	0.11
Khorog	14.1*	14	7.1	6	0.5	4	4.6	12	26.2*	9	0.01
Turkmenistan											
Turkmenbashy	−3.5	−8	−2.7	−5	−3.0*	−28	1.1	3	−8.2	−6	−0.02
Turkmenabad	−3.1	−6	−2.6	−4	0.0	3	−1.4	−8	−7.1	−5	−0.01
Esenguly	−9.3	−13	−8.3*	−13	−2.5	−13	−5.2	−8	−25.3*	−12	−0.04
Serdar	−1.3	−2	2.3	3	−2.2	−9	−1.8	−4	−3.0	−1	−0.02
Ashgabat	−0.4	−1	−1.0	−1	0.5	6	−3.1	−7	−4.0	−2	−0.01

Weather station	Rainfall										HTC, units/10 years
	winter		spring		summer		autumn		year		
	mm/10 years	%	mm/10 years	%	mm/10 years	%	mm/10 years	%	mm/10 years	%	
Bayramaly	−5.3	−7	−4.9	−6	−0.2	−20	−0.5	−2	−11.0*	−6	−0.02
Sarakhs	−9.4	−9	−3.7	−4	0.1	47	1.5	7	−11.5*	−5	−0.01
Uzbekistan											
Chimboy	−0.8	−2	1.0	2	0.1	1	1.4	6	1.7	1	0.00
Tamdy	−4.4	−10	−6.6*	−12	−1.5	−21	−2.8	−15	−15.3*	−12	−0.03
Tashkent	1.3	1	−1.6	−1	2.2	17	−0.7	−1	1.3	0	−0.01
Fergana	−2.3	−4	0.6	1	3.2	20	−4.9	−13	−3.4	−2	0.01
Samarqand	−6.2	−5	9.5	6	0.6	8	−0.3	0	3.7	1	0.02
Termez	1.1	2	−1.2	−2	−0.2	−21	3.1	27	2.8	2	0.01

Note: * 5 percent significance level.

Tajikistan. For most part of Tajikistan, winter-spring period sees maximum precipitation during the year. In the areas with real winters, winter precipitation generates significant reserves of productive moisture in spring. During spring, 40-55 percent of the total annual precipitation falls in the main regions of the country, and up to 90 percent over winter and spring.

Estimates of linear trend coefficients based on the WS Khorog observations suggest a significant positive trend of winter precipitation growth (14 percent). While in northern areas of Tajikistan autumn-winter rainfall rate is hardly increasing (with a weak positive trend), spring rainfall rate is growing. According to observations at WS Dushanbe where the spring months see more than 300 mm of rainfall, it tends to increase by 8-10 percent per decade. Summer precipitation is also increasing (47 percent), but it is only 4.3 mm/10 years in absolute units.

Turkmenistan. In terms of humidity, the plain area is classified as exceptionally dry and very dry zones. Rainfall pattern is characterized by small amount and annual irregularity of precipitation. Average annual precipitation is between 80 and 300 mm. The bulk of precipitation falls in winter and spring, with little or no rainfall in summer. It is only in the south-western part of Turkmenistan that 10-13 percent of the annual rainfall falls in summer.

Negative precipitation trends are observed throughout the country during all seasons. The highest annual negative trends are in the area of WS Esenguly (-12 percent). The linear trend coefficients are statistically significant at the 5 percent level. Winter and spring precipitation decrease rates vary across the country with a minimum of -9 to -13 percent (WSs Sarakhs, Esenguly).

Uzbekistan. Depending on the orographic conditions, the precipitation levels in the region vary widely, from 200 to 870 mm in the piedmont areas. In the lowlands, crops in most years suffer from a lack of moisture. Moisture availability increases with increasing altitude above sea level. The mountain dry-farming lands benefit from the most moisture. Similar to other regions of Central Asia, precipitation is distributed unevenly throughout the year. The autumn-winter period (October-May) accounts for 95-97 percent of rainfall, with its maximum in March-April: by this time, soil accumulates the largest amount of moisture.

In the driest regions of the country, precipitation either shows virtually no trends (WS Chimboy) or has a downward trend (WS Tamdy). In the WS Tamdy area, rainfall tends to decrease throughout all seasons by 10 to 21 percent, while annual precipitation tends to decrease by 12 percent. In the rest of the country (WSs in Fergana, Samarqand, Termez), the annual precipitation change rate is low, ranging from -2 to +2 percent over 10 years. In winter and spring, WS Fergana and WS Samarqand show a negative trend: -4 percent and -5 percent, respectively. In the WS Tashkent area, virtually no change in moisture regime is observed.

2.3 Projected changes in climatic and agroclimatic performance in the 21st century

At this point, we use the climate change scenario data from the CMIP5 – GFDL CM3 climate model comparison project under the RCP2.6 and RCP4.5 CO_2 emission scenarios.

Key climatic parameters are deviations of average monthly air temperature (°C) and rainfall totals (mm or percent of the normal) for 12 calendar months relative to the baseline period (1961-1990) at regular grid nodes (1.0°N × 1.0°E).

