Integrated Water Cycle Management in Kazakhstan

Tempus

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Textbook developed in the TEMPUS IV – 5th Call of Proposals on Joint Projects

I-WEB™

Almaty
"Qazag university"
2014

Editors:

Burghard C. Meyer & Lian Lundy,

The publication should be citated as follows

Meyer B. C. & L. Lundy (Eds). 2014. Integrated Water Cycle Management in Kazakhstan. Al-Farabi Kazakh National University, Publishing House, Almaty, 320 pages

ISBN: 978-601-04-0900-2

Published with active contributions of the TEMPUS IV IWEB-Project partner's institutions:

- Middlesex University, London, UK
- Al-Farabi Kazakh National University, Almaty, Kazakhstan
- Ahmed Yasawi International Kazak-Turkish University, Turkistan, Kazakhstan
- Kokshetau State University named after Shokan Ualikhanov, Kokshetau, Kazakhstan
- Universität Leipzig, Germany
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- Ministry of Education and Science Control Committee, Astana, Kazakhstan
- Center of Bologna process and academic mobility, Astana, Kazakhstan
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Cover page photographs: Burghard Meyer

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Chapter 5

Sustainable Use of Water Resources in Kazakhstan

5. Sustainable use of water resources in Kazakhstan

5.1 Water resources and Sustainable Development

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Introduction

Water is a key natural component enabling the existence of human beings and ecosystems. Water resources are the major factors limiting the economic development in dry areas. According to the "Berlin Rules" sustainable use of water resources is defined as: "*complex management of water resources to promote efficient use of and equitable access to water for the benefit of the current and future generations while preserving renewable resources and maintaining non-renewable resources to the extent possible*" (Anonymous, 2004a). Transition to integrated water resource management (IWRM) in the Republic of Kazakhstan (RK), based on the IWRM National Plan, including focus on efficient water consumption, is a key objective. Enhanced cooperation is a globally recognized approach to sustainable development goals and objectives.

Integrated water resource management

IWRM is defined as: "*a management process that promotes coordinated development and management of water, land and related resources, in order to maximise the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems*" (GWP, 2005). IWRM integrates the following key components:

- All natural aspects of the water system: surface water, groundwater, water quality (physical, biological and chemical);
- All sectors depending on water resources: agriculture, households, industry, hydropower, navigation, fisheries, recreation, ecosystems;
- Relevant national objectives and constraints: social, economic, institutional, environmental;
- Institutions at all relevant levels of governance: basin, national, provincial, local;
- Spatial variations of resources and demands: upstream-downstream interaction, basin-wide analysis, inter-basin transfer;
- Temporal variations: floods, droughts, peak demands, growth patterns.

Sustainability and IWRM

To implement IWRM (and supporting legal frameworks), it is important to consider what sustainability means within each specific context and which actions (e.g. measures, regulations, controls, management instruments) need to be formalised. Specific sustainable development goals and challenges have to be identified, assessed and incorporated as a part of an IWRM approach (Anonymous (2005), Anonymous (2007)). Practical steps of IWRM implementation in global terms have been discussed within the framework of multiple conferences and international agreements: The World Summit on Sustainable Development (Johannesburg, 2002) called for development of integrated water resource management and efficient water consumption plans by 2005 in all the countries. Follow-up agreements were signed at the 3rd Water Forum in Kyoto (2003); the 4th Water Forum in Mexico (2006), the 5th Water Forum in Istanbul (2009) and the 6th Water Forum in Marseilles (2012). It was noted that underlying factors of the global water crisis are poor management of water resources, lack of agreement between stakeholders on the actions to be taken as well as the lack of financing.

Water resources and sustainable development in Central Asia

The largest rivers in Central Asia are the Amudarya (with a yearly flow volume of 79.28 km³) and Syrdarya (annual flow volume of 37.2 km³) with total flow volume of 116.5 km³. The main factors influencing water volumes in these rivers are population distribution of s and types of economic activities in the region. For example, 80-90 % of water resources in Central Asia are used in agriculture and basically for irrigation. In Central Asian region population growth rate is high (e.g. population of Uzbekistan in 2013 was 30.2 million, an increase by5.3 million compared to 2000). Water and water distribution has been and remains one of the focal points of co-operation between Central Asian countries. At the 6th Water Forum (Marseilles, 2012) the following priorities in water resources and IWRM were identified within the context of sustainable development.

Table 5.1.1 Priorities in water resources and IWRM

Order of priority	Priority Descriptors
1	Supply of water for future generations
2	Risk management and water safety
3	International collaboration in managing transboundary water resource management for the benefit of all regional states
4	Implementation of innovation in agriculture in order to ensure food supply safety
5	Integrated water resource management as a way to balance multiple uses of water
6	Climate change and conserving environmental capacity)
7	Promotion of sustainable drinking water supply

Water resources and sustainable development within the context of the governance systems of the RK

Sustainable socio-economic development of RK faces many barriers in managing water resources to enable a balance between existing water supply and demand. Far-reaching sustainable development challenges require new approaches to be developed and implemented. Systematic implementation of IWRM with community involvement into water resource management is seen as the way forward (Anonymous, 2006).

In 2012, in his Address the President of the RK and leader of the Nation N.A. Nazarbayev, identified several major directions for the RK, such as 1) Established Kazakhstan - trial by crisis of our statehood, national economy, civil society, social harmony, regional leadership and authority with the international community; 2) 10 global challenges of the 21st century, listed in Table 5.1.2) Strategy "Kazakhstan-2050" – a new political course for the new Kazakhstan in a fast changing world (Nazarbayev, 2012).

The fourth challenge identified is water famine. President Nazarbayev (2012) highlighted the fact that:

- Global water resources are under great pressure.
- In the last 60 years global demand for drinking water supplies has increased eight fold. By the middle of this century many countries will have to import water.
- Water remains a limited resource, so the fight for water is already becoming a critical geopolitical factor causing tension and conflicts in the world. Kazakhstan also faces water supply challenges. We lack high-quality drinking water. In a number of regions drinking water scarcity is an issue.
- There is a geopolitical aspect to this issue. We are experiencing serious problems with access to the water of transboundary rivers. Given the complexity of this problem, we should avoid politicizing it.

Table 5.1.2 Ten global challenges of the 21st century (Nazarbayev, 2012)

Challenge	Ten global challenges of the XXI century
1	acceleration of historical time
2	global demographic imbalances
3	global food security threat
4	***the acute shortage of water***
5	global energy security
6	depletion of natural resources
7	The third industrial revolution
8	growing social instability
9	crisis of values of the current civilization
10	new global destabilization threat

The Astana "Green Bridge" initiative is a basis for sustainable development of Kazakhstan (Anonymous, 2013); it is the initiative launched by RK and supported by the VI Asian and Pacific Ministerial Conference on the Environment and Development. In turn, the proposal of Asian and Pacific region to establish a partnership program was supported at a meeting of the Committee on Environmental Policy organized by United Nations Economic Commission for Europe (2-5 November 2010, Geneva).The main purpose of the Initiative is to develop partnership between European, Asian and the Pacific countries in planning transition from traditional economic models to the concepts of "green" growth. Key areas of the Partnership Program include:

- protection of water, mining and other ecosystems and increasing the eco-efficiency of the use of natural resources;
- enhancing the availability and efficiency of sustainable energy;
- enhancement of food security and sustainable agriculture;
- promote sustainable urban infrastructure and transportation;
- facilitate adaptation to climate change and resilience to natural disasters.

Geographical Location of the Country

The Republic of Kazakhstan is situated in Central Asia in the middle of the Eurasian continent and occupies the area of 2.72 million km². The western state border runs along the Caspian shore, the Volga steppes, ascending northward to the southern flanks of the Ural and further eastward along the south of the Siberian Plain to the Altai Ridge. The eastern border is along Tarbagatai and Jungar ridges, and the southern borders are the Tien-Shan Ridge and Turan Lowlands to the Caspian coastlines. The highest point of Kazakhstan is Khan-Tengri (6,995 m above the sea level), the lowest point is Karagiye Depression (132 m below the sea level). Specific feature of Kazakhstan's territory is that its greater part belongs to the internal-drainage basins of the Caspian Sea and the Aral Sea, Balkhash Lake, Tengiz Lake, the Alakol Lake, etc., which do not have an run-off into an ocean. As a result, a significant amount of pollutants is accumulated in the lower reaches of the country transboundary rivers (the Syrdarya, the Ili, and the Zhaik deltas etc.). These pollutants are to be found in river flows, in atmospheric precipitation, or in industrial wastes disposed, or come from other sources. Thus the issue of water resource and water quality management is becoming critical for sustainable use of water resources in Kazakhstan (Anonymous, 2004b).

Water Reserves

According to the Water Code of the Republic of Kazakhstan, the State's water reserves' include all water objects located within the territory of the Republic of Kazakhstan, and all water resources contained in these water objects, as well as other registered or subject to registration water resources in the State Water Cadastre (Anonymous, 2010). Estimated fresh water reserves amount to 524 km^3(see Figure 5.1.1).

Rivers

There are around 39,000 rivers, including small ones, on the territory of the RK, 7,000 of which are more than 10 km long. The river network is distributed unevenly in the country. In the north of the country the density of the river is 0.03-0.05 km/km^2 and in the regions of Altai, Jungar and Trans-Ili Alatau the density of the river network is 0.4-1.8 km/km^2. The majority of rivers belong to the internal basins of the Caspian and Aral Sea, Balkhash and Tengiz Lake. Six rivers in Kazakhstan have an annual water discharge ranging from 100 to 1,000 m^3/sec, seven rivers with 50 to 100 m^3/sec water discharge, and 40 rivers with a discharge from 5 to 50 m^3/sec (see Figure 5.1.2).

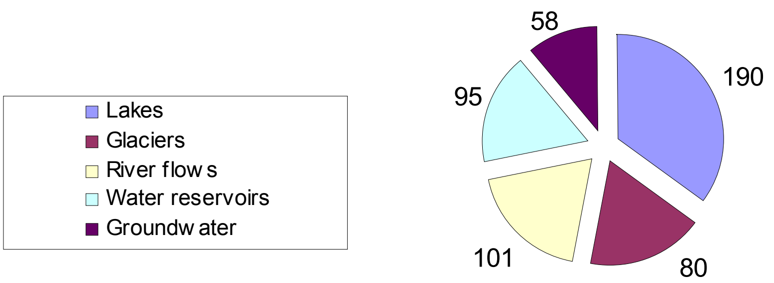

Figure 5.1.1 Fresh water reserves in the Republic of Kazakhstan, in km^3 (Water Resource Committee under the Ministry of Agriculture of the Republic of Kazakhstan (2005)

Lakes

The total number of lakes in RK is 48,262, with the total surface area of 45,002 km^2. Small lakes, the size of which is less than 1 km^2, constitute 94% of the total sum, and cover only 10% of the total area or all lakes. The distribution of the lakes within the territory of the country is uneven: 45% of all lakes are to be found in the north of Kazakhstan, only 36% in Central and South Kazakhstan, and all the rest, that is 19%, are in other regions of the country. The largest lakes in Kazakhstan are the Caspian and Aral Seas, the lakes Balkhash and Tengiz in Central Kazakhstan, the lakes Alakol and Sasykol near Jungar Pass and the lakes Zaisan and Markakol in East Kazakhstan. A great number of lakes are located in the forest-steppe and northern part of the steppe zones, the largest of which are Korgalzhyn, Chelkar-Tengiz, Bolshoye Chebachye, Schuchye, Selety-Tengiz. The total volume of water in these natural reservoirs is 190 km^3.

Glaciers

The majority of Kazakhstan glaciers form a huge ice belt located in the south and east of the country, specifically in the mountains of Tien Shan-Talas, Kyrgyz, Trans-Ili, Kungey and Terskey Alatau, Jungar Alatau and Kazakhstani Altai with the altitude of > 4000m above the sea level. 2,720 glaciers were registered in Kazakhstan at the end of 1980s, 1,975 of which have the area of more than 0.6 km^2. The total area of glaciations is 2,033.3 km^2. The total volume of water reserves of these glaciers, estimated to be 80 billion m^3, is reflected in Table 5.1.3. Currently a trend to significant reduction of glaciation area is observed in Kazakhstan. According to the estimates made by Vilesov (2014), the water reserves of glaciers have reduced by 45 km^3 since 1980.

Table 5.1.3 Glaciers of the Republic of Kazakhstan

Region	km^2
Jungar Alatau	1,000
Ile and Kungey Alatau	660.7
TerskeyAlatau	144.9
Altai with Saur	106.2
Kyrgyz and Talas Alatau	101.5

Reservoirs

Currently, there are more than 200 man-made water bodies in Kazakhstan (see Table 5.1.4) with the total capacity of more than 95.5 km^3 (excluding ponds and minor water reservoirs designed to capture spring flows). The capacity of over 50 percent of water reservoirs is 1-5 million m^3 of water. The greater part of water reservoirs are expected to regulate seasonal flows.

Table 5.1.4 Overview of major water reservoirs in RK

Water Reservoir	Total volume, km^3
Bukhtarma (on the Irtysh River)	49.0
Kapshagai (on the Ili River)	28.1
Shardary (on Syrdarya River)	5.2
Upper Tobol (on the Tobol River)	0.82
Karatomar (on the Tobol River)	0.59
Vyacheslavskoye (on the Yesil River)	0.4
Sergeyevskoye (on the Yesil River)	0.7

Groundwater

The total volume of groundwater used is up to 43 million m^3/day (15.7 km^3/ year), which may be increased, according to forecasted resources requirements, to 100 million m^3/day (36.5 km^3/ year) (Anonymous, 2004b.).

River basins and water supply in the RK

The territory of Kazakhstan can be conditionally divided into eight river basins: Aral-Syrdarya basin, Chu-Talas basin, Balkhash-Alakol basin, Irtysh basin, Ishim basin, Nura-Sarysu basin, Tobol-Torgai basin and Ural-Caspian basin (Figure 5.1.2) (Anonymous, 2010).

Currently, Kazakhstan is not experiencing a national water scarcity, but there are regional deficits, for instance, in the Aral-Syrdarya and Nura-Sarysu basins. The annual average renewable water resources of Kazakhstan are up to 100.5 km^3 (see Table 5.1.5). Only 56.5 km^3 are formed on the territory of the country. The remainder, with a volume of 44.0 km^3, flows in from the neighbouring countries: the People's Republic of China (18.9 km^3), Uzbekistan (14.6km^3), the Republic of Kyrgyzstan (3.0 km^3) and the Russian Federation (7.5 km^3) (Anonymous, 2004b). Kazakhstan is strongly dependent on the inflows of trans-boundary rivers from neighbouring countries. This encourages all countries to negotiate cross border solutions for existing and potential water problems.

2001, a very dry year in RK, water consumption by the economy as a whole was only 20km^3. Fluctuations in the quantity of water consumption are influenced by water availability, as well as the

Figure 5.1.2 Map of Main River Basins and rivers in Kazakhstan (Water Resource Committee under the Ministry of Agriculture of the Republic of Kazakhstan, Anonymous, 2004b)

The total per capita volumes of renewable fresh water resources available in the RK is higher compared to agricultural and industrial countries such as India and China, but lower than in the countries such as Russia, Brazil and Canada. Currently, 38.6 km^{3}of the total renewable water resources per year (estimated to be 100.5 km^3) are required to maintain environmental flows, to conserve river and lake ecosystems. Annually about 29 km^3 of water are lost due to factors such as the lack of necessary infrastructure, processes of evaporation and infiltration within canals and rivers, and the need to ensure compulsory minimum levels of inflow to border states such as China and Russia. In addition, 12.8 km^3 of water resources are not guaranteed, due to the natural variability of river runoff levels e.g. lower volumes are available in low water years. Thus, the amounts of available, sustainable and reliable water resources in the RK currently make up 23.2 km^3 per year (Anonymous, 2014).

Use of water resources

Water consumption by the different sectors of Kazakhstan economy decreased from 35km^3 in 1993 to 26km^3 in 2006 and to 21.4km^3 in 2012. In organizational and structural changes taking place in the country economy. Surface water sources are responsible for 90 % of industrial water supply (about 20.3 km^3 in 2012).The rest is supplied from groundwater, seawater (from the Caspian and the Aral seas) and sewage. The domestic sector consumes about 0.8km^3 of water per year, which makes up about 4% of the total water discharge used. Depending on the technical conditions of water supply networks per capita water consumption ranges from 130 to 250 litres per day (Anonymous, 2014). Overall, the level of water discharge for industrial needs is increasing, amounting to about 5.2 km^3 (24 % of the total consumption) in 2012. The highest water consumption is accounted for thermal power, nonferrous metallurgy and oil industries (located in Karaganda, Pavlodar and Almaty regions). Up to 40 % of the water consumed by these industries is of drinking water quality. The largest proportion of the total water consumption (up to 75 % of all water) is used for agricultural purposes. Currently, the highest volume of water consumption is accounted for agricultural irrigation, followed by estuary irrigation, pasture irrigation and rural water supply. Water use efficiency in Kazakhstan is lower than in comparable countries both within domestic sectors and in industry. In general Kazakhstan uses 97 m^3 of water for every $1,000 of GDP, which is significantly higher than the figures for Australia (15 m^3), Brazil (26 m^3), United States (31 m^3), Russia (33 m^3), and China (67 m^3). Transportation losses, including intake, amount to about 60 % of water for agricultural consumptions, about 40% for industrial consumptions and 50 % for municipal services. It is predicted that current levels of water use will sustain in municipal and agricultural sectors, and that a moderate water use increase is expected in industry. It is predicted that of the 29.7 km^3accumulate water, 24.6km^3 will be used. The difference between these two values relates to water losses (Anonymous, 2014).

km^3/year in 2012 (Dostai, 2012). Given the expected unfavourable climatic changes and transboundary hydrological threats, Kazakhstan should expect reduction in river flow volumes. The annual runoff of 11.4km^3 throughout the Republic of Kazakhstan was calculated for the year 2040 (Anonymous, 2014). The projected decline in river flow volumes is mainly caused by the decrease in the inflow of water from transboundary rivers from 44.7km^3 per year to 32.6km^3 per year (Anonymous, 2014). The main reason for this projection is an increase in the overall water use by the neighbouring countries, associated with the expected economic and social developments in the regions in recent years. The rivers with the greatest risk of water reduction include the rivers, originating on the territory of the People's Republic of China, mainly the Irtysh and Ili, potential volume of runoff reduction is estimated to be 7.7km^3 (Dostai, 2012). From 1998 to 2008, the total inflow of water from neighbouring states has decreased by 26 (Dostai, 2012).This typical pattern in the reduction of cross-border inflows is expected to continue in the next 20 years. Given the current estimates of growth in demand, by 2030, Kazakhstan may face water scarcity of 13 billion km^3 which is valued as U.S. $ 2 billion (Anonymous, 2014).

Table 5.1.5 Water basins and water resources of Kazakhstan (Anonymous, 2014)

Water basin	Local water resources, in km^3	Trans-boundary water resources, in km^3	Groundwater, in km^3	Other sources, in km^3	Total water resources, in km^3
Aral-Syrdarya	3,4	14,6	0,2	3,2	21,4
Balkhash-Alakol	15,4	12,2	0,4	0,4	28,4
Irtysh	25,9	7,8	0,2	0	33,9
Ishim	2,6		0,1	0	2,6
Zhaiyk- Caspian	4,1	7,1	0,2	0,3	11,7
Nura-Sarysu	1,4		0,1	0,1	1,5
Tobol-Turgai	1,3	0,3	0	0	1,6
Chu-Talas	1,6	2,6	0,1	0	4,4
Total in Kazakhstan	55,7	44,7	1,2	3,9	105,5

Conclusion

Kazakhstan is expecting a significant intensification of production in the near future, while total water resources in rivers tend to reduce. The annual average of river flows were estimated at150km^3/year following the high-water 1940s of the last century, at 115-125km^3/year in 1970-80s, about 100km^3/year in2000 and 91

5.2 Theories about degradation processes of hydrological resources by human and climate

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Introduction: Natural and anthropogenic causes of degradation of hydrological resources – long time and short time processes

Since the discussions about the Aral Sea crisis, the processes of drying out of large and small lakes in Kazakhstan is well known and heavily discussed mostly on a time scale of several decades and majorly in the context of not adapted water uptake by man for agriculture. The article more or less excludes the climate change prognosis for Kazakhstan (see chap. 5.3).