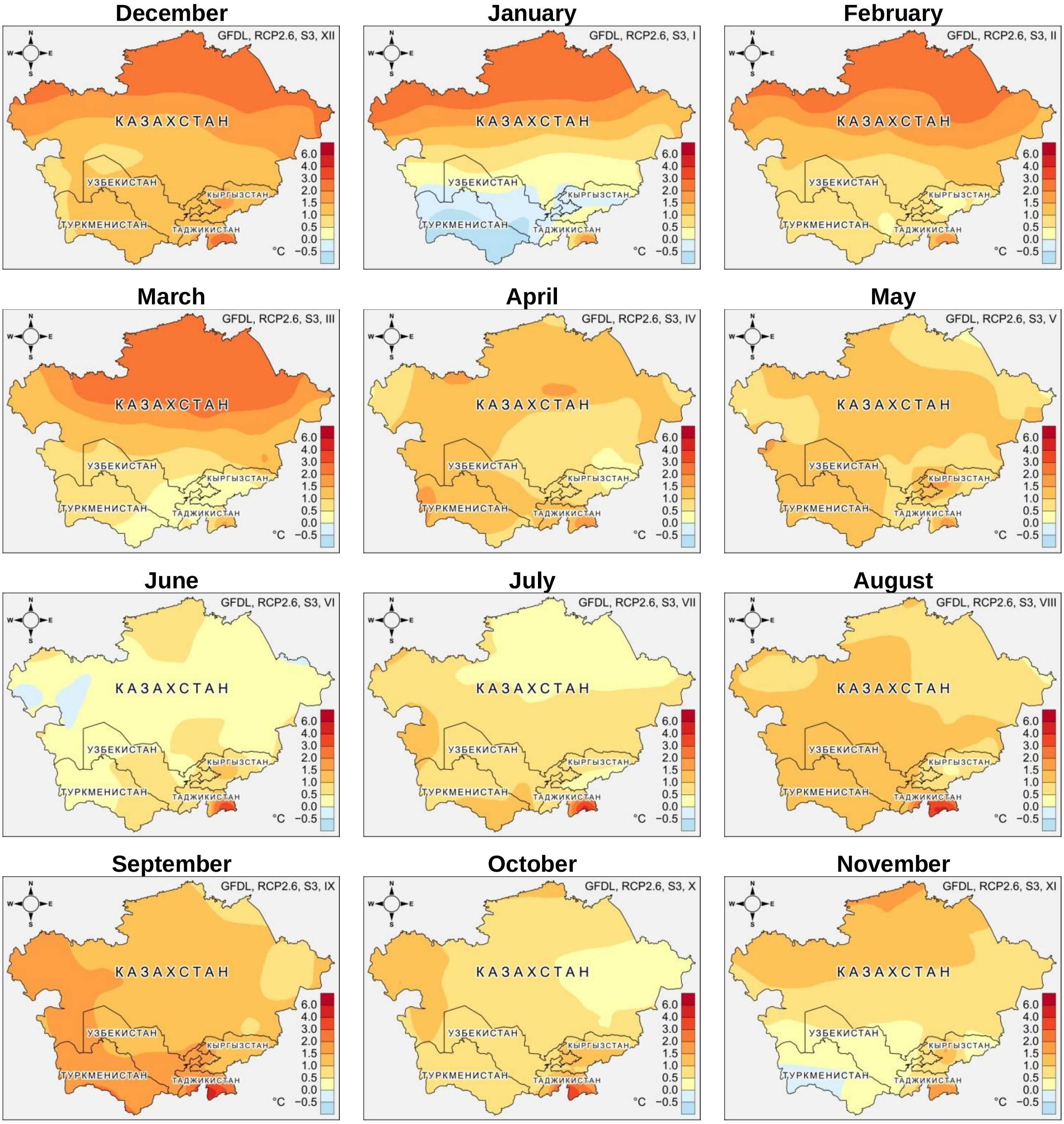
Changes in temperature regime. Under the GFDL scenario, the air temperature will preserve positive anomalies in all seasons throughout the region. Under RCP4.5 emission scenario, temperature growth in autumn-winter period will outpace that in spring and summer in Kazakhstan, Kyrgyzstan, Tajikistan and Uzbekistan. Winter temperatures are expected to grow by 1.5-1.8 °C in Kyrgyzstan and Tajikistan, 1.1-1.4 °C in Turkmenistan, and 3.0-4.0 °C in Kazakhstan. The maximum summer temperature increase can be expected in Turkmenistan (1.4-1.8 °C) and the minimum increase in Kazakhstan (0.3-0.8 °C) (Table 2-4).

Table 2-4 Changes in air temperature (°C) and rainfall totals (mm) in deviations from the 1961-1990 mean by 2050. GFDL scenario (RCP2.6 and RCP4.5)

WS	Average air temperature changes (°C) over a season of the year								Rainfall totals changes (mm) over a season of the year							
	RCP2.6				RCP4.5				RCP2.6				RCP4.5			
	winter	spring	summer	autumn	winter	spring	summer	autumn	winter	spring	summer	autumn	winter	spring	summer	autumn
Kazakhstan																
Aktobe	2.1	1.7	0.6	1.3	3.4	2.8	0.7	1.6	6	13	24	−12	19	10	16	−3
Ridder	1.8	1.3	0.2	0.7	3.0	1.4	0.3	1.4	23	3	30	11	33	18	33	28
Karaganda	1.9	1.9	0.4	0.9	3.4	2.5	0.6	1.6	6	0	25	−2	16	10	30	−1
Kostanai	2.5	1.8	0.6	1.2	3.9	3.3	0.5	1.5	14	19	18	5	23	14	26	15
Pavlodar	2.4	1.6	0.3	0.9	3.7	2.2	0.5	1.6	16	9	19	9	19	9	26	13
Petropavlovsk	2.6	1.5	0.6	1.2	4.0	2.8	0.4	1.6	18	13	7	9	24	13	28	14
Uralsk	2.5	1.2	0.9	1.4	3.5	2.6	0.8	1.8	12	8	19	−16	19	4	20	−17
Nur-Sultan	2.3	1.6	0.4	1.1	3.7	2.6	0.6	1.7	19	12	23	4	26	4	15	2
Kyrgyzstan																
Balykchy	0.7	0.6	0.7	0.7	1.7	1.1	1.1	1.8	−3	15	12	1	7	22	4	−11
Tamga	0.7	0.7	0.6	0.8	1.8	1.2	1.1	1.9	−2	18	13	0	7	20	4	−11
Karakol	0.7	0.8	0.6	0.8	1.8	1.3	1.2	1.9	−2	20	14	0	6	18	4	−10
Naryn	0.5	0.5	0.6	0.8	1.5	1.0	1.1	2.0	0	22	16	−1	7	30	0	−8
Tien Shan	0.4	0.6	0.5	0.8	1.6	1.1	1.2	2.0	2	24	19	−5	6	24	2	−9
Talas	0.7	0.8	0.9	1.1	1.6	1.2	1.2	2.1	2	9	13	−3	6	23	11	−18
Bishkek	0.7	0.8	0.8	1.0	1.7	1.1	1.1	2.0	−3	8	14	−2	5	22	9	−16
Osh	0.6	0.8	0.7	1.2	1.5	1.3	1.1	2.2	6	20	20	−3	8	48	18	−18
Tajikistan																
Khujand	0.7	0.7	0.7	1.0	1.7	1.3	1.1	1.9	14	28	4	−1	7	35	7	−15
Dushanbe	0.6	0.8	0.9	1.1	1.7	1.5	1.4	2.0	20	29	−5	1	3	32	−2	0
Khorog	1.2	0.8	2.1	3.6	2.4	1.8	4.2	6.2	17	13	−8	8	5	64	−6	8
Turkmenistan																
Turkmenbashy	0.4	1.2	0.8	0.9	1.3	1.6	1.4	1.7	3	0	5	3	3	6	−2	0
Turkmenabad	0.5	1.0	1.0	0.8	1.4	1.2	1.5	2.0	−1	7	0	0	−3	11	−1	−4
Esenguly	0.3	1.1	0.7	0.8	1.0	1.4	1.6	1.7	4	17	2	5	1	12	−5	4
Serdar	0.3	1.0	0.8	0.9	1.1	1.3	1.8	2.0	5	11	0	2	−2	9	−3	0
Ashgabat	0.4	1.0	0.9	0.9	1.2	1.2	1.7	2.0	4	7	0	0	−3	11	−2	−2
Bayramaly	0.5	0.9	1.0	0.9	1.1	1.2	1.7	2.0	1	5	−1	−1	1	8	−1	3
Sarakhs	0.4	0.9	1.1	1.0	1.0	1.2	1.8	2.0	2	5	−1	2	0	8	−2	4
Uzbekistan																
Chimboy	0.6	1.1	0.9	0.9	1.7	1.5	1.4	1.7	1	4	2	1	−4	4	−1	−1
Tamdy	0.5	0.9	1.0	0.8	1.6	1.3	1.4	1.8	2	9	0	−1	−3	7	−1	−4
Tashkent	0.7	0.7	0.7	1.0	1.7	1.2	1.1	1.9	10	22	8	−2	6	26	9	−19
Fergana	0.6	0.9	0.8	1.1	1.5	1.4	1.1	2.1	11	25	15	−3	11	53	17	−20
Samarqand	0.4	0.7	1.0	1.0	1.1	1.2	1.6	2.0	5	19	−1	1	2	15	−1	0
Termez	0.6	0.8	1.0	1.1	1.4	1.3	1.6	2.0	16	18	−4	3	0	23	−3	7

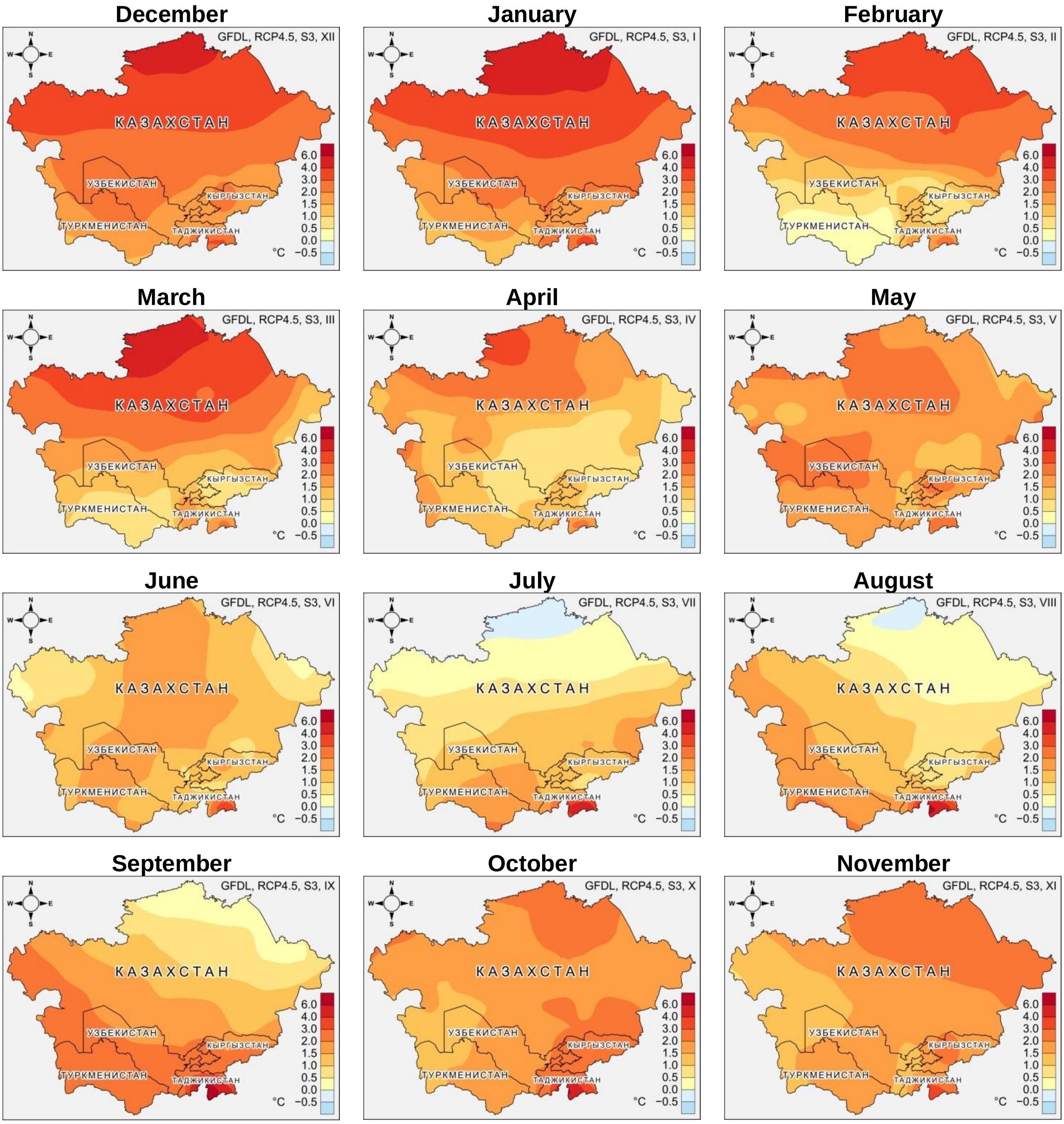
Spatial distribution of the projected change in air temperature from January to December relative to the baseline period in Central Asia is shown in Figures 2-2 and 2-3.