The problem of the degradation of hydrological resources in West Siberia and Northern Kazakhstan has been scientifically researched longer than 100 years. Causes are found by different approaches (1) in local observations on actual processes (e.g. in the siltation of lakes following the cutting of lake-near woods) or (2) in the general investigations on earth system cycling using helio-hydro-climatic, geophysical and biological entrances. We differentiate the causes of degradation processes of the hydrological resources by natural, anthropogenic and man-influenced climate change (Figure 5.2.1). The causes named for drying out of lakes and rivers are also named by (1) isostatic uplifts of the earth surface after the glacial times, (2) natural aging of lakes and (3) long-wave or inter-decadal climate fluctuations.

Most of the theories are stressing the high importance of climate change. The North Kazakhstan is understood as one of the Earth's regions with the highest and most important changes. The higher temperature and a related higher evaporation are named as a natural reason for a decrease in the run-off into rivers and a lower water level of the lakes. A total dry out can result (Smith et al 2005, Zolnikov et al 2011). Other authors discuss majorly the overexploitation of water resources at lakes and rivers and the effects of land use change and increasing land use intensity. (Klein et al, 2012, Xi Chen et al, 2013).

Aim is in the following to start with a short overview about the main causes on (1) time scales in the degradation of hydrological resources. This is followed by information about (2) natural causes and (3) anthropogenic causes. Climate change impacts are active because of natural and man-made causes.

Time scales of impact

Different aspects cause climate and hydrological changes. Natural cyclic and non-cyclic processes are influencing the climate. Table 5.2.1 gives an overview about different time scales relevant in this context.

Table 5.2.1 Time scales and causes of changes in the hydrological resources

Causes of changes in climate	Time scale of the climatological change and impact (ca. in years)
Earth Orbit Parameters	100.000
Earth's axial tilt	41.000
Plate tectonics	Some 100.000 up to several million
Volcano eruptions	1 - 2
Solar variation	11, 22, 42- 50, 80 – 90, 180-210 up to 1.470
Climatic fluctuations (long-wave)	1.470 ± 500 in the Northern hemisphere
Climatic fluctuations (inter-decadal)	7-11, 32-45 and 70-80
Anthropogenic Greenhouse gas emission	Some decades

We can differentiate between changes in energy-input in the atmosphere caused by cyclic changes of the earth orbit parameters or in the earth axial tilt (Milankovic-Cycles) (Bubenzer & Radtke, 2007); changes in the solar variation at different frequencies of the approx. 11-years and of the Schwabe-Cycle up to a 1470 years cycle (Rahmstorf, 2003); plate tectonics, long time periodical changes in tiding (ca. 1.800 years); changes in ocean current and other with impact on the hydrological cycle (1470 ± 500 years). In the very short term, only volcano eruptions with direct impact on the atmospheric circulation are of high importance on the climate by resulting changes in the global energy household. The radiative forcing e.g. of eruptive volcanoes varies since 1850 on the level of ca. 1.5W/m² and is seen at the same level of importance as the anthropogenic effects on the climate (MPI, 2002).

resources in the European Russia and in Western Siberia as a natural process during the postglacial land development by a theory of postglacial lakes in Central Asia. The results of Mangerud et al (2001) and Karnaukhov (1994) show that the

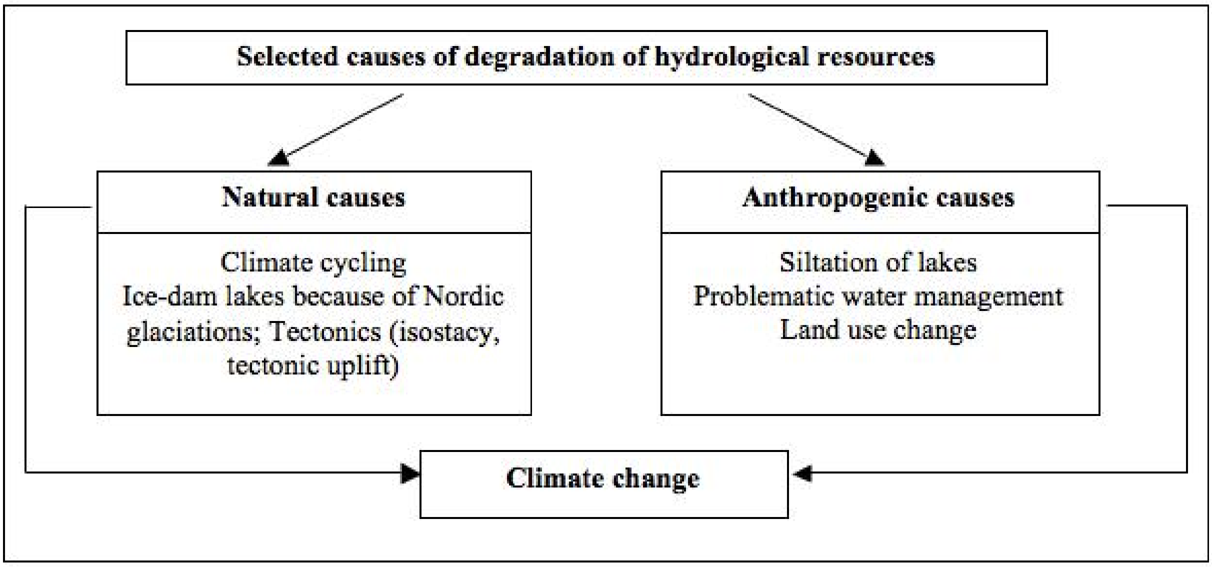

Figure 5.2.1 Natural and anthropogenic causes of the degradation of hydrological resources including climate change

Natural causes

Causes in the land development

Melnikov (2007) discusses that the dry out of lakes in West Siberia and Kazakhstan can not directly be linked to climate change because only minor temperature and precipitation changes of only 0.3° C occurred in the second half of the 20th Century. The same author explains the dry out of lakes by siltation because of soil erosion and by the natural aging of water bodies when the vegetation cover fills up successively at the place of former lakes. Another more important theory about the degradation of hydrological resources in the Northern Hemisphere is the post-glacial rebound (glacial isostacy) with uplifts of land as follow up melting of the ice shield (Kropotkin, 1998). This theory was developed by Jamenson in 1865. The effect is observed far away of Southern West Siberia and Kazakhstan, and was especially observed in Scandinavia, Northern Siberia, Canada and Alaska (Kaufmann & Lambeck, 2002).

Nevertheless, of the minor glacial activity only in the far North of West Siberia glacial processes have been strongly affected by changes in the water discharge systems (Kropotkin, 1998). Some scientists describe the degradation of the Hydro- water flows of Jenissei and Ob rivers were blocked several times because of the Nordic Ice Sheet in the Weichsel glacial period (app 80-90.000 YBP) and later periods. This change in the large scale drainage systems resulted in the Eurasian Ocean, also named as Lake, on the West Siberian Plain at 60 m.a.s.l., an area of ca 631.000 km² and a water volume of 15.000 km³. The lake was existent up to 12.000 YBP (Fig .5.2.2 A).

Karnaukhov (1994) and Karnaukhov & Karnaukhov (1997) have described several glacial and interstadial oscillations between 14.000 and 12.000 YBP. At the end of the last glacial period, in the late Weichsel, a period with different relative warm periods (interstadials), as a result of the break down of the Ice barrier to the Arctic Ocean twice the catastrophic outflow of the Eurasian Ocean water in the Arctic Ocean is investigated (Fig 5.2.2 B, C). Once the water moved also to the Mediterranean Sea (Fig 5.2.2 D). The huge amount of unsalted lake water caused a temporal stop of the Nordic circulation in the North Atlantic, and therefore the Gulf Stream brought less energy to Northern Europe. The last process again originated a new stadial (Fig 5.2.1, D). In the Holocene most parts of the Eurasian Ocean dried out. A huge number of small or larger lakes are the remains of this period.

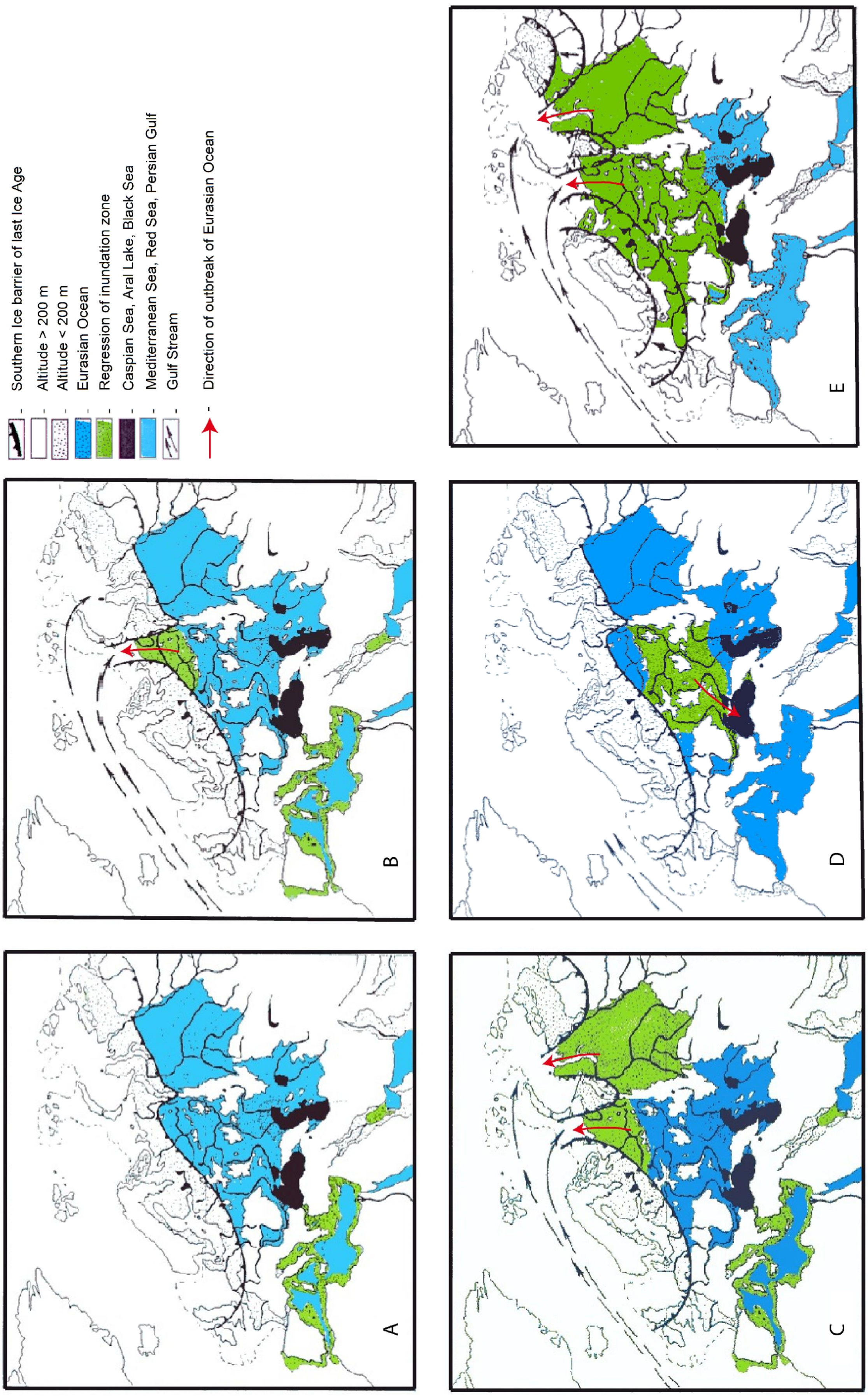

Figure 5.2.2 Areas of water cover of Eurasian Ocean between 14.000 and 10.000 YBP (after Karnaukhov, 1994, changed). [A –Older Dryas ca 14.670 YBP, B, C, D – during Bölling- and Alleröd-oscillations, E – Situation at the begin of the Holocene]

Kropotkin (1998) explained the degradation of the hydrological resources in the area of the Eurasian Ocean by natural drainage – the Holocene is a period of lakes including wide range swamps. Most of the lakes are remains of the Pleistocene Lake period. Kropotkin's idea on the dry out of Central Asia was strongly criticised in the 20th Century because of the focus on climate change and anthropogenic causes as key factors. Other researchers are focussing mainly on tectonic uplifts of Kunlun, Himalaya, Qin Ling and Hinggan Mountains and explain the dry out of Central Asia with a weaker influence of monsoon precipitation in the area north of the Mountains (Gvozdetskij & Michajlov, 1978).

Causes in natural climate variability

It is difficult to differentiate the climate factors into natural causes and anthropogenic causes. Key factor for the water household is the precipitation and the temperature driven evapo-transpiration. Climate records show for West Siberia in 1776-2000 the increase of temperature between +0.4 to + 0.8°C per decade and diverse changes in precipitation cluster (lPCC 2001). The following climatic trends are observed for the area of Kulunda steppe and the Northern Kazakhstan: (1) a decrease of the total amount of precipitation around 10-20 % observed for the 20th Century; (2) an expectation about an increasing variability of the precipitation including longer dry or drought periods; less run-off in summer and higher precipitation in winter time and stronger events of heavy rains (IPCC, 2007b). This can be problematic for areas prone to desertification – mostly for major parts of Northern Kazakhstan. Maynard & Royer (2004) and Baumhauer (2011) have calculated, that an increase of average temperature around 1-2° C combined with a decrease of precipitation can decrease the run-off by 40 – 70 %. This would lead to a serious change in hydrological resources.

Climate fluctuations are integrative aspects of the natural cycling of earth systems. Krivenko (2011) has described the dynamics of the water levels of lakes without outlet to the sea in Northern Kazakhstan as an integral factor of water household and regional water balance in the context of the inter-decadal climate fluctuation (Fig. 5.2.3). Periods of low and high lake water levels are systematised in cycles – the problem herewith is the short period of observation and the problem of statistical significance of the observed signals.

Schitnikov (1950) has founded the theory of long-periodical climate fluctuations by investigating the impact of long-term and inter-decadal climate fluctuations on the population and the areal dynamics of selected plant species in the context of changes in the hydrological regimes of the lakes without outlet to the sea or rivers in Northern Kazakhstan and Eurasia.

The prognosis of climate change predictions for Kazakhstan is explained in chapter 5.3 of this textbook.

Anthropogenic Causes

Anthropogenic causes are of high importance to explain the degradation of hydrological resources. The most important factors for the recent dry out of the Central Asian are the man-made regional redistribution of water resources and land use changes. The impacts on the water cycle are made directly by changes in the rivers and lakes flow and level by water usages or are made indirect by modification of major components of the water balance (run-off, ground water recharge, water uptake etc.) by land use.

Direct impacts are e.g. changes in the hydraulic structure of rivers in form of dams, water update for water supply of urban systems, agriculture or industries including wastewater discharges. Another type of direct impacts, often not clearly visible, are changes in the catchment landscapes e.g. in form of clear cutting of woods, irrigation, overgrazing, agricultural techniques, soil sealing, urbanisation and other (Belz et al, 2007). The man-made negative impacts are often very effective, leading to impacts obvious in short time periods (see chapter 5.6 on Aral Sea hydrology and crisis in this textbook). Examples investigated in the Central Asian part of China by Ma et al. (2010) show the overarching impact of man-made causes on the degradation of hydrological resources. Ma et al (2010) described that between 1960 and 2005, 13 % of all lakes have had a shrinking surface area. 243 lakes are no longer found because of drying out or land use changes and 60 new lakes arose. Unfortunately no detailed information is given about causes. Ma et al (2010) give the interpretation that the degradation of the fresh-water lakes is caused by water uptake for irrigation of agricultural lands. The shrinkage of size of salt-water lakes is explained by the smaller inflowing water quantities by rivers – a general problem in Central Asia. The dry out of Lop Nor Lake and the development of the man made Lop Nor Desert because of the intensive water uptake from the rivers Tarim and Kongi is the single example.

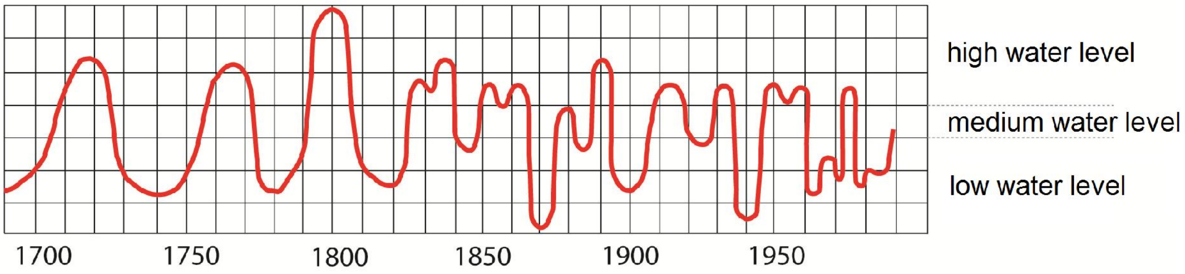

Figure 5.2.3 Dynamics of the water level of lakes without outlet to rivers in Northern Kazakhstan (Krivenko, 2011 citation after Kuznetzov, 1970)

Klein et al (2012) have investigated changes of land cover for Kazakhstan using remote sensing data (MODIS) with classification accuracy of around 90 % for the short time period between 2001 and 2009. This study explains the significant decrease of the area of lakes by changes in land cover and land use. Major anthropogenic impacts of the reduction are man made changes of the lakes, forest fires and the clear cutting of local woods and forests.

Conclusion

We conclude that the water household of dry areas is described as sensible to climatic fluctuation and extreme events. A missing management can lead to the degradation of water resources and to desertification especially during or after dry periods (Baumhauer, 2011). The changes in the level of the Caspian Sea and the large or small lakes without outlet to rivers (e.g. Lake Chany in the Barabinsk Steppe) are still interpreted often in the context of the inter-decadal climatic fluctuations. The fast and sometimes catastrophic anthropogenic impact by the overexploitation of water resources and the excessive water withdrawal from rivers or groundwater is obvious in multiple catchments in Central Asia. In the following most the regional studies show a speeding up of the shrinking of lake covers in size and also in the number of affected lakes.

Another key factor is the expected increase of extreme events and desertification processes related. Heat waves, drought, episodic and rare heavy rains are integral part of the described aridification process. Baumhauer (2011) underlines the importance of understanding the impact of extreme events to avoid desertification processes. Because of a quantitative or qualitative disturbance or degradation of hydro- and hydrogeological resources the risks on soil erosion are higher, especially when heavy or extreme rains coming up resulting soil erosion and lake sedimentation/siltation.

5.3 Climate change on the territory of Kazakhstan

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Introduction

The subchapter shortly summarizes the major challenges of climate change for Kazakhstan. It includes (a) a very brief introduction to the issue of climate change; (b) a short summary of the actual scientific predictions made by global physical climate modelling in the context of Intergovernmental Panel on Climate Change (IPCC); (c) the characterisation of key parameters (e.g. precipitation, temperature and extreme values) and predicted changes in these values for Kazakhstan overtime; (d) a short explanation of the IPCC SRES (Special Report on Emissions Scenarios) storylines on plausible but divergent futures (Economic, Environmental, Global, Regional); (e) a discussion on the basis of IPCC 2012 report on “Managing the risks of extreme events and disasters to advance climate change adaptation” about the prediction uncertainties for Kazakhstan due to insufficient data and studies required to enhance the quality of predictions for precipitation, temperature and wind in the context of potential extreme events like dry periods, flooding etc. and (f) a summary of current political and scientific activities of Kazakhstan to enhance the levels of certainty associated with predictions and hence Kazakhstan’s resilience to climate change.

According to the IPCC, a considerable increase in the surface air temperature during the 20th century in most regions of the Earth was observed. The warming continued from the early 20th century to the 1940s, and then it was followed by a slight cooling. From the mid-1970s to the present day there has been an intensive warming. The average temperature in the decade of 2002-2011 was 0,46 °C higher, compared to the average for 1961-1990. This ten-year period was warmest on a global basis since historic records and observations commenced. The period 2001-2012 includes the list of 13 warmest years since the beginning of instrumental observations (Folland et al.2001).

The prognosis and scenario carried out by the IPCC (2012) is based on a summarized trend of CO_2 equivalent increases as shown in Figure 5.3.1. The figure shows the different corridors when following different basic scenario assumptions.

Research on climate change assessment in Kazakhstan are conducted by various organizations including: the RES “Kazhydromet”, the Institute of Geography, the Kazakh National University named after Al-Farabi, the JSC “Zhasyl damy” (RSE “KazNSRIEC”) and others.

Figure 2 IPCC Projections of Average Temperature Increases

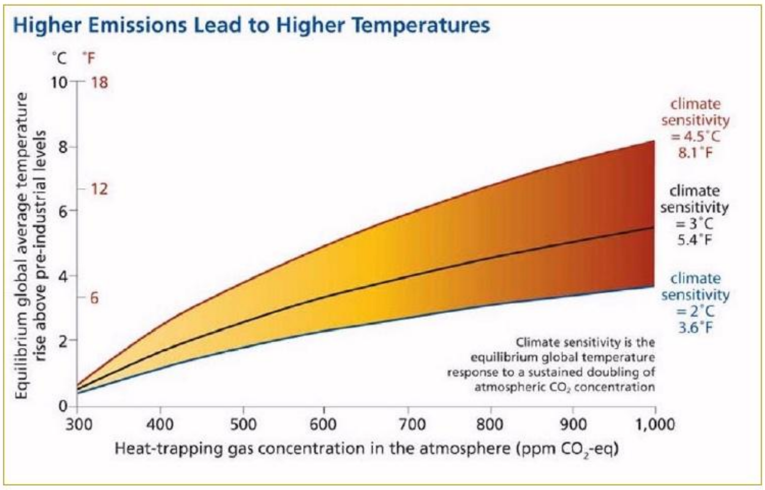


Figure 5.3.1 IPCC projections of the average temperature increases (IPCC, 2012)

Salnikov et. al. (2011) provides the results of the research on climate change assessment in Kazakhstan over the last 70 years. The following data is used as an input: (1) the series of average monthly air temperature values and monthly precipitation values from 1941 to 2011 based on the data from more than 190 weather stations. The time period 1971-2000 was used to define climatic reference periods and data from more than 110 weather stations were used to analyze trends; (2) the series of daily maximum and minimum air temperatures and rainfall for the period of 1941-2011 (more than 80 weather stations) are used for the analysis of weather extremes.

Basic approaches and methods

The mean annual values of the climate variables for the period of 1971-2000 were used as a reference period (i.e. the norm). Temperature and precipitation anomalies were regarded as deviations from this norm. Percentages of deviation of the norm were calculated, that is e.g. the proportion of percentages that were more or less than the calculated precipitation norm. The probability of not exceeding the norm characterizes the frequency (in %) for a corresponding anomaly values on the records.

An analysis of trends in surface air temperatures and precipitation levels was undertaken at the level of individual weather stations, for the average mean for the 14 Kazakh regions and for Kazakhstan as a whole. For summarizing, the data was approximated into a linear function using the least squares method. The average values for the meteorological variable anomalies of certain territories were calculated by averaging the anomaly data for each station. The indices of climate change, provided by the World Meteorological Organization (WMO), were used to assess the trends in extremes of precipitation and air temperature.

Results

Temperature

Figure 5.3.2 shows the number of ranked anomalies of average surface air temperature dated from 1940 to 2011 compared with the basic period of 1971-2000 (the average of data from 118 weather stations in Kazakhstan). The ten warmest years in Kazakhstan in descending order of anomaly values have been the years 1983, 2004, 2002, 2007, 1995, 2008, 1997, 2006, 2005, and 1999 (Table 5.3.1). The five warmest years in Kazakhstan are included in the list of the ten warmest years worldwide. During the period from 1940 to the present the coolest year in Kazakhstan was 1969, when the average anomaly for the annual air temperature was minus 2,5 ºC, and the warmest was 1983 with an anomaly air temperature of +1.6 ºC.

The evaluation of spatial-temporal changes in air temperature for the period 1941- 2011 was carried out both for Kazakhstan as a whole and for the administrative regions areas separately. A widespread increase in surface air temperature was observed throughout the territory of Kazakhstan in the last 70 years, referring to yearly – as well as to seasonal - averages. The average annual air temperature in Kazakhstan increased at a rate of 0,28 ºC every 10 years. The greatest warming was found in winter with an increase of 0,35 ºC/10 years. Increases were slightly lower in autumn and spring with values of 0,32 ºC/10 years and 0,27ºC/10 years, respectively, while the lowest rate of temperature increase was observed in summer with 0,18 ºC/10 years reported. In most cases, the trends are statistically significant (at a 95% confidence interval). At the same time, the contribution of the trend to the total variance of

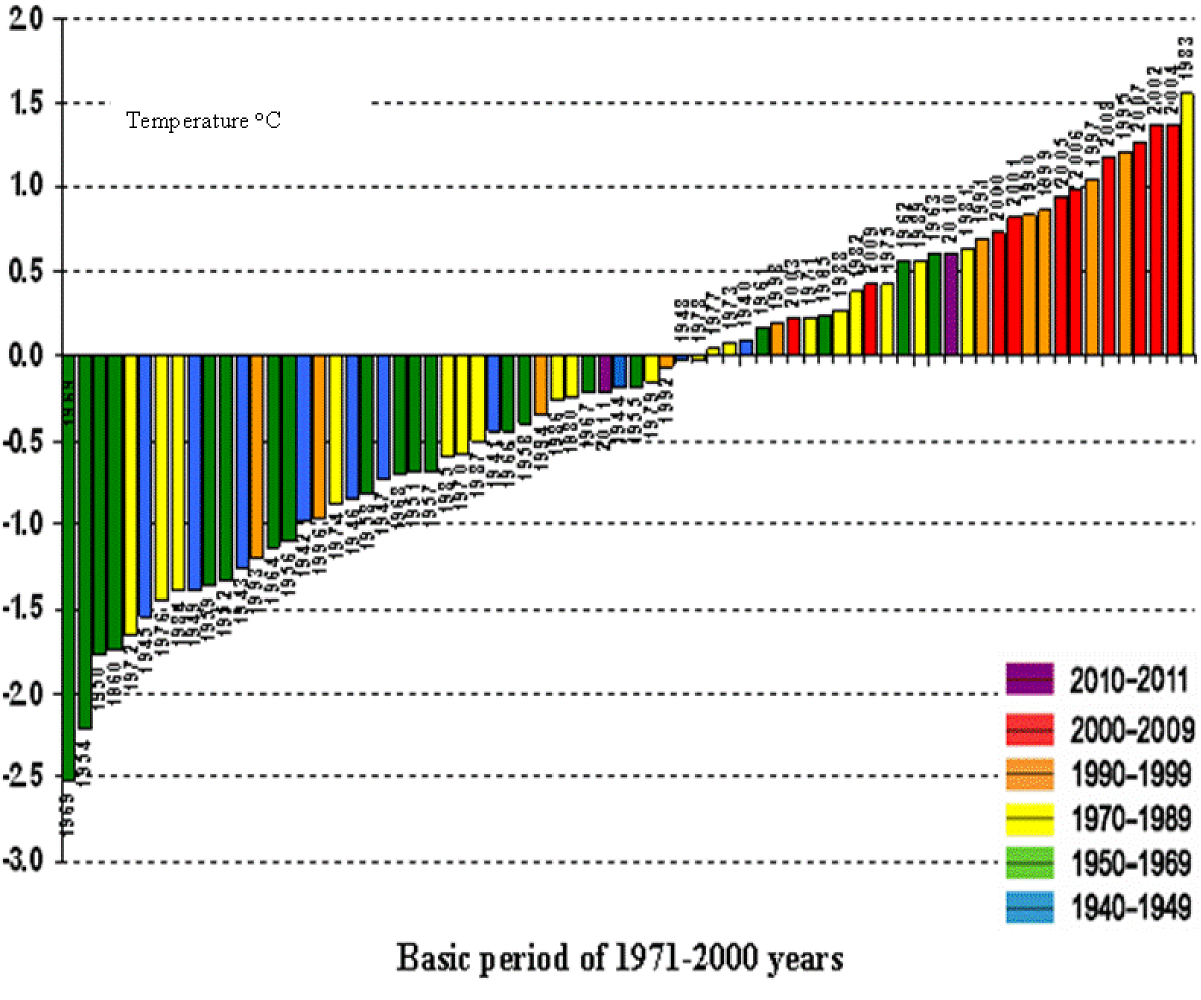


Figure 5.3.2 Yearly and decadal ordered anomalies of the average air temperature between 1940 and 2011 in Kazakhstan compared to the average of the reference period 1971-2000

average annual temperature is 37%, with seasonal variations ranging from 9 to 24 %. Results and trends identified clearly show positive responses to global warming in Kazakhstan. These processes are believed to be associated with an increased frequency of extreme weather events in Kazakhstan.

Table 5.3.1 The ranks of the warmest years for Globe and Kazakhstan

Rank	Globe	Kazakhstan	Anomalies of average annual temperature averaged for Kazakhstan's territory, °C
1	2010	1983	1,56
2	2005	2004	1,38
3	1998	2002	1,38
4	2003	2007	1,27
5	2002	1995	1,21
6	2009	2008	1,17
7	2006	1997	1,05
8	2007	2006	0,99
9	2004	2005	0,94
10	2001	1999	0,87

If considered by area, the highest rates of increase in the average air temperature were observed in the regions of West Kazakhstan (0,37 ºC/10 years). Meanwhile, the lowest increases were recorded for South Kazakhstan, East Kazakhstan, Almaty and Mangistau regions with increases of 0,24-0,26 ºC/10 years reported. In all other regions the growth in the average annual temperatures ranged between 0,28-0,31ºC/10 years. The highest rate of warming appears in winter in all regions of Kazakhstan. The increase in temperature in winter varies between 0,34-0,40ºC/10 years in the northern areas, 0,30-0,51ºC/10 years in the western, 0,34-0,35ºC/10 years in the central and eastern regions, 0,22-0,36ºC/10 years in the south. The lowest rates of warming are observed during summer periods varying from 0,12ºC/10 years in the Almaty region to 0,27ºC/10 years in the Jambul region. The rates of warming are consistent both in spring and autumn, and vary in regions ranging between 0,21-0,40ºC/10 years. Based on this data, the following observations are provided as a summary: a positive trend of average monthly air temperatures is recorded almost everywhere. The exception is selected weather data in certain months of the year, but all negative trends are statistically insignificant at the 95% level. The daily peak values of surface air temperature in most weather stations, in all regions of Kazakhstan, have a high tendency to increase. However, statistically significant trends are characteristic for the East Kazakhstan territory, the Pavlodar and the Kyzylorda regions. Daily peak temperatures rise by 0,01-0,40ºC/10 years, with some stations showing an increase of 0,41-0,60 °C/10 years.

The statistically significant upward trend in the number of days with an average air temperature higher than 35°C has been observed throughout the Western and Southern regions of Kazakhstan showing an increase in the number of days from 1 to 3 days for every 10 years. The periodicity of hot days was virtually unchanged in the northern regions during the period of 1941-2011. The frequency of frosts, when daily minimum temperatures fall below 0°C, faces a tendency to reduce in occurrence in almost all territories. The decline in the periodicity of frosts is highly significant in the mountains and mountainous regions of southern Kazakhstan, with a reduction in the number of frost days of 5-6 days/10 years. The reduction in the number of such days in all other regions is 1-4 days/10 years.

Precipitation

In contrast to the trends and patterns in air temperature reported, the changes in precipitation in Kazakhstan during the same study period present a more complex picture. Based on data from 121 stations, the linear trend was initially assessed by ranking monthly, seasonal and annual precipitation values. Some insignificant increases of precipitation were recorded in some regions of Kazakhstan, with reductions reported for others. The time series analysis of annual precipitation totals was carried out for the period of 1941-2011, calculated in relation to the reference period of 1971-2000 and again spatially averaged throughout the territory of Kazakhstan. On average throughout Kazakhstan, there is a weak trend (statistically insignificant) on the reduction in the amount of rainfall in all seasons of approximately 0.7 mm/10 years. The exception to this trend is in winter, when a statistically significant increase of precipitation of 1.7 mm/10 years is reported. The amount of annual precipitation decreases slightly by 0.5 mm/10 years (equivalent to 0.3 %).

If we consider the changes in precipitation by region, a slight increase in the annual precipitation (0,2-5,1 mm/10 year) was observed in Pavlodar, Aktobe, Karaganda, Mangistau and Almaty regions, with a slight decrease (0.2 - 5.5 mm/10 years) observed in Akmola, Zhambyl, Kyzylorda, Kostanai, South Kazakhstan, West Kazakhstan, Atyrau and East Kazakhstan regions. All these annual trends are statistically insignificant.

The analysis of trends in rainfall extremes for the period between 1941-2011 years was carried out based on the use of representative indices proposed by the WMO. The values of maximum daily rainfall in Kazakhstan have not changed. Throughout all regions of Kazakhstan only weak trends are found, which reflect both reductions and increases in the maximum daily amounts of precipitation of ± 0,1-1,0 mm/10 years. The analysis of the trend, in terms of shares (%/10 years) of extreme amounts of rainfall in the annual totals, shows some weak trends in Kazakhstan, with again both decreases and increases of 1-2%/10 years identified. It is important to note that the trends of decreases were observed more in the northern regions of Kazakhstan, while trends of increases were found in the southern regions. The increase in extreme amounts of precipitation in summer leads to an increased risk of erosion processes, and risks of mud floods in mountainous areas. There is a tendency of a reduction in the maximum duration period without precipitation in most parts of the Kazakhstan. Statistically significant trends of decrease are observed in the north of the country – for 1-4 days for every 10 years. In the rest of the regions the trends are statistically insignificant.

Climate change forecasts and its consequences

The climate scenarios for Kazakhstan are based on the results of various global climate models and take into account the scenarios of greenhouse gas emissions developed by the IPCC. Using this data, it was possible to obtain a range of possible climate changes in Kazakhstan for different time periods of this century (Table 5.3.2) (Anonymous, 2009a; Anonymous, 2009b.)

Temperature

We should expect a further increase in surface air temperature in Kazakhstan – by the end of the century, the annual average temperature could rise by more than 4 °C; the increase of the periodicity of hot days and duration of heat waves are possible.

Precipitation

The rainfall change scenarios are variable, suggesting both increases in winter rainfall, and reductions in some areas in summer rainfall levels by the end of the century.

Table 5.3.2 Probable average climate change predictions in the territory of Kazakhstan Salnikov et al (2011)

Change	Period		
	By 2030 (2016-2045)	By 2050 (2036-2065)	By 2085 (2071-2100)
Average annual temperature	+1,4 °C (+1,3 ÷ +1,9 °C)	+2,7 °C (+2,3 ÷ +3,5 °C)	+4,6 °C (+3,8 ÷ +5,9 °C)
Amount of annual precipitation	+ 2% (-2%÷ +7%)	+ 4% (-3%÷ +13%)	+ 5% (-5%÷ +20%)
Amount of precipitation in winter	+ 8% (+5%÷ +11%)	+ 13% (+8%÷ +18%)	+ 24% (+11%÷ +33%)
Amount of precipitation in summer	+ 5% (+1%÷ +14%)	+ 0% (-11%÷ +18%)	-11% (-28%÷ +18%)

Moisture conditions

Due to the fact that most regions in Kazakhstan have droughts because of small amounts of precipitation, an increase in air moisture levels of 20 % (driven by warmer air temperatures) can play an adverse role for ecosystems, agriculture and water resources as a result of increased evaporization. The main effect of the changes in temperature and precipitation will be a shifting of the dry moisture zone borders towards the north of Kazakhstan.

Melting of glaciers

The degradation of mountain glaciers in the East and South-East of Kazakhstan will continue if the upward trend in air temperatures is maintained. The majority of mountain glacier systems may disappear by the end of the 21st century.

River runoff (Flow volume of surface runoff entering rivers)

The river runoff of the majority of Kazakh Rivers has changed insignificantly over the last 50-60 years. An exception is the rivers of Lake Balkhash basin, where the runoff has increased by 8 %, mainly due to the melt water of mountain glaciers. By 2050, in accordance with the climate scenarios, the river runoff of plain rivers will reduce by 4-8 %, but in the majority of the basins of mountain, rivers it will increase by 1-13 %. However, the disappearance of small glaciers will lead to the drying-up of small mountain rivers in the summer. The annual distribution of river runoff will changes: the river runoff will increase in the spring and early summer months (May-June) and decrease significantly in the later summer months (July-August). The projected change in the seasonal rainfall regime will also have an impact: an increase in snow storage will be caused by increase in winter precipitation in mountainous areas, which will lead to increased runoff in the spring. According to estimates, as a result of deglaciation the river runoff in the northern slope of Ile Alatau will decline by the end of the 21st century, by more than 15 % percent (Anonymus, 2009a).

Mudflow activity

An increase in the mudflow activity (of rain and glacial origins), is inevitable given the fact that the climate will warm by 2-3 °C. By 2050 year, the upper borders at which torrential rain events that can generate mudflows will increase in to an elevation of 4000-4200 m and the relative activity of torrential rain genesis in the rivers will increase by many times. The volumes of cavities in the moraine-glacial complexes will increase due to the heat generated by melting glaciers.

The report on extreme events (IPCC, 2012)

As demonstrated earlier in this text, the occurrence of extreme events will change as a result of climate changes. It is essential to state that the knowledge about the future changes are not yet validated and further intensive research is needed in this field. The analysis of current and climatic data available for Germany by Rannow et al. (2010) indicates that the sensitivity of various German districts to a range of climatic issues will change (Table 5.3.3). This analysis has led to multiple German districts being required to adapt to a wide range of possible climate change related impacts using instruments of spatial planning and governance. Comparable analysis is needed to enable both the impact of the climatic predictions on all aspects of water cycle in Kazakhstan to be better understood, and appropriate responses implemented at national to local scales.