Figure 2-2 Changes (deviations from the mean 1961-1990 values, °C) in average air temperature from January to December by 2050. GFDL scenario, RCP2.6 CO_2 emissions case



Disclaimer: The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations.

Figure 2-3 Changes (deviations from the mean 1961-1990 values, °C) in average air temperature from January to December by 2050. GFDL scenario, RCP4.5 CO_2 emissions case



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Changes in rainfall patterns. The projection shows that under RCP4.5 ("moderate") emissions scenario, rainfall rates will grow over the winter period in Kyrgyzstan, Tajikistan and eastern part of Uzbekistan. The projected estimates of rainfall changes differ insignificantly by area in the range of 3-8 mm. Spring rainfall will increase in all regions without exception: 18-48 mm in Kyrgyzstan, 32-64 mm in Tajikistan, 15-53 mm in the western part of Uzbekistan. Changes in the eastern part of Uzbekistan are insignificant – 4 to 7 mm. In Turkmenistan, one can also expect an increase in precipitation rates but not much – 6 to 12 mm. Summer precipitation anomalies are likely to vary by region of Central Asia, both in magnitude and sign. Maximum increase can be expected in Kyrgyzstan – 4 to 18 mm. In northern Tajikistan, as well as in the western regions of Uzbekistan, summer rainfall will increase. In Turkmenistan, summer rainfall anomalies relative to the current levels will be negative throughout the country. In Kyrgyzstan, autumn precipitation is projected to decrease by 10-22 percent. In other regions, changes in quantity and sign vary considerably by area (Table 2-4).

The most significant growth of precipitation can be expected in Kazakhstan – it is projected to increase throughout the country in winter and summer in the range of 16 to 33 mm (Table 2-4).

In GFDL RCP2.6 scenario, precipitation distribution patterns across the region in spring will not change utterly compared to the GFDL RCP4.5 scenario. Rainfall will be thicker across the region. Kazakhstan, Tajikistan and Uzbekistan will have more winter precipitation. Quantity of summer rainfall will be more in Kazakhstan and Kyrgyzstan, by 7 to 30 mm (Table 2-4).

Bioclimatic potential. One of the promising methods to study the problem of climate change and its impact on crop productivity is dynamic agroclimatic models that allow evaluating the effect under any scenario of climate change. We use the Climate-Soil-Harvest (CSH) simulation model [Sirotenko O.D., 1991, 2007; Sirotenko O.D. and others, 1997; Pavlova V.N. and others, 2020; Pavlova V.N. and others, 2020]. The primary biological productivity of agroecosystems or bioclimatic potential is used as an indicator to assess the productivity of climate and its changes [Gordeyev A.V. and others, 2008].

The proposed methodology calculates the values of primary biological productivity of agro-ecosystems for four variants of farming intensification: BCP – for current farming; BCP_W – with adequate moisture; BCP_N – with adequate mineral nutrition; BCP_{WN} – with adequate moisture and mineral nutrition.

Calculation of the bioclimatic potential values, i.e. the total dry mass produced during the warm period of the year, starts on the date air temperature goes higher than 5ºC in spring and continues until the crop's standard condition (leaf area index) reaches 5. The crop is then "cut" and its growth continues until the standard condition is reached again or air temperature drops below 5 ºC in autumn. The total dry biomass yield resulting from the simulation represents the desired estimate of bioclimatic potential.

Table 2-5 shows bioclimatic potential estimates under the current climate scenario (BCP) and its expected changes in the 21st century according to the forecast estimates for selected observation sites calculated using the Climate-Soil-Harvest model.

As the CSH model calculations show, the highest bioclimatic potential under current climatic conditions is in the WS Karakol area (949 kg/ha) and the lowest one (<300 kg/ha) is in Turkmenistan. The analysis suggests that changes in the selected productivity measure, *i.e.* bioclimatic potential, as calculated using projected estimates of hydrometeorological parameter changes (GFDL RCP2.6 and RCP4.5 scenarios), will be multidirectional in the given region by the middle of the century. The range of BCP changes in Kyrgyzstan, Tajikistan and Uzbekistan varies between -4 percent (WSs Osh, Khorog) and ~ +12 percent (WS Samarqand). In Turkmenistan, a more significant decrease in bioclimatic potential can be expected – 6 to 14 percent. In Kazakhstan, the projected rainfall growth against a slight temperature increase in the warm period of the year may lead to an increase in the bioclimatic potential by 10 to 30 percent in the north-east of the country. In the west (WS Uralsk), bioclimatic potential is likely to decrease.