Table 5.3.3 Sensitivity of German NUTS 3 districts against climate change related impacts (Rannow et al. 2010)

Sensitivity against:	**Number of NUTS3 districts with classification**		
	low	**middle**	**high**
longer and more intensive heat waves	*103*	121	215
increase of heavy rain and flash floods	254	94	91
increase of large river flood events	*98*	139	202
increase of storm surges	*404*	16	19
increase of mass movements	*239*	0	200
increase of forest fires	*155*	183	101
more frequent destruction of infrastructure	150	102	187
increased loss of soil by water erosion	159	200	80
loss of species and biodiversity	*170*	168	99
increased fluctuation of the ground water level	-	-	-
fluctuation in the availability of water for industrial use	*209*	69	122

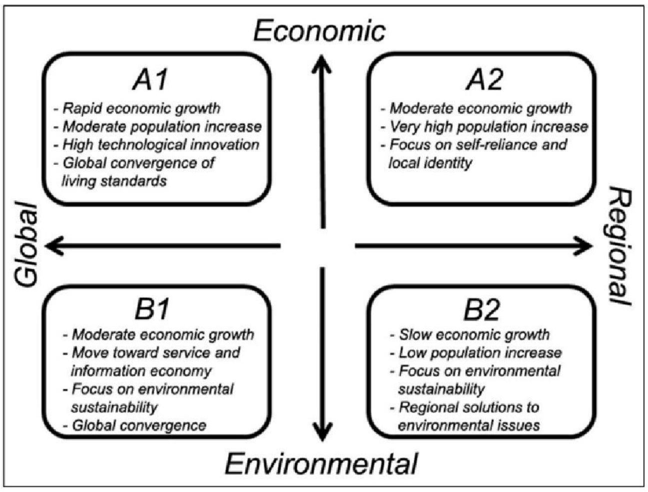
Adapting to climate change

Climate change storylines for climate change

The IPCC (2012) uses different integrative storylines oriented on two axes: the first relates to the economic versus environmental priorities applied by the governance of multiple nations and the second to the global versus regional development aspects. The different orientations for the scenario estimations on climate change describe divergent and plausible futures for the earth (Figure 5.3.3).

The Framework Convention of United Nations on Climate Change (FCUNCC) was ratified by Kazakhstan in May 1995, and the Kyoto Protocol was ratified to the Framework Convention in April 2009. In September 17, 2009, Kazakhstan became an official Member of Kyoto Protocol.

The assessment of vulnerability of Kazakhstan to climate change was carried out as a part of preparation for the National Concept of Kazakhstan on adaptation to climate change (Anonymous, 2010.).



IPCC SRES storylines are oriented along two axes: 1) economic vs. environmental priorities, and 2) global vs. regional development. The four scenarios each describe divergent, yet plausible futures.

Figure 5.3.3 IPCC SRES storylines for climate change scenario and analysis (IPCC 2012)

Normalized regional coefficients, based on four groups of indicators, were used for aggregated assessment of vulnerability of Kazakhstan's regions to climate change. The following aspects are described approximately:

- the economic potential of adaptation;
- the sensitivity to climate change;
- the climate change;
- the emergency exposure.

Based on data available in the literature, Almaty, South Kazakhstan, North Kazakhstan and Zhambyl regions are estimated to be the most vulnerable regions to climate change (Figure 5.3.4). These most vulnerable regions are located in the south, south-east and north of Kazakhstan. Their vulnerability is related to the low-income of local populations largely dependent on low-productivity agriculture in areas with inadequate water supplies. Water resources in general are becoming the most powerful factor influencing vulnerability within both social and production spheres of the republic. Figure 5.3.4 shows the results of a process where regions were ranked in relation to performance against four summary indicators (economic potential for adaptation; climate change; sensitivity to climate change;; exposure to risk of emergency situations). The first four columns are highlighted to indicate regions anticipated to suffer highest levels of vulnerability to climate change.

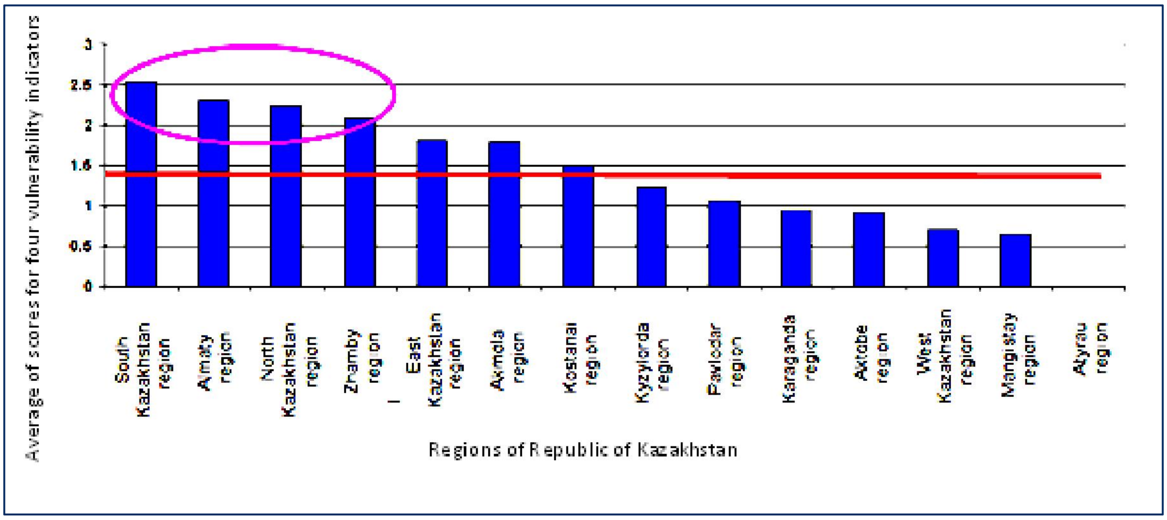


Figure 5.3.4 Ranking regions of Kazakhstan in terms of their vulnerability to climate change (adapted from Anonymous, 2009a)

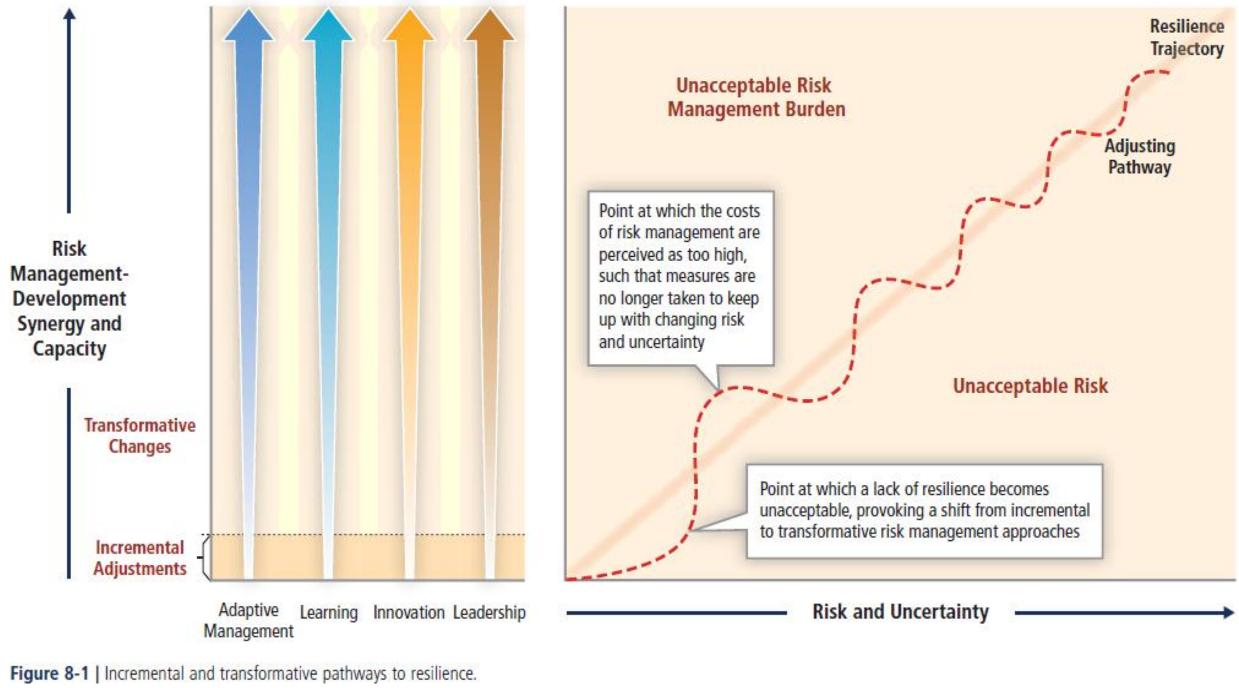


Figure 5.3.5 Incremental and transformative pathways to resilience when adapting on climate change (IPCC 2012)

Conclusion

Adaptation to ongoing climate changes provides an opportunity for science, governance, practice and stakeholders to act in a way to manage change by avoiding unacceptable risks (IPCC 2012). The transformation of society to adapt to climate change is achieved by movement along incremental and transformative pathways towards a resilient future (Figure 5.3.5). A high need of development of risk management capacities is needed.

5.4 Groundwater systems in the context of Kazakhstan economy

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Introduction

Groundwater plays an important role in the economic development of the Republic of Kazakhstan (RK) supporting a range of vital activities. In particular, fresh and slightly brackish groundwater is of the utmost importance. Fresh groundwater is the scarcest part of the RK water resources; therefore they should be used rationally for domestic water supply. It is important to note that currently domestic water supplies for 80 % of Kazakhstan cities are sourced from groundwater resources. For this reason, maintenance and protection of fresh groundwater to ensure the country population needs should be considered as the most important social problem (Dostay, 2012; Iskakov & Medeu, 2007). Taking into account hydro-geological conditions of the territory of Kazakhstan, hydro-geological regions, groundwater basins of first (province), second (sub-province) and the third local level are presented in Table 5.4.1 (Akhmedsafin, al., 1979; Smolar, et al., 2012).Using the “Classification of Exploitable Resources and Prognostic Resources of Groundwaters” (Water Code, 2000) exploitable resources of groundwaters are defined (see Table 5.4.1) as category A, B, C_1, C_2 and P as follows:

- Category A: stocks identified on the basis of activities that allow reliable prediction of their quantities, quality and operating conditions.
- Category B: stocks identified on the basis of studies, which allow a reliable assessment of their quality and quantity and forecast of their operating conditions.
- Category C_1: stocks identified the following activities, which enable an approximate assessment of their quantity, quality and operating conditions for the settlement term of water consumption.

- Category C_2: stocks are established on the basis of general geological and hydro-geological data supporting an approximate identification of their quantity, quality and operating conditions.
- Category P: expected operational resources are estimated within large hydro-geological structures on the basis of the general geological and hydro-geological representations, theoretical prerequisites and using results of regional estimates of expected operational resources of the groundwaters (often carried out with application of mathematical modelling methods).

As noted below, the main groundwater deposits in Kazakhstan are utilised for domestic water supply (DWS), in some cases for drinking water, and for other purposes including irrigation (IR) or technical- industrial water supply (TIWS). The diverse hydro-geological and natural-social conditions of Kazakhstan territory suggest different degrees, to which its groundwaters have been explored. Table 5.4.1 reflects the main resources of explored groundwater (21.026,58 thous.m^3/day or 7,64 km^3/year), concentrated in the southern part of Kazakhstan, in the Zhetisu-Tien-Shan hydro-geological region. Moreover,

Table 5.4.1 Hydro-geological zones of Kazakhstan and current status of exploitable resources of groundwaters (km^3/year)

Regions	First level basins (province level)	Number of groundwater deposits	Explored groundwater resources ($A+B+C_1+C_2$)	
			Total volume	Mineralization Up to 1 g/l
Skif-Turan	Ustirt, Amudarya, Syrdarya, Aral-Torgay-Shu-Sarysu, Mangystau	229	2,46	1,80
West Siberian	West Siberian	273	1,92	1,64
Eastern European	Western Russian compound basin, Preduralsky, Caspian	211	0,63	0,41
Zhetisu-Alatau-Tien Shan	Central Tien-Shan, northern Tien-Shan, Zhetisu-Alatau-Balkash	121	7,67	7,64
Yenisei-Altay-Sayan	Sauyr-Tarbagatai, Zahrmino- Rudny-Altay, Sayan-Altay	99	1,27	1,26
Central Kazakhstan	Shyngys Kokshetau, Teniz-Qorgaljyn, Ulytau-Zhezkazgan, Balkash, Shu-Ile	306	1,39	0,74
Taymyr-Ural	Bolsheuralsky	43	0,09	0,03
Total for Kazakhstan		1282	15,44	13,52

fresh groundwaters explored here are used mainly for irrigation (at rates of 15.088 thousand m^3/day or 5,51 km^3/year) and DWS (5.525 thousand m^3/day or 2.02 km^3/year) (Smolar et al., 2012). The second richest region in terms of groundwaters is Skif-Turan , with explored resources of 6.739, 84 thousand.m^3/day (2,46 km^3/year), including for DWS – 3.342,51 thousand.m^3/day (1,22 km^3), for IR – 2.365,87 thousand.m^3/day (0,86 km^3) and TIWS – 1.023,78 thousand m^3/day (0,37 km^3/year). The main groundwater resources are concentrated in Syrdarian and Shu-Sarysu artesian basins. In the remaining four hydro-geological regions, available resources are not very large in comparison with the above groundwater reserves and are not usable for domestic water supply because of their high mineral content (Smolar et al., 2012).

Groundwater resources of Kazakhstan

Assessment and regulation of groundwater resources of Kazakhstan has been conducted (Medeu et al, 2012; Dostay, 2012) for all 8 hydro-economic basins (Figure 5.4.1). The main resources of fresh groundwater (59%) are concentrated in the Southern Region of the Republic – in Almaty, Zhambyl, Kyzylorda and South Kazakhstan oblasts. The Eastern Region (East Kazakhstan oblast) accounts for 14% of groundwater reserves, central region (Akmola, Karagandy oblast) for a further 10% and the northern region (Kostanay, North Kazakhstan, Pavlodar oblasts) for approximately 1,2%. The Western region (Aktobe, Atyrau, Mangystau, West Kazakhstan oblasts) holds 6% of the total quantity of groundwaters with mineralization levels of up to 1 g/dm^3 reported throughout Kazakhstan. The deficit of fresh groundwater resources is observed in Atyrau, North Kazakhstan, Mangystau, Kostanay and Akmola oblasts (Iskakov and Medeu, 2007; Akhmedsafin, Shlygina, 1965; Akhmedsafin et al., 1979).

The total volume of exploitable groundwaters of Kazakhstan constitutes 42.306,44 thousand m^3/day (equivalent to 15,44 km^3/year) or approximately 24% out of the total resources with mineral content up to 10 g/l (176.105 thousand m^3/day) and 38% out of prognostic resources with the mineralization up to 1 g/l (110.789 thousand m^3/day) (Table 5.4.2).

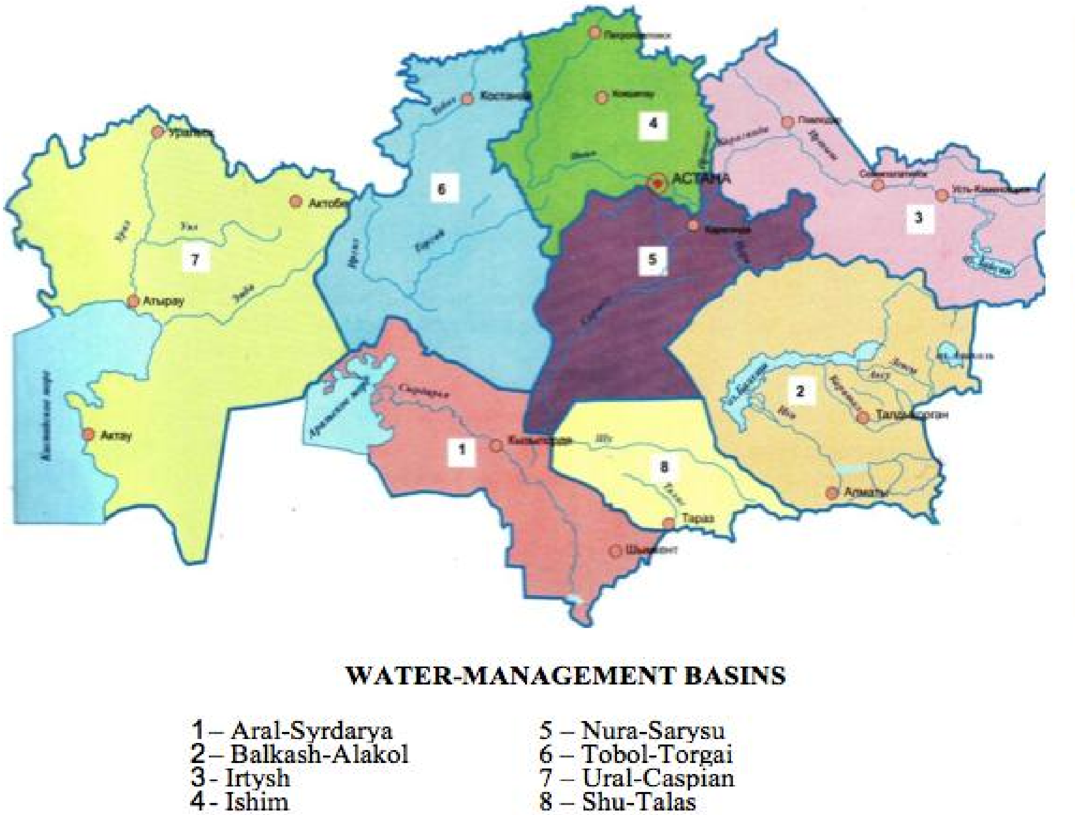

Figure 5.4.1 Map of the 8 water management basins of the Republic of Kazakhstan

Among the exploitable resources, fresh waters constitute 37.042,93 thousand m^3/day or about 88% of the total quantity. According to the intended purpose the explored resources are divided as follows, thousandm^3/day:

- *domestic water supply (*DWS*)* – 15.793,87;
- *technical- industrial water supply (*TIWS*)* – 3.835,35*;*
- *irrigation (*Ir) – 22.639,84*;*
- *balneological purposes (mineral waters)* – 37,38.

Table 5.4.2 Current and predicted status of established exploitable resources of groundwaters of the Republic of Kazakhstan (km^3/year) (Groundwaters of Kazakhstan,1999).

Hydro-economic basins	Exploitable resources		Prognostic resources	
	Mineralization			
	Up to 10 g/l*	Up to 1 g/l*	Up to 10 g/l*	Up to 1 g/l*
Aral-Syrdarya	1,134	0,691	9,2902	3,6752
Balkash-Alakol	7,258	7,003	20,0121	15,5125
Ertish	2,868	2,788	9,5637	8,5159
Esil	0,164	0,049	2,3135	1,1187
Zhayik-Caspian	0,966	0,600	7,3733	2,2225
Nura-Sarysu	0,824	0,491	3,3144	2,4549
Tobyl-Torgay	0,479	0,213	3,6205	0,9425
Shu-Talas	1,748	1,686	8,791	5,996
Total for Kazakhstan	**15,441**	**13,521**	**64,28**	**40,44**

Key: Concentration of <1 g/l is considered acceptable for drinking water purposes

Groundwater quality

Groundwaters, particularly shallow subsurface waters, have close hydraulic connections with surface waters, whereby groundwater quality is strongly dependant on the surface water quality. Ground water quality of exploited deposits basically complies with the Kazakhstan drinking water standards (State Water Cadastre, Surface Water and Groundwater Use and Quality, 2008). However several parameters (e.g. hardness, colour, suspended solids, manganese, iron and ammonium concentrations) of groundwaters in most water intake sites do not meet drinking water requirements. Surveys of centralized domestic water supply sources in Kazakhstan show that almost 30 % of water samples taken from these sources do not comply with drinking water standards (State Water Cadastre; Surface Water and Groundwater Use and Quality, 2008). The main reasons for the breach of standards are elevated concentrations of iron and associated elevated levels of suspended solids and colour. In general almost half of the examined water samples exceeded standard iron concentration set for drinking water (MPC[10]=0,3 mg/dm^3). In 13% of cases, the iron MPC was exceeded by a factor of 5 (or more). Hence, drinking water quality is a serious issue in rural areas where the population use drinking water from shallow wells. At a national level, it is estimated that 30-40 % of wells utilised for the supply of drinking water do not meet the required sanitary norms. On an annual basis, the sanitary-epidemiological service examines more than 50,000 sources of decentralized drinking water supply (usually informally dug wells). Water samples do not meet sanitary standards in approximately 21% of samples. About 50% of water samples do not meet sanitary and chemical standards and 40% of samples fail to meet hygienic standards set for microbiological content (Smolar, et al., 1997).