Table 2-5 BCP estimates for Central Asian regions for 1976-2020 and 2034-2053 (GFDL RCP2.6, RCP4.5 scenario). Calculated using the CSH model

Weather station	1976-2020			2034-2053, GFDL BCP change, %	
	BCP, cwt/ha	average temperature of the period with T>5 °C, °C	rainfall over the period with T>5 °C, mm	RCP2.6	RCP4.5
Kazakhstan					
Aktobe	37.7	16.0	180	3.9	8.7
Ridder	45.6	14.5	199	24.3	16.9
Karaganda	33.9	14.7	196	12.3	15.6
Kostanai	43.1	15.1	214	20.4	10.0
Pavlodar	34.6	15.3	172	29.8	24.0
Petropavlovsk	54.9	14.1	244	19.3	4.2
Uralsk	38.0	16.5	159	−4.5	−3.0
Nur-Sultan	42.9	14.8	199	11.4	12.8
Kyrgyzstan					
Balykchy	38.9	13.8	120	3.4	−3.6
Tamga	72.8	13.3	209	5.6	−5.2
Karakol	94.9	13.1	312	5.1	−3.4
Naryn	54.3	13.4	208	1.0	−2.0
Talas	55.9	14.7	205	9.7	10.7
Bishkek	60.0	16.9	315	−2.0	−4.7
Osh	46.4	17.7	201	−4.0	−4.8
Tajikistan					
Khujand	38.5	19.1	126	−1.0	−3.4
Dushanbe	65.8	17.6	479	1.0	3.2
Khorog	30.9	16.1	138	−4.0	−2.3
Turkmenistan					
Turkmenbashy	27.8	18.1	121	0.0	0.0
Turkmenabad	25.3	19.2	118	−6.8	−10.2
Esenguly	27.4	17.4	188	−6.6	−11.1
Serdar	24.7	20.3	152	−6.1	−13.5
Ashgabat	27.4	19.6	209	−3.3	−6.0
Bayramaly	24.8	19.4	149	−12.5	−9.0
Sarakhs	26.1	19.5	186	−13.8	−9.6
Uzbekistan					
Chimboy	26.3	18.7	87	3.0	−2.0
Tamdy	29.0	20.3	88	0.0	−4.9
Tashkent	48.2	18.1	284	7.1	3.7
Fergana	30.7	18.5	113	1.6	0.8
Samarqand	48.9	17.3	234	11.8	4.7
Termez	38.4	19.2	140	−2.0	1.8

Major uncertainties of the above estimates of the bioclimatic potential of the region are primarily related to the existing differences between the IPCC adopted scenarios of future radiative forcing on the global climate system, the sum of which corresponds to limited ideas about the future development of the world economy [Van Vuuren D.P. and others, 2011].

Another source of uncertainty is natural climate variability that overlaps with agroclimatic system response to human impact. To minimize this type of variability impact on assessment of climate trends in crop productivity, large ensemble climate model simulations are used, *e.g.* those based on regional climate modeling (RCM) [Shkolnik I. and others, 2017].

3. Adaptation measures

Based on the assessment of water resources vulnerability due to possible anthropogenic climate change, adaptation to these changes under new conditions is extremely important. Water resources adaptation measures are mainly determined by the specifics of water consumption. Agriculture remains the major water-consuming sector for all countries of the region [UNECE, 2016].

When selecting adaptation measures, it should also be kept in mind that in addition to expected decrease in surface runoff, extreme climate events incapable of being predicted in the long term pose an additional problem that amplifies the negative effect of reduced surface runoff. However, there is solid reason to believe that floods will be more severe and prolonged and droughts will be more frequent and lengthy. In fact, adaptation measures include integration of the expected climate changes into various long-term plans, programs, etc., both at the national and regional level. For Kyrgyzstan and Tajikistan, this also applies to hydropower development plans [UNECE, 2016].

Joint climate change adaptation measures are one of the important areas of regional cooperation among the Aral Sea Basin countries. Apparently, the negative socio-economic and environmental consequences of global climate change in the Aral Sea basin, as well as in the Aral region, considering the impact of the dried seabed area, will be the less, the higher the water levels at which the main water bodies singled out of it will be stabilized [Bortnik V.N., 1990]. This approach to the Aral Sea reconstruction was used as the basis for the project to reconstruct the northern part of the Sea as part of a larger scale project on "Regulation of the Syr Darya River Channel and Northern Aral Sea." The project included construction of the Kokaral Dam with the length of 12.7 km and the height of about 3 m, with the upper crest elevation of 43.7 m and slopes of 1:45 upstream and 1:5 downstream (the latter protected by gravel). The spillway was designed for a maximum flow of 367 m^3/sec. The water level in the Northern or Small Sea should be maintained at 42 m with its surface area of 3,290 km^2 and volume of 27.1 km^3. Water mineralization in this regulated water body would not exceed 4-17 g/L.

With the completion of the Kokaral Dam in 2005, as planned, a water body has emerged with the above design parameters. The North Sea made it possible to preserve this part of the Sea in the reconstructed form, to eliminate removal of toxic salts from the seabed by wind and to restore the fishery, contributing to the ecological improvement of the Aral Sea region. It is important to note that ASBP-1 envisaged the preservation of the northern part of the Aral Sea and will continue with the second phase of the project on "Regulation of the Syr Darya River Channel and Northern Aral Sea" which will significantly increase the water surface area of the Small Aral, allowing to lessen insalubrious salts carried out from the dried seabed by wind [Aladin N.V. and others, 2017; Aladin N.V. and others, 2017a].

Analysis of the Aral Sea satellite images between 2001 and 2009 shows that the level in the Small Aral has stabilized, while the Large Aral has continued to shrink at a rapid pace. The eastern part of the Large Aral has disappeared, with only the western deep-water part remaining. Today's level of the remaining part of the Large Aral Sea, as reported by the Uzbek post of Aktumsuk and Kazakhstani post of Kulandy, is around the marks of 26 ... 28 m BS. Even if water withdrawal from the Amu Darya and Syr Darya is completely stopped, it will take at least 200 years to restore its previous water level. Presently, the task is to preserve its separate parts. For this purpose, it is important for the countries in the region to join efforts to preserve what water bodies remain in place of the Aral Sea [Ivkina N.I., 2010; Karimov B.K. and others, 2020].