Analyses of groundwater pollutants have been carried out in all the main river basins of Kazakhstan (see Figure 5.4.1 and Table 5.4.3).

Environmental monitoring of groundwater shows that, of the 803 groundwater deposits in Kazakhstan, 112 reserves (13.9%) are contaminated, of which about 40% are classified as dangerous or extremely dangerous.

Groundwater use in the Republic of Kazakhstan (RK)

According to surveys undertaken by the Water Resource Committee under the Ministry of the Environmental Protection and Water Resources of RK, the river basins Balkash-Alakol (888,55 thousand.m^3/day), Aral-Syrdarya (559,97 thous.M^3/day) and Zhayik-Caspian (526 thousand m^3/day) basins report the highest volumes of groundwater extraction. Household needs account for the main intake of groundwaters (Table. 5.4.4). During severe shortages of drinking water (i.e. during seasonal droughts) increased usage of groundwaters is observed for drinking and household purposes. Across Kazakhstan, current water consumption of groundwaters constitute 56% of total water consumption on average, although in areas with drinking quality groundwaters the percentage of their use must be much higher.

[10] MPC – maximum permitted concentration

Table 5.4.3 Overview of the levels of contamination determined in groundwaters (GW) used for drinking water in the river basins of Kazakhstan

Agricultural basins	Number of GW deposits	Exploitable GW resources (km³/year)	Number of GW resources with contamination	Exploitable GW resources (km³/year)	Contamination level of ground waters (GW)*		
					Moderately dangerous*	Dangerous*	Extremely dangerous*
Aral-Syrdarya	46	2,16	15	0,415	9	1	
Balkash-Alakol	73	4,73	11	1,47	8	3	
Ertish	104	3,01	19	2,27	4	6	9
Esil	118	0,294	9	0,111	6	3	
Zhayik-Caspian	228	1,38	15	0,414	8	4	3
Tobyl-Torgay	127	1,10	28	0,515	25	3	
Nura-Sarysu	62	0,96	14	0,485	6	1	7
Shu-Talas	45	2,16	6	2,12	6		
Total Kazakhstan	**803**	**15,79**	**112**	**8,99**	**72**	**21**	**19**

Agricultural basins	Total extraction	Groundwater use by various economy branches						Total use
		Domestic	Industry	IR	Agricultural water supply	Flooding of pastures for IR	Other	
Aral-Syrdarya	299,8	52,85	45,24	0,00	93,25	23,95	0,00	204,4
Balkash-Alakol	495,0	215,0	63,10	7,84	34,22	3,13	0,00	324,3
Ertish	267,0	87,50	65,79	0,22	25,41	11,48	0,00	195,2
Esil	47,67	5,63	2,21	0,00	29,15	0,98	0,00	39,19
Zhayik-Caspian	213,958	60,9	47,67	0,17	8,18	14,19	0,00	192,0
Nura-Sarysu	123,4	52,75	14,39	0,00	9,13	0,00	0,52	102,1
Tobyl-Torgay	101,3	4,64	0,86	0,00	1,12	0,00	0,00	20,64
Shu-Talas	131,1	43,59	15,75	0.00	4.79	5.11	0.00	69.19
Total for Kazakhstan (km³/year)	**1,679**	**522,8**	**255,0**	**8,03**	**197,3**	**57,96**	**0,52**	**1,147**

Table 5.4.4 Overview of the current uses of groundwater by various economy sectors of the RK, million.m³/year

On average the consumption of explored groundwater makes up 8% of the total explored resources of groundwaters in Kazakhstan. In several administrative oblasts (Atyrau, Akmola, Zhambyl, Kyzylorda, Kostanay, Pavlodar, North Kazakhstan) it is below 5%. Only in Mangystau oblast water extraction makes up 23,7% of the exploitable resources.

Conclusion

Since 1993, a decrease in the volumes of water intake in almost all the areas of water management has been observed due to economic downturn (Dostay, 2012). Currently, the percentage of groundwater use by different sectors of the economy out of the total water intake is as follows: DWS - 74.8%; TIWS - 17.0%; Ir - 3.0 % and pasture irrigation - 5.2%. The main consumers of drinking water sourced from the groundwaters are the population of cities and workers' settlements. Rural population accounts for about 26% of the total groundwater consumption. The greatest use of groundwater is specific for Almaty, East Kazakhstan, South Kazakhstan and Karagandy regions - from 886 to 252 m^3/day. The lowest uses are reported to be in North Kazakhstan, West Kazakhstan, Mangistau and Atyrau regions, – where abstractions range from 64 thousand to 2 thousand m^3/day. For industrial-technical purposes, groundwaters are mostly used in Karagandy, East Kazakhstan and Zhambyl oblasts and, to a lesser extent, in North Kazakhstan, Akmola, West Kazakhstan and Pavlodar oblasts. In total groundwater volumes currently abstracted and used for a variety of different purposes do not exceed 10 % of the potential exploitable resources. An analysis of the spatial distribution of groundwater in Kazakhstan indicates the need of its re-distribution from the Southern and Eastern regions with relatively large groundwater reserves, to waterless regions of Kazakhstan (e.g. its deserts).

5.5 Study of Physical and Chemical Properties of Water Bodies of Kazakhstan

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Introduction - The concept of chemical composition of natural waters

The chemical composition of natural waters is a complex of mineral and organic substances in various forms of ion-molecular and colloidal states. The chemical composition of natural waters can be divided into the following five groups (Romanova, 2004):

- Major ions (the content in the largest amount of CL, SO^{-2}_4, HCO^-_3, CO^{2-}_3, Na^+, K^+, Mg^{2+}, Ca^{2+});
- Dissolved gases (O_2, N_2, CO_2, H_2S and others);
- Hydrogen parameter (pH);
- Biogenic elements (compounds N, P, Si, Fe);
- Organic substances;
- Micronutrients.

Primary sources of water composition are:

- Gases emitted from the Earth's interior in the process of mantle degassing.
- Products of chemical interaction of water with crystalline - volcanic rocks (granites, sionites, balzamites and others).

Two factors determine the formation of natural water chemical composition: direct and indirect. Mountain and sedimentary rocks, soil, living organisms and human factor are direct factors. Climate, relief and water regime refer to indirect factors. Considerable chemical composition differences in the atmospheric water, surface (rivers, lakes, seas, bogs, oceans) water and groundwater should be observed because of sharp difference in conditions, under which natural waters get formed. The common fact is that mineral or main components constitute the bulk of the composition of SiO^{2-}_3, HPO^{2-}_4, CO^{2-}_3, Cl, HCO^-_3, SO^{-2}_4, Fe^{3+}, Ca^{2+}, Mg^{2+}, Na^+, K^+. 90 - 95% in these fresh water components, 99% are in saline water and brines.

Contribution of chemists in the development of Kazakhstan hydrochemistry

Figure 5.5.1 B.A. Beremzhanov

Beremzhanov B.A. (1911 – 1985) was an eminent scientist in the field of inorganic chemistry and hydrochemistry. His name is associated with the development of the continental salt formation theory. B.A. Beremzhanov left a great legacy in science that is being successfully developed by his numerous students at the present time. The following scientists, graduated from KazNU named after Al – Farabi, are included into the list of chemists who have made valuable contributions to the development and establishment of hydrochemical science in Kazakhstan. They are Snegireva N.E., Ibragimova M.A., Tokseitov H.K., Kruchenko S.S., Chirkova G.D., Romanova S.M., Taranina G.V., Kunanbayeva G.S., Kazangapova N.B., Bataeva G.O. etc. The range of creative interests of Beremzhanov B.A. is unusually broad: besides applied research on the practical use of natural salts, there is extensive theoretical work on the study of continental salt genesis. This enormous work, based on multiple investigations of the water of the Lake Balkhash, Alakol and around 100 salt lakes, 15 rivers and 39 inflows, was summarized by him in the theory of continental salt formation (Romanova, 2004).

Physico-chemical Characteristics of Natural Waters

Sources of dissolved gases in natural waters are:

1. Atmosphere (N_2, O_2, Ar, CO_2);
2. Biochemical processes (CO_2, CH_4, H_2, N_2);
3. Mantle degassing and metamorphic rocks (CO_2, CO, H_2S, H_2, CH_4, NH_3, HCL).

The solubility of gases in water depends on the chemical nature, temperature, pressure, water mineralization (Table 5.5.1).

General indicators of natural waters quality

General mineralization

Water mineralization is the sum of all mineral substances in mg/l or mg/dm^3 found during the analysis resulting in equilibrium between oxidation and reduction in the water, the potential difference between the Σ u - the amount of ions - actually it is the sum of all kinds of ions in mg/l or mg/dm^3.The chemical composition of the lake waters depends on the composition of surface and groundwater feeding the lake and mineralization depends on its regime.

pH

Ion concentration in natural water is very low but their value is significant. There are standard methods for pH determination in natural waters. Humus and other organic acids are the sources of H^+ ions. The hydrolysis of heavy metals leads to the hydrogen emergence in ions solution: $Fe^{2+} + SO_4^{2-} + 2H_2O \rightarrow Fe(OH)_2 + SO_4^{2-} + 2H^+$.

Oxidation-reduction potential

In case a reversible oxidation-reduction reaction takes place, solution and the plate occurs. It characterizes the magnitude of oxidation-reduction potential (Eh). The value of the redox potential is associated with the oxygen content in water.

Table 5.5.1 Solubility of some gases at t = 0^0 C and at pressure of 1 atmosphere (mg/l)

Gas	Solubility	Natural limits of concentration in surface waters	Gas	Solubility	Natural limits of concentration in surface waters
O_2	49,2	0-14 10-16	CO_2	17,1	CO^2: River 1-30 mg/l, lakes 0.1-30 mg/l
N_2	23,6		CH_4	55,6	
			H_2S	46,3	

Physico-chemical parameters of water quality are hydrogen ion concentration (expressed as pH), salinity, solids, total hardness, biogenic elements, trace elements and other. These parameters are characteristic of a water body in its natural state. Table 5.5.2 shows typical ranges of the basic physical and chemical characteristics of the water systems of Kazakhstan

Organic substance

In natural waters, the organic substance is very diverse: numerous carbohydrates, protein substances, amino acids, esters, fats, aldehydes, etc are to be found there. When natural waters are polluted by industrial and domestic wastewaters, the concentration significantly increases. The OS presence in water is one of the first indications of natural water pollution. Oxidation of water, the degree of which changes according to oxygen quantity that is consumed for the oxidation of organic substances in 1 liter, is applied to estimate

Table 5.5.2 Basic physico-chemical parameters of natural waters

Physico-chemical parameters	Average numerical values	Example
Hydrogen parameter (*pH*)	Rivers and lakes 6,8-9,5	Balkhash lake 8,2 – 9,25 (Romanova, 2003) Kopa lake 7,23 – 9,56 (Kazangapova, 2010) Zhalanashkol lake 7,6 – 8,6 (Philonets, 1981) Kamyslybas lake 7,3 – 8,2 (Philonets, 1981) Ili river 8,10 – 8,65 and shallow collectors 7,60 – 8,60 (Romanova, 2003)
Oxidation-reduction potential (Eh)	*In natural water it fluctuates from* -400 to +700 mV.	The content of dissolved oxygen is the main factor that has an impact on the magnitude of Eh in surface waters.
Organic substance (OS)	The concentration of organic substances in natural unpolluted waters is not high: in rivers it is on the average 20 mg/l	Lake Balkhash 1,9 – 14,5 mgO/l (Kazangapova, 2003) Ili, Karatal, Lepsy rivers 10,8 – 11,4 mgO/l (Romanova, 2003)
General mineralization	Rivers – up to 1 g/l, lakes – from 1 to 25 g/l	Lakes with high salinity of 25-50 g /l
Biogenic elements		
Ammonium ions (NH_4^+)	The ion concentration fluctuates from 0,01 to 0,5 mg N/l.	Borovoye Lake 0,01 – 0,05 mg N/l (Kazangapova, Romanova, Nurmukhanbetova, 2010) Balkhash lake 0,08 – 0,34 mg N/l (Kazangapova, 2003)
Nitrites (NO_2^-)	0,001-0,05 mg/l	Balkhash lake 0,006 – 0,014 (Romanova, Kazangapova, 2003)
Nitrates (NO_3^-)	The nitrate concentration fluctuates within 0,01-0,1 mg/l	Balkhash lake 0,017 – 0,019 (Romanova, Kazangapova, 2003)
Phosphates	The phosphate concentration in natural waters is very low: 0,01 rarely 0,1 mg/l.	Balkhash lake 0,013 – 0,028 (Romanova, Kazangapova, 2003)
Silicon	In surface waters the silicon concentration is 1-10 mg/l,	In shallow collectors 0,8 – 4,2 mg/l, Balkhash lake 3,5 – 4,9 mg/l
Microelements		
Fluorine	Fluorine content in rivers and freshwater lakes is 0,05 - 1 mg/l;	Balkhash lake 3,56 – 4,5 mg/l (Romanova, 2003)
Boron	Limits of variations of the boron content in the river waters are 38-200 mkg / l	Ili river 50-340 mkg/100 g (Romanova, 2003) Balkhash lake from 0,22-0,34 mg/l in I area to 2,45-2,70 mg/l in VIII hydrochemical area (Romanova, 2003)
Bromine	In freshwaters - from 1 to 200 mcg/l.	In shallow collectors 130 – 640 mcg/l, In groundwater 177 – 220 mcg/l (Romanova, 2003)
Iodine	The average concentration of iodine is 5-10 mcg/l	Balkhash lake 84 – 88 mcg/l, groundwater 60 – 125 mcg/l (Romanova, Kazangapova, 2003) In groundwater 60 – 125 mcg/l (Romanova, 2003)

organic substance. Oxidability is the quantity characterizing the content of organic and mineral substances in water, oxidized (under certain conditions), by one of the strong chemical oxidants. This indicator reflects the total concentration of organic matter in the water. There are several types of water oxidation of: permanganate, bichromate, and iodate. Permanganate oxidation is expressed in milligrams of oxygen that used for oxidation of these substances in 1 dm^3 of water. The highest degree of oxidation is achieved by bichromate method. In practice, for natural low polluted water treatment permanganate oxidation level needs to be determined. For more polluted waters, as usual, bichromate oxidation (COD - "chemical oxygen demand") is used. Humic material is a major source of organic substances. Humic acids (high molecular weight compounds) and fulvic acids are very easily transferred from it. Moreover, these acids add aggressive properties to waters and contribute to weathering of igneous rocks. They form organic complexes with micro-elements.

Biogenic elements

N, P, Si, Fe belongs to the biogenic component of natural waters. Nitrogen and phosphorus compounds are a required part of each living organism, in particular plants. Nitrogen compounds may exist in the form of inorganic and organic compounds. Inorganic compounds forms are NH_4^+, NO_2^-, NO_3^- ions. In the organic compounds nitrogen is a part of the protein or its breakdown products such as urea formed during the processes of ammonification. In water, it exists in the most diverse forms: suspensions, colloids, dissolved molecules.

Ammonium

Presence of ammonium ions in unpolluted surface waters is associated with the biochemical degradation of proteins through the ammonification pathway. The main sources of ammonium ions entering water bodies are agricultural, food and chemical industry wastewaters.

Nitrites

They are an important health indicator. Their concentrations are insignificant, they are easily oxidized and if it is found, it indicates the strengthening transition of $NO_2^- \rightarrow NO_3^-$.

Nitrates

They are easily assimilated by plants; they also disappear during the growing season. Their maximum contents are observed in winter.

Phoshates

In natural waters, dissolved *phosphorus* is presented as inorganic and organic compounds. They can be present there in dissolved, colloidal and suspension forms. Inorganic phosphorus is in the water in the form of H_3PO_4derivatives, but the prevailing form is HPO_4^{2-}. Exchange between inorganic and organic forms is specific for nitrogen as well as for phosphorus. This exchange is carried out in the process of photosynthesis and decomposition of organic substance.

Silicon

Silicon is a permanent component of natural waters. Silicon compounds are spread permanently and everywhere but only slightly soluble. Forms of silicon are diverse (silicic acid, polysilicic acid, etc.). Furthermore, silicon is present in natural waters as colloids x Si02 * y H20. Temperature and pH affect solubility of silicon.

Microelements

Knowledge of the distribution of rare and dispersed elements in water bodies is of great scientific and practical interest because they are biologically active. Most microelements have very low concentration in all natural waters (< 1 mg / l) (Zenin & Beloussova, 1988). So far, the form of the migration for most of them has not been determined yet. Features of elements that have to be considered include the main migration regularities and mode of nonmetals F, B, Br and I, as well as radioactive elements.

Fluorine

It has an important physiological significance for humans and animals. The excess and the lack of it lead to severe endemic diseases as fluorosis or tooth caries. An excess of fluoride in drinking water leads to problems in bone mineralization. In particular, increase of the concentration of fluorine in drinking water up to 3.2 mg/l leads to the appearance of dental fluorosis, while fluorine content of 4-6 mg/l results in suppression of functional activity of the central nervous system. During the period of the water volume reduction in water reservoirs, for example during the evaporation, concentration of fluorine increases. Thus, in Syrdarya basin lakes and groundwater with the fluorine concentration up to 14 mg / l are detected. In most freshwater lakes fluorine content is 1 mg/ l, in brackish and saline reaches 9 mg/l (Mun, 1971). Among all the lakes of Kazakhstan Dzhasybay, Chebache, Schuchie, Burabai lakes are the richest in terms of fluorine content. Research of Beremzhanov (1986) showed that in the water of the rivers of Balkhash basin the scale of fluorine concentration is varying from 0.10 to 2.20 mg/l. There is certain regularity in this. Higher concentration is found in the rivers of mountain type (Issyk, Talgar, Turgen) and lower concentration in the river Ile. Therefore, piedmont area of Zaili Alatau and Central Kazakhstan forms biogeochemical province with high content of fluorine.

Boron

It is one of the most dispersed elements. Researches have proved that rivers and lakes of Kazakhstan differ in Boron concentration although generally in the plain rivers, the boron content is much higher than in Mountain Rivers. The Syrdarya river basin has similar situation: Chirchik River concentration is 28-59 mcg/l, Bozsu River - 192-284 mcg/l, Kurkeles River - 396-1000 mcg/l and Syrdarya River - 93-140 mcg/l. In lakes with fresh waters this concentration is 20-550 mcg/l; with brackish water - 770-2700 mcg/l; in saline water lakes it is 5-20 mg/l; in selected lakes - up to 350-360 mg/l.

Bromine. The main sources of bromine in natural water are volcanic gases. Bromine is gets into the soil and the river waters with rainfalls and plant litter. Bromine concentration in river waters is directly related to its content in soils and groundwater. It was revealed that bromine concentration in the Ile river is 12,8 – 163 mcg/l (Romanova, 2003).

Iodine

The average concentration of iodine is 5-10 mcg/l. So, in Balkhash basin there are 1-4 mcg/l of iodine, in mountain rivers Turgen, Issyk and Ile there are 4-10 mcg/l of iodine (up regulation of the flow). Syrdarya basin includes the following rivers, where iodine is found too: in river Chirchik there are 1,7-14,7 mcg/l of iodine, in river Bozsu there are 13-25 mcg/l of iodine, in river Kurkeles there are 21-50 mcg/l of iodine, in Syrdarya River there are 9-16-198 mcg/l of iodine.

Bromine and iodine was found in the lower reaches of the Ile River irrigation system. It was revealed that the water in the irrigation channel contains iodine (1,0-34,0 mcg /l) and bromine (12,8-163,0 mcg/l) in the same concentration as in the Ile River. In most cases, higher concentrations of bromine (16,0-180 mcg/l) and iodine (2,5-32,0 mcg/l) are typical for rice field areas. Groundwater is richer than surface water in terms of the content of these microelements.

Metals (Cu, Zn, Mn, Pb, Co, Ni, etc.) and different groups of *radioactive elements* refer to the microelements in natural waters. Since 1945 and up till now radioactive elements of artificial origin (nuclear explosions, waste of Atomic Power Station and nuclear industry) get into natural waters, and pose a serious threat to the environment this is why solution of this problem is very important and urgent. Table 5.5.3 shows the values of the of activity (Bk/ l) of some natural and artificial radionuclides in natural waters of the RK.

Table 5.5.3 Content of Radioactive Elements in Natural Waters (Tokarev et.al, 1985)

Radionuclides	Rivers	Lakes
U-238	0,005-1,850	0,0025-492
Ra - 226	0,004-0,155	0,007-0,30
Pb-210	0,001-0,011	0,002-0,008
K-40	0,037-0,370	0,480
Sr - 90	0,02-0,09	0,018-0,17
Cs-137	0,007-0,07	0,01-0,10

Conclusion

It can be noted that the knowledge of chemical composition of water and its behavior in different areas of the Earth have to be focused on a number of theoretical and practical problems. One of theme is the problem of potable, industrial and irrigation water quality. Correct understanding of natural hydrogeochemical processes makes it possible to confidently tackle the problem of forecasting hydrochemical regime of certain water bodies in their long-term operation.

5.6 Hydrophysics, hydrochemistry, and hydrobiology of the Large Aral Sea

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Introduction

At the beginning of the 21st century many physical, chemical and biological characteristics of the rapidly shrinking Aral Sea were studied, though insufficiently. Some of them are almost unknown to the international scientific community. In 2002 the P.P. Shirshov from the Institute of Oceanology (Russia) in collaboration with the International Kazakh-Turkish University (Kazakhstan) and other research institutions in Russia, Kazakhstan, and Uzbekistan initiated a long-term program of the Large (Southern) Aral Sea field monitoring at. The following text is a short report of the main results of this program. All material presented in this article have been previously published in Russian (Zavialov et al., 2012).

Hydrophysical state

The most important physical characteristic of the Large Aral Sea is the strong vertical stratification of salinity and density. An overview of the thermohaline structure of the Aral Sea for 2002-2010 is given in Tab. 5.6.1. The values of vertical stratification highly differ from those which are known from before shrinking process. Before the desiccation onset, the difference in salinity between the surface and the bottom never exceeded a few tenths of g/kg, while the mean salinity changed only slightly around 10 g/kg. By the 2000s, the absolute salinity increased by an order of magnitude, and the salinity jump between the bottom and the surface was typically as large as about 10 g/kg or even more. The changes in the vertical structure occurred at any time between 1990 and 2002.

It is important to emphasize that before 2004 the vertical structure of the water column in the lake was mainly two-tier. Salinity minimum was observed in the upper mixed layer whose thickness spanned between 7 and 23 meter, while

Table 5.6.1 Physical state of the Aral Sea (2002-2010). The bottom values correspond to the depth of 38 m, the surface values correspond to 1 m.

Field campaign	Date of Obser-vation	Area	Sea level a.o.l., [m]	Salinity, [g/kg]		Temperature, [°C]	
				surface	bottom	surface	bottom
1	Nov 2002	West Basin	30.47	82	94	10	15
2	Oct 2003	West Basin	30.50	85	96	14	2
3	Apr 2004	West Basin	-	86	87	5	1
4(1)	Aug 2004	West Basin	30.71	91	87	25	2
4(2)	Aug 2004	Strait	-	100	100	23	23
5(1)	Oct 2005	West basin	30.12	98	101	18	4
5(2)	Oct 2005	Strait	-	132	132	17	17
5(3)	Oct 2005	East basin	-	130	134	15	15
6	Mar 2006	West basin	30.20	99	-	-2	-
7	Sep 2006	West basin	29.60	101	98	19	3
8	Nov 2007	West basin	29.18	104	115	10	11
9(1)	Jun 2008	West Basin	29.28	104	107	23	2
9(2)	Jul 2008	East basin	-	211	-	-	-
10	Aug 2009	West basin	27.64	114	114	24	5
11	Apr 2010	West basin	-	115	-	11	-
12	Sep 2010	West basin	26.79	117	132	20	12

the salinity maximum was measured next to the bottom. These two layers were separated from each other by a halocline. However, starting from 2004, the pattern of the vertical structure changed significantly. An example of stratification typical for the recent period is shown in Fig. 5.6.1. In this case (August 2009), the upper mixed layer with a temperature of 24ºC and a salinity of 113.5 g/kg extended to the depth of 13 meter, followed by an intermediate, relatively fresh layer, where the minimal temperature and salinity (5.5ºC and 110.5 g/kg, respectively) were detected. A distinct bottom layer was identified below 25 meter, characterized by a local salinity maximum accompanied by temperature inversion. Therefore, the thermohaline structure exhibited three-tier pattern with two salinity maxima: one near the surface and one near the bottom, separated by a fresher layer in between. Zavialov et al. (2012) show, that the two salinity maxima are the results of concurrent action of convective and advective mechanisms. The upper salinity maximum results from the accumulation of salt in the upper mixed layer after intense evaporation in summer. This mechanism is called "convective" because it implies sinking of the upper layer water following their cooling in autumn and winter. In contrast, the "advective" mechanism - responsible for the near-bottom layer salinity maximum - is related to horizontal exchanges of water between the deep western basin and shallow eastern basin of the Large Aral Sea. Saltier and denser water of the eastern basin penetrate into the western hollow through the strait in the northern part of the Sea and propagate down the bottom slope, forming the near-bottom salinity maximum, often accompanied by temperature inversion.

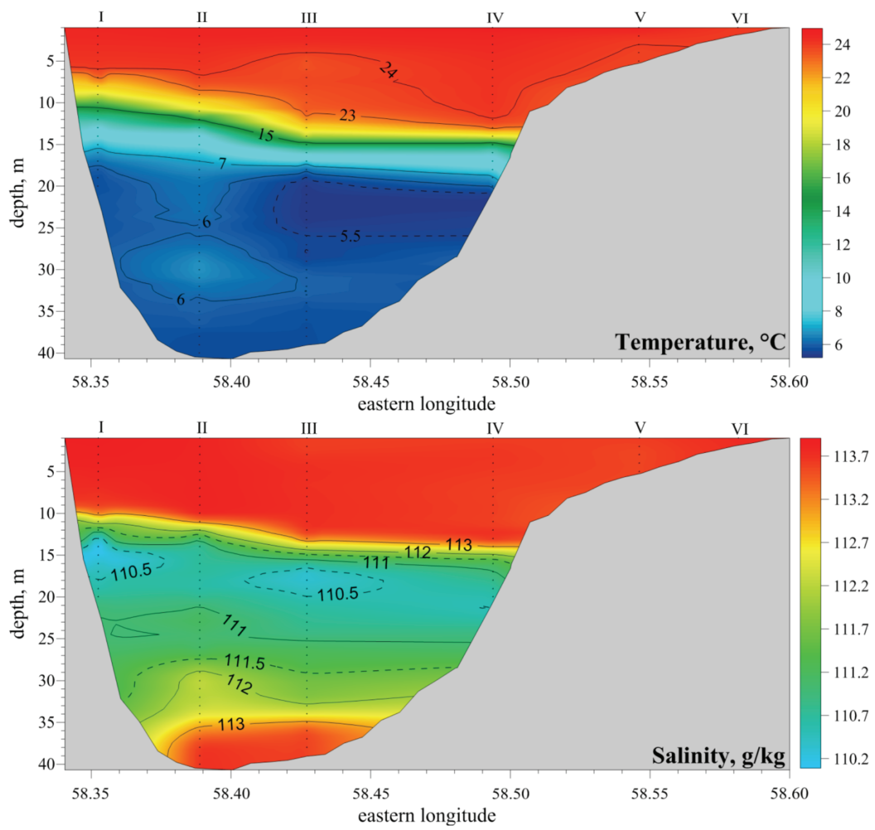

Figure 5.6.1 Vertical distributions of temperature (ºC, upper panel) and salinity (g/kg, lower panel) at zonal cross-section in central Western basin of Large Aral Sea in August 2009

Hydrochemistry

The hydrochemical state of the Aral Sea is tightly connected with its hydrophysical regime.

Sequential chemical precipitation of calcium and magnesium carbonates, gypsum, mirabilite, halite accompanying desiccation and salinity build-up has led to significant and continuous alterations of the ionic composition in the residual water mass of the Sea. The progressive interannual changes are evident in the yearly observations for 2002-2009 (Tab. 5.6.2). These trends are manifested in both basins of the Large Aral Sea. Notable decrease of calcium content is more pronounced in the east basin. Another characteristic feature is the decrease of the ratio SO_4/Cl associated with the consumption of sulfate by gypsum precipitation.

Table 5.6.2 Ionic composition of the Large Aral Sea water in 2002-2009. The following data are given for each ion: absolute mass content, relative content (%) with respect to the total mass of salts, and relative content with respect to Cl

№	Unit	Time, place	CL^-	SO_4^{2-}	HCO_3^-	Na	K^+	Ca^{2+}	Mg^{2+}	Mineral
1	mg/kg	05.07.02	27155	20160	494	18964	175	802	4378	72.1
	%	West	37.67	27.95	0.67	26.29	0.25	1.10	6.07	
	ion/Cl		1.00	0.742	0.018	0.698	0.006	0.029	0.161	
2	mg/kg	25.10.03	38010	22100	458	8634	1000	700	13220	84.1
	%	West	35.97	25.74	0.53	20.38	1.16	0.81	15.4	
	ion/Cl		1.00	0.581	0.012	0.227	0.026	0.18	0.348	
3	mg/kg	08.04.04	33175	22938	442	21137	1133	600	5400	84.9
	%	West	39.09	27.01	0.54	24.92	1.35	0.73	6.36	
	ion/Cl		1.00	0.691	0.013	0.637	0.034	0.018	0.163	
4	mg/kg	10.08.04	34790	23823	366	22313	1214	580	5412	88.5
	%	West	39.31	26.92	0.41	25.21	1.37	0.66	6.12	
	ion/Cl		1.00	0.685	0.011	0.641	0.035	0.017	0.156	
5	mg/kg	30.09.05	37577	25056	152.5	24095	1209	540	5760	94.5
	%	West	39.81	26.55	0.16	25.23	1.28	0.57	6.1	
	ion/Cl		1.00	0.667	0.004	0.641	0.032	0.014	0.153	
6	mg/kg	03.10.05	39562.2	34660	183	27382.5	1080	456	7164	110.5
	%	Strait	35.81	31.37	0.17	24.78	0.98	0.41	6.48	
	ion/Cl		1.00	0.876	0.005	0.700	0.027	0.012	0.181	
7	mg/kg	10.10.05	44667	36660	183	30953.4	1180	416	7524	121.6
	%	East	36.74	30.15	0.15	25.46	0.97	0.34	6.19	
	ion/Cl		1.00	0.821	0.004	0.693	0.026	0.009	0.168	
8	mg/kg	25.09.06	38924	25996	564	23920	1184	568	6544	97.7
	%	West	39.84	26.61	0.58	24.48	1.21	0.58	6.70	
	ion/Cl		1.00	0.668	0.014	0.614	0.030	0.014	0.168	
9	mg/kg	01.06.08	44357	23145	579	25346	1550	550	6870	102.4
	%	West	43.32	22.60	0.57	24.75	1.51	0.54	6.71	
	ion/Cl		1.00	0.522	0.013	0.571	0.035	0.012	0.155	
10	mg/kg	08.06.08	78975	67775	945	57316	2500	250	12330	220.1
	%	East	35.88	30.79	0.43	26.04	1.14	0.11	5.60	
	ion/Cl		1.00	0.858	0.012	0.726	0.031	0.003	0.156	
11	mg/kg	20.08.09	50558	25912	673	28934	2250	650	15060	115.4
	%	West	40.76	20.89	0.54	23.33	1.81	0.52	12.14	
	ion/Cl		1.00	0.513	0.013	0.572	0.044	0.013	0.29	

Based on these data, we estimated the total masses of minerals that had been deposited on the bottom. The following figures were obtained (in 10^9 tons): calcium carbonate: 0.07 (2%); magnesium carbonate: 0.1 (2%); gypsum: 2.3 (49%); mirabilite: 1.9 (40%); halite: 0.4 (8%). Therefore, precipitation of mirabilite has been almost as intense as precipitation of gypsum, and precipitation of halite was also considerable. Analyses of bottom sediment samples indicated that gypsum precipitates all over the lake, whilst mirabilite sedimentation is widespread in winter, but restricted to the deep portion of the deep western basin where water is cold enough. Over shoals, in summer mirabilite can partly redissolve again, which should leads to significant seasonal cycle of ionic composition. These issues remain poorly explored.

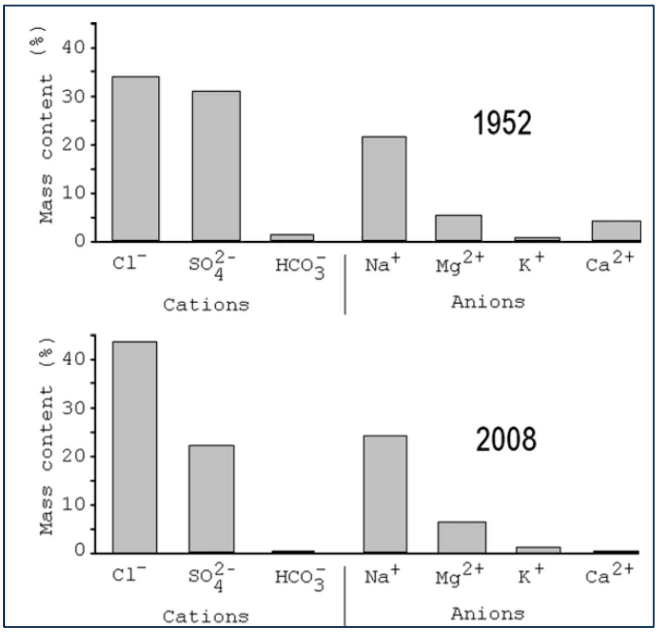

Figure 5.6.2 Relative content of principal ions in Aral Sea water in 1952 (after *Blinov*, 1956) and 2008 (authors data).

The Aral Sea desiccation and the stratification of water column led also to dramatic changes in the regime of dissolved gases. In the past, the Aral Sea had been fully ventilated by oxygen. Since 2002 the near-bottom layer developed anoxic conditions and sulfide contamination (Fig. 5.6.3). The upper limit of the anoxic zone lies at the depths spanning from 12 m to 39 m, while the maximum concentration of H_2S varied between 5 and 80 mg/l. The characteristics of the sulfide zone vary strongly at the interannual scale.

Hydrobiology

The taxonomic biodiversity of phytoplankton in the Aral Sea has reduced significantly since the beginning of desiccation in 1960, when it totaled to 306 species. In 2008, only 28 species of phytoplankton were observed, including 17 diatoms. The average concentration of phytoplankton was $2.3*10^6$ cells/l and 231 micrograms of carbon per liter. The two dominant species were the following: *Nitzschia insignis* Gregory (71% of the total amount) and *Fragilaria brevistriata* Grunow (27% of the total amount). Cryptophytic algae were represented by *Rhodomonas sp.* (salina?) and *Chroomonas sp.* About 90% of the biomass of green algae was represented by *Chlamidomonas sp.,* while the green-blue were dominated by *Synechococcus elongates.*

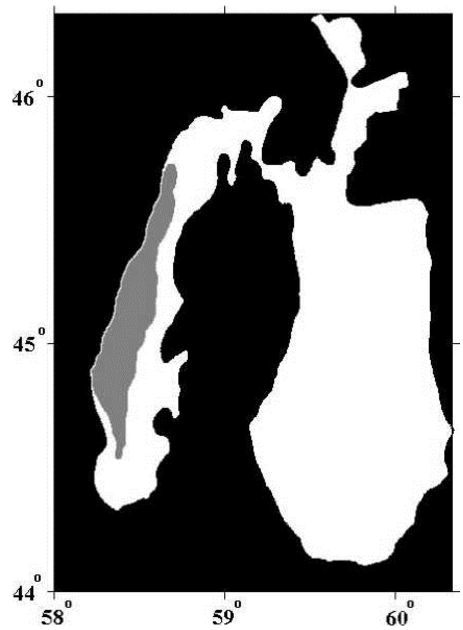

Figure 5.6.3 Typical location of anoxic sulfide contamination zone in the Aral Sea

Table 5.6.3 Phytoplankton of the Large Aral Sea in 2008-2009 (data of L.S. Zhitina et al., published in Zavialov et al., 2012, Chapter 6)

	Cyanopyta	**2008**	**2009**
1.	Synechococcus aeruginosus Näg.	+	+
2.	S. elongates Näg.	+	+
	Cryptophyta		
3.	Chroomonas cf. marina (Bjittner) Butcher	+	+
4.	Rhodomonas salina (Wisl.)Hill et wetherbee	+	+
	Euglenophyta		
5.	cf. Euglenophyta		+
6.	Trachelomonas cf. verrucosa Stokes		+
	Dinophyta		
7.	Gymnodinium sp.1	+	
8.	Gymnodinium sp.2	+	+
	Chromophyta		
	Bacillariophyceae		
9.	Amphora coffeaeformis Kütz.	+	+
10.	Amphora holsatica Hustedt	+	
11.	Amphora normanii Rabenh.	+	
12.	Amphora ovalis Kütz.	+	
13.	Chaetoceros sp.	+	
14.	Cocconeis placentula Ehr.	+	
15.	Cuclotella cf. caspia Grun.		
16.	Culindrotheca closterium (Ehr.) Lewin et Reimann	+	+
17.	Diatoma tenuis Ag.	+	+
18.	Diploneis smithii (Breb.) Cl.	+	
19.	Entomoneis alata Kütz.	+	
20.	Fragilaria brevistriata Grun.	+	+
21.	Navicula digitoradiata (Greg.) Ralfs	+	
22.	Navicula laterostrata Hustedt	+	
23.	Navicula sp.		+
24.	Navicula sp.1	+	
25.	Navicula sp.2	+	
26.	Nitzschia acuminate (W.Sm.) Grun.	+	
27.	Nitzschia amphibia Grun.	+	
28.	Nitzschia fasciculate Grun.	+	
29.	Nitzschia hungarica Grun.	+	
30.	Nitzschia hubrida Grun.	+	
31.	Nitzschia insignis Grun.	+	+
32.	Nitzschia punctata (W.Sm.) Grun.	+	
33.	Nitzschia sigma (Kütz.) Grun.	+	
34.	Nitzschia sp.	+	+
35.	Surirella fastuosa var. suborbicularis Grun.	+	
36.	Sunedra cf.acus Kütz.		+
37.	Thalassiosira baltica (Gun.) Ostenf.		
	Chaetoceros spp. Споры		
	Chrysophuceae		
38.	Actinomonas mirabilis Kent	+	
	Chlorophyta		
	Chlorophyceae		
39.	Chlamidomonas sp.	+	+
40.	Coenococcus planctonicus Korsch	+	+

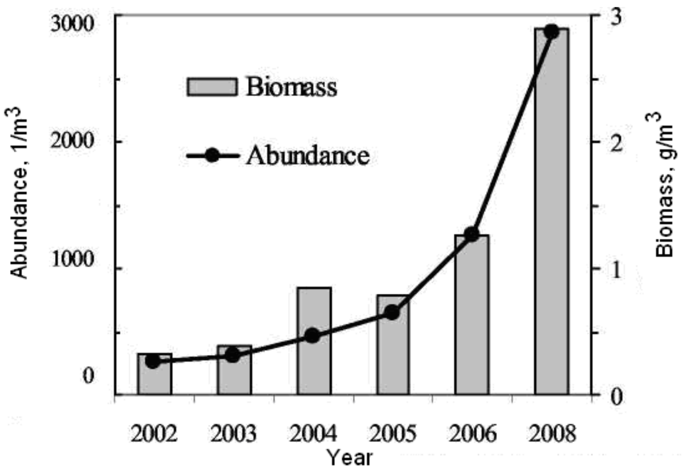

Figure 5.6.4 Growth of Artemia population in the Large Aral Sea in 2002-2008 (after Arashkevich et al., 2009)

The main species in today's Aral zooplankton is *Artemia parthenogenetica,* a typical inhabitant of hyperhaline lakes, which became an absolute dominant in the zooplanktonic community since 2002. Currently, it constitutes over 99% of the total biomass. The interannual dynamics of Artemia's biomass and abundance for 2002-2008 are shown in Fig. 5.6.4

Conclusion

Since the beginning of its desiccation, the Large Aral Sea experienced drastic changes in its physical, chemical, and biological regimes. The lake whose thermohaline fields had been relatively uniform became strongly stratified, with maximum salinity values exceeding 110 g/kg. The Large Aral Sea split into two separate water bodies, the Western and the Eastern basins, which intermittently exchange water through a narrow connecting strait. These water exchanges play an important role in maintaining physical structure and stratification in both basins. From the hydrochemical standpoint, the most important governing process currently taking place in the Aral Sea is chemical precipitation of minerals from oversaturated brines (e.g. *Zavialov and Ni*, 2010). This leads to continuous changes in the ionic salt composition of the residual water mass. Once fully ventilated, the Sea is now subject to anoxia and sulfide contamination in the bottom layer. Despite the harsh environmental conditions, biological systems of the Large Aral Sea are not dead, although their taxonomic structure and abundance changed very strongly accompanying the desiccation. The lake still exhibits developed communities in algae, phytoplankton, zooplankton, and benthos.