Such regional cooperation must also focus on combating desertification. The dried seabed still poses a threat of salt and dust transport to vast desert areas and requires not only monitoring of salinization processes and mobile substrate movements, but also proactive countering them in order to stabilize the natural environment of the Aral Sea region [Novikova N.M., part 2, 2020]. Since 1995, Kazakhstan and Uzbekistan have been implementing a long-term program to combat desertification. To date, tremendous work has been done including the development of the dried seabed site conditions typology, revegetation methods and techniques to improve seedling survival, and developmental challenges of phytoameliorant plants under different cultivation technologies and conditions. By 2017, the afforestation area reached 500,000 hectares with the dried seabed area of 4.7 million hectares [IFAS EC, Bekniyaz M.K., 2020].

Figure 3-1 Kokaral Dam spillway

Source: IFAS ED in Kazakhstan, 2021.
Disclaimer: The boundaries and names shown and the designations used on this map do not imply official endorsement or acceptance by the United Nations.

However, despite establishment and operation of such regional organizations as IFAS and its various institutions, coordination among the region's countries to address the Aral Sea problem requires further improvement. The so-called "Blue Peace Index" proposed by the Economist Intelligence Unit (EIU), an international think tank, highlights the need to strengthen legal, institutional, financial, and infrastructure frameworks and instruments for water management in Central Asian countries [EIU, 2020].

Table 3-1

Countries and Blue Peace Indexes	Blue Peace Index	Blue Peace Index (BPI)				
		policy & legal frameworks	institutional arrangements & participation	water management instruments	infrastructure & financing	cooperation context
Kazakhstan	53.2	57.5	59.7	41.7	45.9	61.0
Kyrgyzstan	46.5	52.7	52.8	45.8	26.3	55.0
Tajikistan*	43.3	47.1	54.2	37.5	37.1	40.7
Turkmenistan	39.2	51.3	52.8	29.2	26.5	36.1
Uzbekistan*	48.6	53.3	65.3	41.7	44.4	38.2

Source: EIA, 2020.

Government programs in this field should comprehensively cover all components of integrated water resources use and protection at the local, national, and basin levels, taking into account various aspects of transboundary water use and its nexus factor in regional cooperation.

The key indicator of climate change in Central Asia is the state of glaciers and snow cover. Man-made cause of glaciation degradation is also connected with the drying up of the Aral Sea and enhanced wind erosion of the dried seabed surface. In Central Asia, lengthening of heat exposure (drought) is becoming increasingly noticeable. Impact of the observed climate change manifests itself in increased number and severity of weather and climate anomalies – a 40 percent increase in their number over the last 20 years. The ongoing climate change in the region affects both the ecosystem and economic activity, primarily in the areas related to the use of water and land resources [Yassinsky V.A. and others, 2010].

With climate change comes a number of challenges that concern, for example, investment policies in irrigation and hydropower. With time, shrinking of glaciers and snow cover areas in mountainous areas leads to water deficit in plains, changing the surface flow patterns and, as a result, bringing forward new requirements for the use of hydropower potential of transboundary rivers and sustainability of irrigated farmlands in neighboring countries.

Climate change is a process with multiple risks, in particular, related to the extent, timing and nature of these changes, affecting water management in transboundary river basins and sustainability of interstate water use. Considering their high nexus factor and competitive water use, reduced water availability of rivers may lead to conflicting situations. Therefore, adapting water management at the regional or basin level to climate change implies, in the first place, a coordinated policy of water use and development of hydropower resources.

Many Central Asian river basins face water scarcity, so the climate vulnerability assessment (CVA) for investment projects needs to identify the likely level of risk and the measures to reduce or eliminate such risk. Important pre-project preparations include identification of the facilities at risk and assessment of the vulnerability sources and causes. Regrettably, there is as yet no universal methodology for such an assessment, therefore CVA must be prepared for each specific facility in a particular transboundary river basin.

The specifics of transboundary river water resources use resulting from the natural and geographic and economic conditions of the river basin countries, as well as competing national interests create specific management challenges. In this regard, adaptation requires an integrated approach based on the basin-wide principle of river water use while taking into account the specifics of each country's development and the nature of economic integration of the basin countries.

It is clear that effective and long-term achievement of most adaptation goals and objectives in transboundary river basins requires transboundary coordination and cooperation. Political, legislative and institutional frameworks at the national and regional levels must jointly support adaptation to climate change. This needs to be done at the basin level as well, which will require more effective international cooperation and appropriate mechanisms for its coordination.

Central Asian countries need to further improve their national meteorological agencies and increase the accuracy and timeliness of hydrometeorological services. The region is known to be in the highest risk group for natural disasters. Economic losses caused by transboundary floods and mudslides, droughts and frosts, avalanches, hailstorms, strong winds and other dangerous weather events are quite significant and average 0.4 to 1.3 percent of GDP per year in the region. For this reason, the provision of quality hydrometeorological and climate services needs to be regarded as an important component of climate change adaptation measures. Disaster risk management is a core component for sustainable social and economic development of the region, especially such sectors as agriculture, transport, water management and hydropower. Economic estimates suggest that even small additional investments in the development of national hydrometeorological services in the region could have a positive effect. Just putting in place effective early warning systems in Central Asian countries would theoretically reduce the casualties by 50 percent and the economic damage by 20 percent. In 2012-2018, the Central Asia Hydrometeorology Modernization Project was implemented with the assistance of the World Bank, IFAS EC, its Regional Center of Hydrology (RCH) and with the involvement of the national hydrometeorological services of the region (except Turkmenistan). The implementation of this project allowed developing a cooperation mechanism for the countries in the region to reduce the risk of material damages and potential reduction of general economic losses as a result of natural disasters. It appears that the strengthened cooperation in the field of hydrometeorology among Central Asian countries will be continued as a priority for IFAS and its institutions [Sudas L.G., 2017].

Information needs of the parties must be satisfied in order to monitor water management situation and to support modeling of water vulnerability scenario due to climate change, which informs water policy priorities, strategies and plans for development and management of the water bodies. The water-related information should support understanding of the need for cooperation between the river basin countries and water users (agriculture, industry, hydropower, etc.). Impact of climate change on water resources depends not only on changes in volume, timing and quality of river flow, but also on water management system properties, varying impact factors (technical condition of water management system, timeliness of and adequate financial resources for repair and reconstruction, development of water- and energy-saving technologies, improvement of system management, human and R&D support, etc.) [Yassinsky V.A. and others, 2010].