5.7 Lake Balkhash - a drainless lake

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Introduction – General information about lakes in the arid zone

This article provides summary information on the hydrochemistry and hydroecology of Lake Balkhash necessary for geo-ecological research and monitoring of water bodies. The research has revealed the emergence of lakes in arid zone.

A significant part of Central Asian territory is arid. Almost entire territory of Central Asia, more than three-quarters of Kazakhstan, the whole territory of Xinjiang Uygur Autonomous Region (XUAR) in Chinese People's Republic, part of Siberia and Mongolia include inland drainage basins, i.e. they are not hydraulically connected to any world ocean or even with each other (Tursunov and Tauipbaev, 1997). The territory of Kazakhstan is one of the least water supplied Republics in CA. Only 200 rivers and temporary watercourses from the 85,000 ones have the length of more than 100 km, and only 6 rivers are more than 1000 km long. Of the 48,000 lakes in Kazakhstan, 270 have a water surface area over 10 km^2 , 16 have a surface area of >100 km^2 and Lake Balkhash has a surface area of more than 2000 km^2 (Severskiy, 1998). Basins of such large water bodies as the Caspian and the Aral seas, lakes Balkhash, Alakol, Eby-Noor and Lobnor (Chinese People's Republic), Issyk-Kul, Teniz, a group of Northern Kazakhstan and Western Siberia lakes, a group of Bayanaul and Kokshetau lakes, the wastewater storage Sorbulak in Kazakhstan, Arnasay and Aydarkul in Uzbekistan, and others are local lake drainage basins. The local lake drainage basins are featured as having specific moisture circulation of, pollutants, and energy. Alakol Lake is characterized as a drainless lake. However, considering the historic section, Lake Alakol is a periodically flowing lake (Kurdin, 1998). These lakes are also in the arid areas.

Hydrographic network of Lake Balkhash drainage basin

The Balkhash basin is enclosed in a vast hollow in the south of Kazakhstan, at the center of Eurasia, west of Junggar Gate. In the south the expanses of Balkhash area are limited by the Jungar Alatau Mountains; Chingiz-Tau and Tarbagatai mountains are located near the lake to the east and northeast of it, with highlands of the Aral-Irtysh watershed to the north. The Balkhash drainage basin area is 390,000 km^2 and includes Tien Shan and Jungar Alatau glaciers (Figure 5.7.1).

Today the lake is an elongated shallow water body, of boomerang–like shape. Consisting of outer and inner basin parts the lake is divided by Uzunaral peninsula into a shallow broad western part, and a deep narrow eastern part. The western part of the lake is fresh water flowing body, because streams carry away all the salt into the drainless and saline eastern part. The area of the Balkhash lake drainage basin is 413,000 km^2. 304,000 km^2 of them are within the Republic of Kazakhstan (80%). Five large rivers disgorge into Balkhash Lake. Total amount of the regional water resources e in the flow formation zone makes up 28,85 km^3 per year, out of which 22,87 km^3 per year is formed in the basin of Ili river; 5.36 km^3 per year is formed in the basins of Karatal, Lepsy and Aksu rivers, 0,57 km^3 per year is formed in the basin of Ayaguz river, while 0,08 km^3 per year is formed in the river flow formation zone of the northern Balkhash area. Only about 15,11 km^3 of these water resources reach lake Balkhash every year, which are mainly lost due to evaporation. The remaining annual 13.74 km^3 of water go into the natural hydrographic network; with an average of 3.12 km^3 out of this amount are spent per year in the delta of Ili River (Dostay, 1999). The rivers carry not only water but up to 10 million tons of silt. The rivers of the North Balkhash area are Bakanas, Aschiozek, Tokrauyn, and Karabulak. Thus, hydrography of the of the North Balkhash area is characterized by low density river network (0,2-0,5 km/km^2), especially in the central flat part of the territory (up to 0,01 km/km^2), while river network density in mountainous areas (from 0,6 to 3,0 km/km^2) is pretty dense. In the piedmont areas the hydrographic network consists of transit sections of Karasu river channels, and numerous irrigation canals.

Climatic conditions during the research period

The Balkhash Lake has an inland location and is exposed to northern, northwestern and western intrusions of polar, tropical and arctic air masses. The Polar air mass recurrence is quite frequent while that of the Arctic air mass is rare. Spring particularities are the frequent cyclones. Wet air

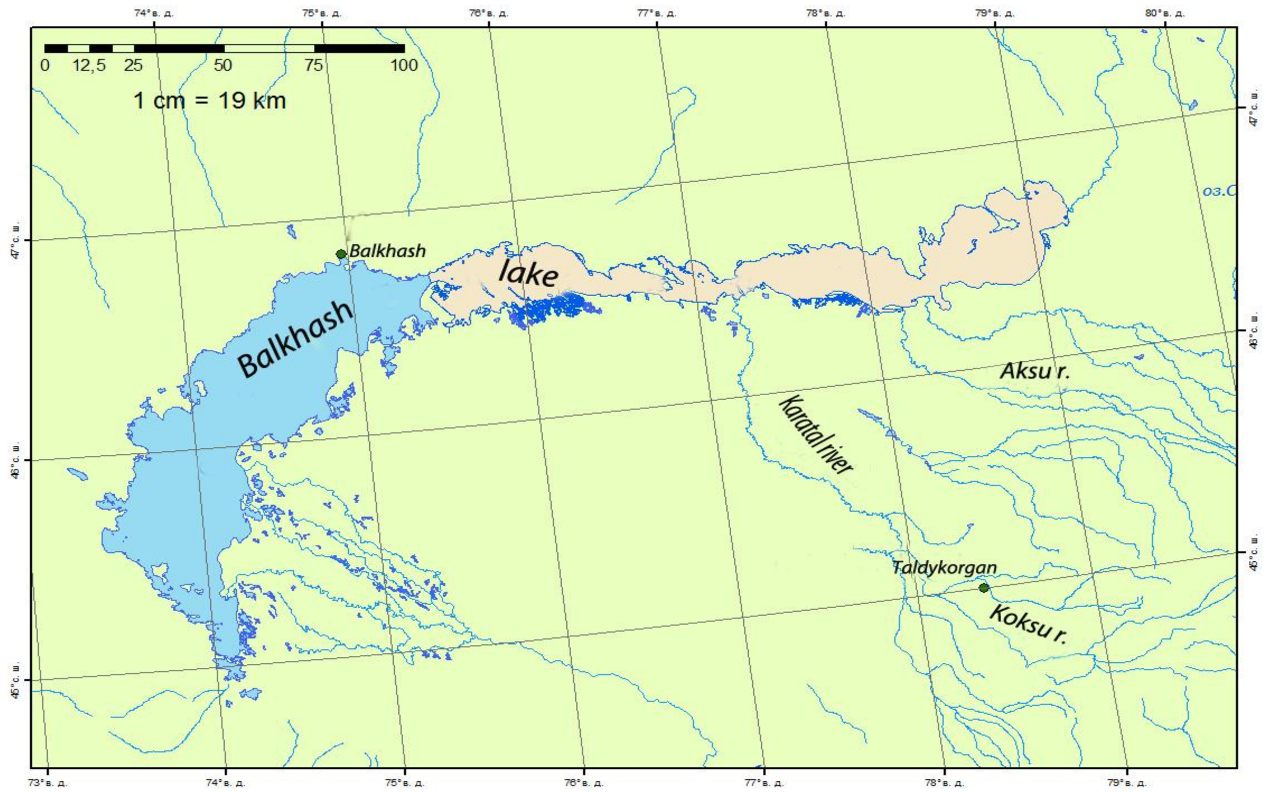

Figure 5.7.1 Map of Balkhash Lake (Lomakina, 2014)

masses from the Atlantic area, Mediterranean, and Black Sea bring some amount of precipitation. Weather conditions in summer are characterized by frequent intrusions of warm tropical air. The climate is heterogeneous because due to differences in the relief structure (Sokolova, 1989). This area is characterized by large daily and annual temperature fluctuations, cold winters, and lengthy, hot, and dry summers. Spring seasons are basically short and are characterized by unstable weather conditions and frequent recurrence of cold weather. Intrusion of cold arctic air masses in autumn is becoming more frequent, thus facilitating the onset of winter. The average annual temperature varies from 7°C in the west to 5,3° C in the eastern of the lake area. Maximum summer temperature is up to 40 ° C, while the minimum winter temperature is -45° C (Tarasov, 1961).

Winds are for drainless lakes in Central Asia of great significance. A full picture of wind currents on Lake Balkhash has been developed by Malkovskyi (1991) based on calculations with the use of a two dimensional mathematical model, which was later updated given the outcomes of the research backed up by a large-scale physical model of the lake. Malkovskyi (1991) states that wind currents are localized in some parts of large lakes. They form complex interactions of drift and compensatory currents, as well as discrete large-scale vortices, which cover a considerable part of the lake or it's certain reaches. Synoptic situation research of wind currents showed that by the end of the first 24 hour monitoring in Western Balkhash the progressive movements of water dominated along the axis of the lake with the coastal drift currents (speed up to 0,21 m/s) and the central compensation current (speed up to 0,09 m/s). On the first day of research, in 15 hours, maximum current velocity could be observed in the narrowest place of the lake, called Sary-Yessik strait. The flow velocity is 0,38 m/s. The third hydrochemical area is characterized by a clearly expressed anticyclonic circulation. The circulation diameter is 2/3 of the lake width. Tarassov (1961) proposed lake zoning, whereby Lake Balkhash is divided into 8 hydrochemical areas from the west to the east. In hydrochemical areas V and VIII belonging to Eastern Balkhash, there are large-scale vortex currents, while in general drift currents are most common (Figure 5.7.2). Measurements showed that the mutual exchange of water masses occurs between hydrochemical areas I and II, II and III, III and IV, and VII and VIII, while a one-sided crossflow of water occurs the lake areas VI to VII, and V to VI. A phenomenon known as an upsurge (rise of water level) is observed in areas I, IV, VI and VIII.
Figure 5.7.2.

Figure 5.7.2 Chart of Lake Balkhash hydrochemical areas (Tarasov, 1961; I-VIII hydrochemical areas; * - point of water sample)

Special research showed that after a sharp drop in water level of Lake Balkhash and the Aral Sea fine sediments that have got formed earlier increase in the drift currents. They are quickly transported over long distances by coastal currents, forming elongated ridges and spurs separating the majority of shallow gulfs, coastal lakes, and boggy lowlands from the main area. All these lead to the second phase of the lake drying out, which is characterized by shrinking water surface area and water volume decrease due to evaporation processes. At the same time migration of salts to coastal bays increases. This is further evidence of the self-preservation mechanism in natural water bodies.

Morphometric features of Lake Balkhash

Modern Lake Balkhash is represented as a water body, consisting of eight expressed reaches (Picture 2). The lake is divided into the Western shallow water and the Eastern deepwater parts by the Sary Esik peninsula. The average depth of the largest reach is -3,4 meters with the width of 35 km, which is 4 times greater than the water depth. Maximum depth of 32m is observed in Burlutubinskiy reach, where no inflow of a river has taken place for a long time. Water levels of drainage basins of the arid zone in Central Asia, including Balkhash Lake, have suffered from large-scale long-term and ancient cyclical fluctuations caused by climate variability (Chistyaeva, 1990). In general, water level in the Lake is characterized by phases of the rise and fall. The Lake Balkhash water level is determined by the sum of its annual increments over a number of previous years, i.e. climatic conditions of the previous multi-year period.

Processes of carbonate formation in Lake Balkhash

For more than five decades, the unique nature of the Balkhash water basin and regional problem related to it attracted numerous researchers (Abrosov, 1973). The lake mineralization level ranges, on the average, from 2,05 to 4,65 g/l (Romanova, Kruchenko, 1989, Sapozhnikov, 1951). The problem of carbonate formation in Lake Balkhash (Sapozhnikov, 1951) was of specific interest to researches; and this problem has not been resolved so far. In contrast to the Black, Caspian, and Aral seas, where calcium carbonate setting occurs as well, magnesium carbonates attached to it can be found only in Balkhash water. This process suggests the dolomite crystallization in Balkhash water. This dolomite was found in the sediments (Strakhov, 1945, Levchenko, 1975). Only in the water of Lake Balkhash the dolomite formation can be observed. Balkhash is a unique water body given its carbonate formation, as well aschemogenic sediments including not only calcite but also dolomite. According to Khrustalyov (1999), a regularity that is inherent to intercontinental sea water bodies of the arid zone like the Aral and Caspian Seas, can be observed in the distribution of calcium and magnesium carbonates in the bottom settings of Balkhash Lake as well. The highest contents gravitate to fine-grained bottom settings of deep-sea trough. Towards the coast their concentration gradually falls, i.e. isolines of equal value of carbonate material are arranged more or less parallel to the coastline. Therefore, the main factor controlling the distribution of carbonates is the hydrodynamic regime.

Dolomite formation processes in Lake Balkhash

After many years of research of arid water bodies, the chemical process of accelerated salt settings was studied for the first time (Beremzhanov, 1966, Domrachev, 1931). Such distinctive particularity is determined by morphometric and climatic factors. Water bodies of humid zone are relatively deep and evaporation layer does not exceed precipitations. Therefore, dissolved carbon dioxide in alkaline conditions of large concentration (Ph 8,51-9,05), being the product of vital activity of biocenosis of aquatic organisms, is accumulated from the surface water , as well as in the bottom layers. The research authors proved (Tarasov, 1961, Beremzhanov, Romanova, 1986), that the smallest particles of sediments (suspengeli) play a significant role in the accelerated salt deposit (of lower concentrations). The smallest particles of sediments are formed due to constant turbulent water mixing by wind waves, their flotation in the coastal zone, and bottom sediments roilines sand abrasive wear of large sediments during the longshore movement. The smallest particles of sediment absorb ions contained in water, catalysing chemical reactions of bicarbonate formation, and actively react with dissolved salt ions in water. This leads to the formation of solid bottom settings, i.e. the mechanism of self-preservation works, when the arid pond gets rid of salt surpluses. Salt sediments, including calcium and magnesium carbonates, are the first but not the main discharge part in salt balance of arid water body. The research (Chistyaeva, 1981) shows that another discharge part of salts in arid water bodies or lakes is the salt migration in the coastal zone. This migration is due to three factors (Beremzhanov, 1986). Firstly, shallow water coast and numerous bays get warmed faster and stronger, and the layer of evaporation is bigger. Therefore, there is a large concentration of remaining salts. As a result, there is a concentration gradient, which is due to molecular effects, enhancing the salt migration from the middle parts of the lake water area to the coastal zone. Secondly, on an episodic basis, coastal salt waters surge over low-lying lands. Following a change in wind direction, water is driven off and the remaining salt dries, forming a white tarnish. The same wind bears them easily into the atmosphere, and there the mechanism of "eolian desalination" enters into force. Thirdly, large salt migrations move on to coastal lakes and separating gulfs.

It should be noted that quite extensive and relatively deep depressions of groundwater level are formed in the coastal zone of the majority of arid water bodies. These depressions are caused by more intensive water evaporation from the underflow surfaces of water body. Such process is one of the main discharge stages of salts in arid lakes, due to the depression and the powerful seepage flow from the coastal zone of the lake towards the depression.

Hydrochemical processes in Lake Balkhash

Field research has been undertaken on Balkhash Lake. The authors actively participated in three staff expeditions of the Inorganic Chemistry Department of Al-Farabi Kazakh National University, and three staff expeditions of the Hydrology Institute of Geography Laboratory of the National Academy of Sciences of the Republic of Kazakhstan (NAS RK) to Balkhash Lake region, including the Shympek gulf. In the period of 1985-2000 total 1478 samples were selected from the lake for chemical analysis, the inflowing rivers (40 samples) and 164 silt samples referring to the catchment basin of Balkhash Lake

It is known that the presence of major ions in water (HCO^-_3, CO^{2-}_3, SO^{2-}_4, Cl^-, Ca^{2+}, Mg^{2+}, Na+ and K+) determines water mineralization and its chemical composition. The mineralization is the sum of all the items found as a result of the analysis of mineral substances in mg/l or mg/dm^3.

The inhomogeneity of water mineralization across the lake is one of the features of Balkhash Lake that distinguishes it from other continental lakes in the world. Western Balkhash (WB) water mineralization was on average 1,18 g/kg, Eastern Balkhash (EB) 3,87 g/kg, the entire lake 2,63 g/kg before the level recession (1929-1969) (Kurdin, 1998). Regulation of the Ili river flow and the increase in water volume used for irrigation led to shrinkage of the lake water level and resulting changes in the concentrations of the ionic and salt composition (Table 5.7.1).

Table 5.7.1 Comparative characteristic of level and mineralization changes of Lake Balkhash during 1970 - 1987

Period of change	Average recession level in meters (Baltic system*)	Mineralization increase, g/l		
		Lake	Western Balkhash	Eastern Balkhash
1970-1985	2,13	0,89	+0,54	+1,25
1970-1986	2,22	0,98	+0,66	+1,31
1970-1987	0,7	1,06	+0,82	+1,32

* Baltic system of height (BSH) was adopted in the USSR in 1977; it is the system of absolute heights. Height measurement starts from zero in Kronstadt gauge.

Intensive salinization of WB compared to EB confirms the water mineralization relationship between these two lake parts. If the ratio of WB / EB water mineralization for 1929-1969 was 0,24-0,35 (on average it is 0.29), then in the period from 1970 to 1987 this ratio was 0,37-0,44 (on average it is 0.41).