The integrated water resources management includes a special feature of system or ecosystem approach that involves collection and analysis of hydrological information, forecasting and assessment of the hydrological and water management situation, which informs decision-making on regulating water demands of economic sectors and ecosystems, control over the implementation of such decisions and compliance with water legislation [WMO, 2012]. This requires strengthening the role of basin organizations at the national and regional levels which will allow improving water resources accounting and monitoring system, forecasting changes in their qualitative and quantitative status in the light of climate change, developing an effective information exchange and early warning system for adverse hydrological phenomena.

In recent decades, the global community has increasingly focused on the development of climate change and climate variability adaptation measures in the agro-sphere as part of national adaptation plans. These plans vary from country to country depending on the level of development and the degree of exposure of the country's economy to weather and climate risks. At the same time, they share common features and approaches that should be taken into account when developing adaptation plans in Central Asian countries. Development of the adaptation strategies and plans should make use of advanced databases updated by the national and regional climate centers that monitor and forecast climate and serve a wide range of users [Report on the Scientific and Methodological Framework…, 2020].

One of the key inputs to adaptation plan is the analysis and assessment of current and future weather and climate risks, including current state of the climate system and future climate change scenarios, exposure and vulnerability of the subject, namely plant industry. Maintaining food security in Central Asian countries in a hot arid climate with scarce water resources for land irrigation is a challenge. Adaptation measures should include widespread adoption of modern agricultural practices to reduce dependence on climate change and variability.

An effective adaptation implies combining different farming systems, developed irrigation techniques, maintaining a high level of soil fertility, effective crop rotations (using green manure and legumes), and the use of highly productive and stress-tolerant crop varieties. The use of new drought-resistant varieties is one of the most effective ways of adapting grain farming to climate change in this region. Expanding drought-resistant crops such as corn and sorghum and breeding new varieties of other drought-resistant crops can not only offset the negative effects of changing agroclimatic resources in the region, but also benefit from the new climate conditions.

The primary areas of agriculture adaptation in Central Asia to the observed and expected climate changes include:

-Adapting to the increased heat resources of the growing season. Adaptation measures: increasing the cultivation areas of heat-loving high-intensity crops such as corn, soybeans etc., increasing catch crops and energy crops production.

-Adapting to the cold season conditions. Adaptation measures should include increasing the areas of winter grain crops (wheat, barley) as more productive crops under climate change.

-Adapting to the changing moisture conditions. Adaptation measures: wider implementation of water-saving techniques; expanding drought-tolerant crops production; expanding winter crops production.

These proposals, while well-known, are generally rational and relevant to food security in the countries of the region.

Summary

Water resources use in the region demonstrates high growth rates due to demographic factors, industrial and agricultural development, mainly irrigation. Central Asian countries, primarily in the Aral Sea basin, are notable for their socio-economic development that unfolds amidst complete depletion of their water resources, *i.e.* water use exceeds available resources, and this trend will determine the nature of inter-State relations of the region's countries. It should also be noted that by 2030-2050, the countries of the region will also reach the limits of irrigated land expansion because of its limited availability. Despite the depletion of water and irrigation resources in the region, in their national strategies and programs, each country provides for further growth of water use for irrigation and hydropower in the future. Given this, a coordinated regional water policy is required which must seek to balance the water resources use and improve the ecological situation in the region.

Climate change significantly affects the water situation in Central Asia. Agriculture and hydropower in the region are particularly sensitive to climate change as it has a direct impact on the river flow and, consequently, on the development of hydropower and agricultural production. Reducing negative effects of climate change on the region or individual economic sector depends on the degree of preparedness at the regional and national levels to counteract and reduce the potential economic damage. In this regard, investment projects should include a special section on assessing the climate change impact that includes adaptation measures designed to reduce or eliminate investment risks, *i.e.* a climate vulnerability analysis of the project should be carried out. To produce unbiased cost estimate of adaptation and risk reduction measures, it is necessary to strengthen research work on predicting and monitoring climate change, while treating it as the most important step in the pre-investment preparation of projects related to water use in various economic sectors.

Large-scale development of irrigation and other water use types, particularly hydropower, has changed the water cycle of transboundary rivers in the region and created serious socio-ecological problems such as the drying up of the Aral Sea and destruction of its ecosystem; desertification of vast areas around the Sea, deterioration of water quality and impact on public health; local climate change, etc. Prospects for socio-economic development of all Central Asian countries are largely determined by the availability of water resources. Accordingly, reaching consensus on interstate water allocation in transboundary river basins is the overarching objective that requires political will and a comprehensive solution, considering socio-economic and environmental changes and the political situation in the neighboring countries of the region. Rapprochement of positions in the field of joint use of transboundary water resources cannot be considered outside the economic development models of each country and economic cooperation in the region as a whole. Strengthening the trade and economic ties of the countries in the region and their close cooperation where water policy becomes an active factor of economic integration, should help to solve the problem of joint use of transboundary water resources.

The Aral Sea basin countries lying in the arid zone are most exposed to high risks and threats as a result of global and local climate change. Climate warming can be observed throughout Central Asia, and long-term assessment made on the basis of the climate scenarios above suggests no increase in water resources in the region. As projected, countries in the middle and lower reaches of transboundary rivers will face depletion of available water resources and increased water scarcity as water quality degrades, including groundwater. This will primarily affect the population's access to quality drinking water. Hydrographic regime of surface waters is expected to change significantly due to the accelerated glacier melting and reduced snow cover, accelerated desertification, land degradation and salinization, loss of biodiversity, and increased deforestation. The cumulative negative effects of climate change will increase competition for water among the countries in the region with long-lasting and significant implications for political, food, energy, sanitation, and environmental security in the region. With the increasing frequency of dangerous and extreme hydrometeorological phenomena, such as hail, drought, extremely high or low temperatures, etc., the frequency of natural emergencies is forecast to rise, including heavy showers, mudflows, landslides, avalanches, floods, and droughts. Climate change can also pose a threat to the existing ecosystems and biodiversity [Orlovsky N.S. and others, 2019].

The region's climate is aggravated by the dried out Aral Sea which, having lost its role as a climate and geochemical runoff regulator, has turned into a source of aeolian salt transport to the surrounding area. The resulting ecological, social, economic problems require new approaches to irrigation development and water management in the region, especially in the transboundary context [Pankova E.I., 2016]. They should be regarded as practical measures for adaptation of economic sectors in the region to climate change. First of all, this concerns such large water-using and water-consuming sectors as agriculture, hydropower, industry, and public utilities. In these sectors, step-by-step comprehensive reconstruction of water infrastructure is needed, with universal transition to water-saving technologies and waste water reduction. In the agricultural sector, it is important to promote the practice of more drought-resistant crop varieties cultivation on a wider scale, improve the technical level of engineering irrigation systems equipped with automated means of water distribution and monitoring the condition of irrigated lands. In the industrial sector, low-water technologies and water recycling systems need to be implemented. In the public utilities sector, technical condition of water supply and sewerage systems should be improved while reducing their water losses, and new technologies for wastewater treatment should be adopted.

The future water needs of the countries in the region can only be met through a sustainable and efficient use of available water resources and implementation of integrated climate change adaptation measures, strengthening of regional cooperation for joint use and protection of transboundary river basins.

Central Asian states contribute greatly to the achievement of the Sustainable Development Goals (SDGs) in every dimension – environmental, social and economic: the SDG targets are integrated into strategies and policies of the government planning systems of the region's countries. Strengthening cooperation between the national authorities of Central Asian countries and international organizations in water management, water supply and sanitation is an important aspect of ensuring national water security.

Joint solution of environmental and resource problems in transboundary river basins, implementation of multilateral investment projects, development of scientific and technical base and personnel training must become important drivers of sustainable development and expansion of integration cooperation. Coordination of regimes and rules of operation of hydropower plants with reservoirs, main channels and large pumping stations, construction plans of facilities for different types of transboundary river water resources use and protection, requires joint actions based on integrated water resources management. In doing so, it is fundamental for cooperation in transboundary river basins that water-using states observe the principles of reasonable and equitable use of international watercourses and avoid causing harm to other neighboring states.

Cooperation between water management bodies and water-using and water-consuming economic sectors (land-water-energy nexus) is the basis for integrated water resources management. It is important to strengthen cooperation between the hydrometeorological services of the region – at the local, national and regional levels. It should be noted that an integral system of water resources management in the countries of the region is still in its infancy, and its legal development requires harmonization with many branches of law relating to environmental protection, economy and finance, construction, education, science, international relations, and national security.

The priority goal of water strategy and policy is to implement national actions to preserve the water and resource potential of the river system and its environmental security. In order to implement the basin-wide principle of water resources management, the basin authority should be vested with sufficient powers and functions, have infrastructure to manage water assets (reservoirs, rivers, lakes, groundwater) and physical facilities, be able to automate collection and permanent storage of information base of basin data, etc. Full-fledged strengthening of the basin authority (at the national and regional level) will enable to maintain sustainability of water resources management in the country as a whole irrespective of the multiple reorganizations of superior entities (ministries, committees). In this regard, it is necessary to develop a policy to strengthen the national and regional basin authorities (Syr Darya BWMA and Amu Darya BWMA).

Key Recommendations

Capacity development workshop on science and policy interfaces for climate and disaster resilience in the Aral Sea basin

On 14 March 2022, the Information and Communications Technology and Disaster Risk Reduction Division of UNESCAP organized an online international seminar titled 'Capacity development workshop on science and policy interfaces for climate and disaster resilience in the Aral Sea basin'. With a focus on Central Asia, the seminar took up discussion on an array of issues like climate change, melting glaciers, shrinking Aral Sea, negative impacts of the drying bottom of the Aral Sea, increasing usage of water resources and deteriorating water quality, degrading land resources and increasing desertification, population growth as well as insufficient food and energy security. The gathering also took stock of the ongoing work in the sub-region to achieve the Sustainable Development Goals (SDGs) and the Sendai Framework for Disaster Risk Reduction 2015-2030 targets as well as the functioning of regional cooperation and programs already in place to tackle the Aral Sea issue.

Key Recommendations for Central Asian countries:

- *Developing* a regional water policy aimed at the balanced use of water resources and improvement of the ecological situation in the region.
- *Developing* new mechanisms and instruments for cooperation in transboundary river basins, based primarily on deep economic integration of countries in the region.
- *Accelerating* gradual and a holistic reconstruction of water management infrastructure with a widespread transition to water-saving technologies and reduction of wastewater.
- *Promoting* cultivation of drought-resistant crop varieties.
- *Introducing* green and low-water usage technologies, water recycling systems, and developing new wastewater treatment technologies.
- *Improving* the accuracy and efficiency of regional hydrometeorological services for climate change adaptation and disaster risk management in Central Asian countries.
- *Creating* sub-regional mechanisms for adaptation to climate change, risk assessment, early warning and prevention systems for transboundary hazards in the Aral Sea basin.
- *Strengthening* efforts to achieve the Sustainable Development Goals, in particular SDG 13 'Take urgent action to combat climate change and its impacts' and SDG 14 'Conserve and sustainably use the oceans, seas and marine resources for sustainable development'.
- *Organizing* a network on the ESCAP platform inclusive of the existing networks of experts on water resources, ecology, climate and socio-economic sector in the region with the aim of strengthening regional cooperation and attracting investment for implementation of projects concerning the Aral Sea and related ecosystem.
- *Involving* educational institutions and students on the issues like water resources management and environment protection in order to ensure participation of youth in solving present day challenges and threats.

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