The general character of the mineralization distribution in all the considered periods remained the same; the mineralization increased continuously in the direction of the Ili River mouth to the eastern extremity of the lake. At the same time, water mineralization at the eastern and south-eastern coasts of the western part of lake has always been higher than in the western and north-western coasts (Kwon et al., 1991). Water mineralization of the lake in the site where it falls into the Ili River was 1.25 in July 1985, in 1986 - 1.12, in 1987 - 1.02 g/l. Approaching the eastern coast of the lake, water mineralization increases on average (according to the 1985.) up to 1.48 in the second site; further up to 1.95 in the third site; in front of the Sary Esik strait - up to 2.27; near Algazy island - up to 4.01 and near the end eastern coasts - up to 5.81 g /l. A similar pattern was observed in the following years (1988-1994). Thus, there is a more than 4-fold increase in salinity.

Moreover, with the increase of water mineralization across the entire lake from the West to the East, mineralization grows in the transverse direction from the South to the North. Such mineralization distribution is basically explained by desalinating effect of Ili River and flowing waters of WB. Flows in this part of the lake due to the inflow of the same Ili River water and evaporation significantly affect have a great influence on the character of the levels of mineralization in WB.

In contrast to the strongly shown horizontal stratification of water mineralization, vertical stratification on the lake is almost absent due to the good mix of water masses by frequent and strong winds. Orographic and climatic heterogeneity of the territory, hydrogeological and hydrological conditions of the Lake Balkhash basin, land cover areas, and intensive hydrochemical and hydrobiological processes determine the distinctive properties of the investigated water body. In connection with the above-mentioned factors, Lake Balkhash should be characterized as a unique ecological system.

Conclusion

Thus, the research of terminal lakes in Central Asia in recent years showed that they, as sediment and salt accumulators in their extensive catchment basins, also have a number of emergent properties. These properties are determined by exceptionally high solar radiation, strong winds, greater evaporation, shallow water, and developed water biosystems; and their resulting high desalination effect on these lakes is pretty much significant for the entire region. Therefore, neither the Aral Sea can be considered as a "nature mistake" (Tursunov, 1997), nor Lake Balkhash - a "fresh-water lake without a source, in the country with a dry continental climate among deserts, where rainfall annually receives less than 200 mm - a geographical paradox" (Berg, 1960). On the contrary, they represent a natural and important component of a complex natural and economic system operating in an arid climate.

5.8 Lakes of Northern Kazakhstan

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Introduction

Kokshetau territory is part of Northern Kazakhstan. About half of all lakes in Kazakhstan are concentrated in this region. However, in the last 20 years they have been exposed to a range of human impacts, due to their use within agricultural activities, as well as for tourism purposes. As a result, their water volume has reduced and their eutrophication is going on. In particular, exceedence of a tolerable level in the concentration of a range of pollutants relative to maximum permissible concentration (MPC) identified for the lake waters e.g. fluorides, copper and sulphides. Hence, North Kazakhstan, including the Akmola region, incurs significant deficits of high quality water resources, both in terms of surface and groundwater. At one time intensive development of virgin lands has had negative impact on the surface water quality indicators such as increasing pesticide concentrations. Ploughing is often undertaken during periods of snow melt (i.e. April-May) as a way to enhance soil moisture content, increasing the amount of water infiltration to the groundwater. As a result, significant amount of the land runoff water is lost for the lakes, especially for the shallow ones, since the water volumes in many of them are going down. Lakes sizes are decreasing. A further impact is an increase in the salt levels both in the water bodies and in soils surrounding these lakes. There has been no support in tackling these issues on the part of State bodies such as the Committee on Water Resources in implementation of urgently needed global projects to address these challenges; once the idea to turn the course of some of the Siberian rivers towards Kazakhstan as a way to improve water supply of the northern regions in Kazakhstan (Vilesov, 2009) was about to develop into a “century project”. However this project has not been implemented.

Water systems in Kazakhstan

In the Akmola region there are no whatever significant reserves of groundwater, since the stocks of groundwater are mainly localised in areas of fractured rocks, dispersed throughout the territory. Most of these waters are weakly mineralized (on average the lake mineralization ranges from 325 - 475 mg/l) (Vilesov, 2009). The main water arteries of Akmola region are the Yesil river, with tributaries including the Nura-transit, the Chaglinka river, the Seleta river and several minor rivers (in terms of both their length and hydraulic capacity). Rivers throughout the Akmola region do not have continual inputs from groundwater bodies, and only receive inflows from surrounding lands during snow melt or periods of heavy rains (i.e. they have no permanent flow). However, there are many lakes on the territory; dozens of lakes occupy upland hollows and elevated plains within the Akmola region. These lakes can be either freshwater or saline in nature.

Overview of types of impacts on water bodies in North Kazakhstan

Almost all the lakes there are drainless (i.e. a lake has no surface flow but is fed by the groundwater) and are characterized by sharp fluctuations in water level. The water level in these lakes depends on the ratio of input and debit processes (e.g. combination of abstraction and evaporative processes). In spring snow melt water bodies contributes to the water level of many lakes. This source of inflow gradually reduces with the onset of summer, with episodic heavy rains leading to temporary increases in volume. However, in between heavy rainfalls some shallow lakes may periodically dry up. Apart from these permanent water bodies, there are also the so called seasonal steppe water saucers (‘flat-footed’ depressions filled with water). Many steppe water reservoirs are used for recreational purposes, as sites for sanatoriums and health resorts etc. They are also sources of surface water for economic activities in the areas of these lakes, thus offering benefits the combination of mineralization levels of the waters and the aesthetic nature of the landscape. The lakes of the Akmola region have suffered relatively higher levels of negative impact (e.g. climate and anthropogenic effects) compared to water resources of other regions of the country, since agriculture is actively developing in this area. The process of eutrophication and irreversible pollution resulting from long-term intake of water for economic needs has significantly impacted many of the water resources and resulted in deterioration of number of quantitative and qualitative indicators of these water bodies' (e.g. higher levels of nutrients). The degree of eutrophication in many lakes of the region has increased due to the increasing discharge of wastewater volumes from residential areas. Lake Belenkoye proved to be the most susceptible to eutrophication in the Akmola region. This degradation in water quantity and quality is not only observed in rural and urban areas, but also in water bodies located within national parks such as Burabai, and in specially protected areas e.g. the Copa Lake (located Kokshetau region). In order to understand the dynamics of water quality, the quality of surface waters is assessed in comparison with concentrations specified within the polluting substance index (PSI) (see Table 5.8.1)

Table 5.8.1 Criteria of surface water quality based on PSI (Water Resources of Kazakhstan in the New Millennium, 2004)

Quality class	Characteristics of water quality	PSI*
1	Very clean	≤ 0,3
2	Clean	0,31 - 1,0
3	Moderately polluted	1,01 - 2,5
4	Contaminated	2,51 – 4,0
5	Dirty	4,01 – 6,0
6	Very dirty	6,01 – 10,0
7	Extremely dirty	> 10,0

*PSI values are an aggregated index of six parameters (including dissolved oxygen, easily oxidized organic substances, ammonia nitrogen, nitrite nitrogen, phosphorus, phosphates and petroleum products).

Due to the increasing anthropogenic load (e.g. construction of new tourist facilities), positive changes in ecological condition of several lakes in the Akmola region e.g. Burabai, Big Chebachye, Small Chebachye, Shchuchye and Copa are minimal if any at all (see Table 5.8.2) (Newsletter on the Environment of Kazakhstan, 2013).

Table 5.8.2 Classification Dynamics of lakes in Kokshetau region, 2012-2013 (Newsletter on the Environment of Kazakhstan, 2013)

	January 2012	December 2012	December 2013
Copa lake	very dirty	moderately polluted	moderately polluted
Burabai lake	clean	clean	clean
Big Chebachye lake	polluted	polluted	polluted
Small Chebachye lake	very dirty	very dirty	very dirty
Schuchye lake	moderately polluted	moderately polluted	moderately polluted

Overview of water quality in selected lakes in North Kazakhstan

Data in Table 5.8.2 indicates that from 2012 to 2013 lake water quality has not changed significantly in any of the five water bodies for which the data is reported. Thus, the lake water of Burabai consistently belongs to the "Clear" class and the lake Small Chebachye to "Very dirty." Analysis of the main hydrochemical indices for 2012-2013 showed that such pollutants as fluoride, sulphate, nickel, barium and copper exceeded the maximum permissible concentration (MPC) set by the Ministry of Environmental Protection of RK in the standards on sanitary requirements for water sources, drinking water intake places, drinking water supply, for cultural and household water use and security of water bodies (2012; Table 5.8.3). The MPC of harmful substances is defined as the maximum concentration of harmful substances which, for a certain time of exposure, does not affect human health, ecosystem components and/or the natural community as a whole.

The greatest MPC excess in the lakes considered was observed for fluoride (Figure 5.8.1).

Table 5.8.3 The maximum permissible concentration of harmful substances permitted in fishery water bodies in the Republic of Kazakhstan (Newsletter on the Environment of Kazakhstan, 2013)

Name	MPC (mg/dm^3)	Hazard Class
Copper	0,001 (compared to natural background concentrations)	3
Sulphates	100	
Fluorides	0,05 (total content not exceeding 0,75)	2
Chlorides	300	

Figure 5.8.1 shows the change of the fluoride content over the time period reported. For example, in Burabay Lake the fluoride content increased from 3.3 mg/dm^3 to 4.3 mg/dm^3, in the Big Chebachye the values decreased from 11.1 mg/dm^3 to 9.1 mg /dm^3 and in the Small Chebachye from 11.9 mg/dm^3 to 9.4 mg/dm^3. In Schuchye Lake the fluoride values increased from 6.6 mg/dm^3 to 7.0 mg/dm^3 (Table 5.8.3). While analyzing the water quality of these lakes, it is advisable to consider the changes month by month (Figure 5.8.2) to better understand the environmental behaviour of the lake water chemistry.

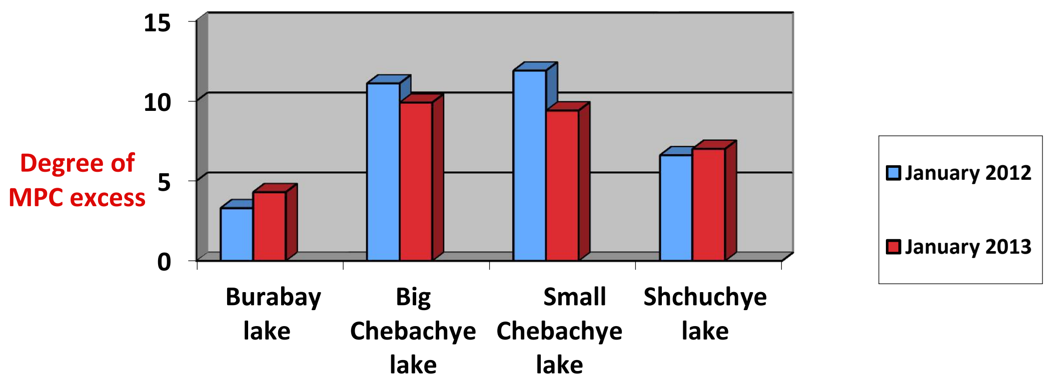

Figure 5.8.1 Degree of fluoride MPC excess in selected lakes in the Kokshetau region

Data indicates that the exceedence number of the MPC on a month by month basis varies in association with seasonal changes in water quality, as well as with the level of activity of tourism on the lake shore. In addition, exceedence of the MPC is influenced by the natural geology of the lake basin substrates. Levels of sulphates and Cu exceeding the MPC were also reported in various water bodies (Table 5.8.3). In January 2013 the contents were distributed as shown in Figure 5.8.3.

It it can be seen that the MPC of copper is exceeded in all four lakes and the MPC of sulphates in Large and Small Chebachye lakes. By December 2013 the situation had changed (see Figure 5.8.4). Such differences of copper content in the lakes are due to seasonal changes in the water flow, as well as by anthropogenic loads.

As can be seen from the Figure, in December 2013 hydrochemical indicators changed compared to January 2013 (Figure 5.8.3), copper content decreased in all lakes. Excess of MPC sulphates was registered at the beginning of the year in the Big and Small Chebachye Lakes.

Conclusion

Deterioration of the lake water quality and quantity in North Kazakhstan, and specifically in the vicinity of Kokshetau, is associated with the promotion of tourism activities on water bodies and increasing agricultural activity. Many of the lakes are part of the national parks, where tourism is currently actively developing.

In addition, discharges of wastewater from agricultural and urban areas to these lakes have a negative impact. Summarizing the above, it should be noted that the MPC of fluoride, sulphate and copper is exceeded in the lakes considered. This is of concern because MPC excessive levels water bodies may be hazardous for human health; they can cause cardiovascular system dysfunction, urinary and gall stone disease, teeth loss, adverse effects on bone and nervous system. To change this negative situation, it is necessary to reconsider the extent of tourist activity in the region, as well as to ensure rational use of water resources of these lakes by different sectors, including agriculture and domestic water supply and discharge.

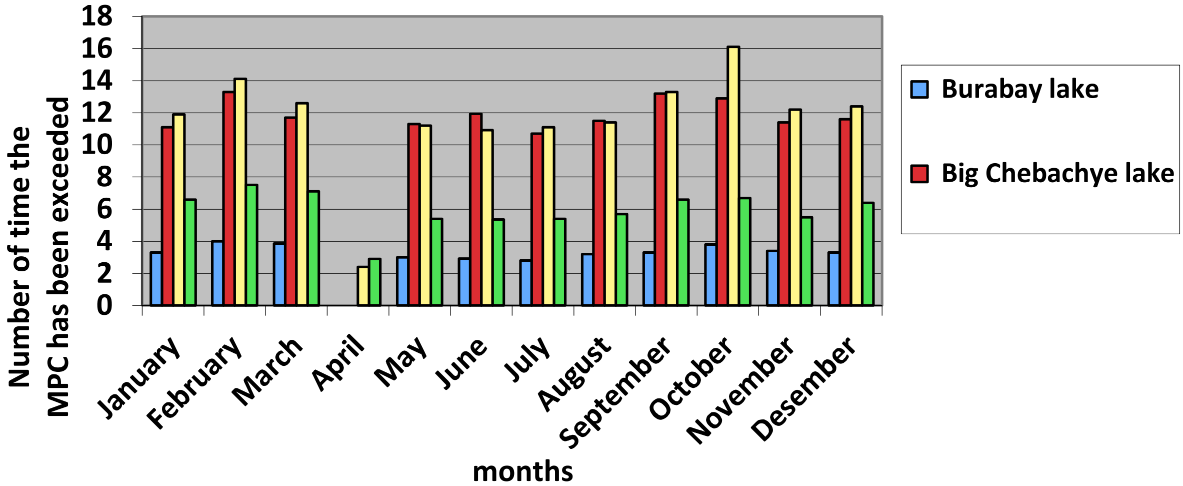

Figure 5.8.2 Number of times the MPC for fluoride has been exceeded (monthly in 2013)

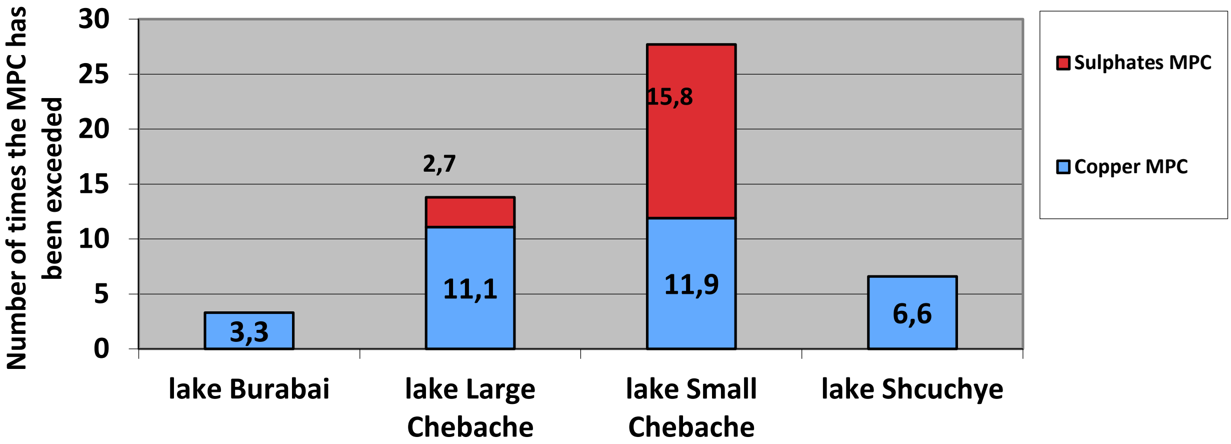

Figure 5.8.3 Number of MPC exceedences of sulphate and copper concentration (January 2013)

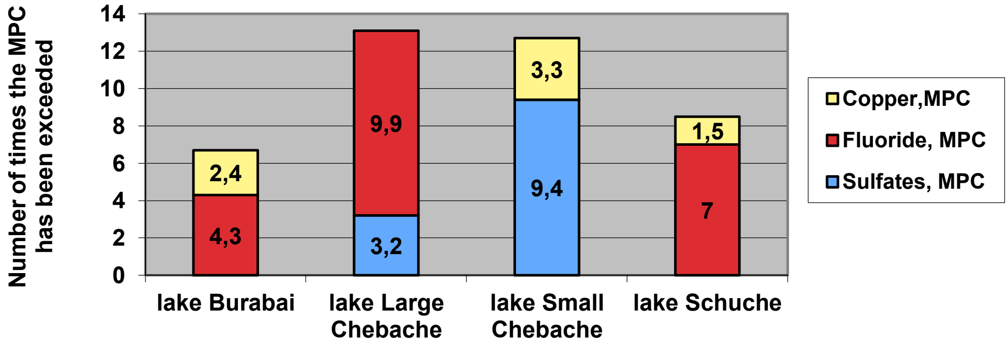

Figure 5.8.4 Number of MPC exceedence of sulphate and copper concentrations in selected lakes in December 2013

5.9 Current state of fishery reservoirs of the Republic of Kazakhstan

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Introduction

The four major water basins of the Republic of Kazakhstan (the Ural-Caspian, Aral-Syr Darya, Balkhash-Alakol and Zaysan-Irtysh) are transboundary. These basins generate almost all the river water resources of Kazakhstan, currently estimated at 56.5 km^3. Further 44.0 km^3 per year come from the rivers originating in neighbouring states. These basin's water resources are the main fishery waters of the country, producing approximately 97% of all fish caught in the Republic. Water resources are generally used in an integrated manner across all sectors of the economy. The influence of anthropogenic factors on fishery waters is changing the qualitative and quantitative composition of the fish fauna (Isbekov and Alpeisov 2014). In particular, increases in ichthyomass (fish biomass) of some of non-commercial fish species (e.g. crucian, roach) has led to a sharp decline in commercial species (e.g. sturgeon, carp, etc.) which fed on them. In some waters the balance between predator and other species of fish has been disturbed. These negative effects lead to increased food competition, reducing the growth rate of fish and increasing fish mortality rate.

Changes in fish community structures

As a result of re-location of fishery stocks and river modifications (e.g. dam constructions) on the rivers in the Ili-Balkhash basin, some native species (e.g. *Schizothorax, Perca schrenkii*) have become rare and are listed in the Red Book of Kazakhstan (which records species, endangered and/or at risk of extinction), alongside with other endangered species (e.g. *Salvelinus and Gymnodiptychus dybowskii*) no longer inhabiting the estuary of the Ili–Balkhash basin (Isbekov and Timirkhanov 2008). Over the last century a further number of species have disappeared. For example, in the Caspian Sea and Aral Sea, the caspian and aral salmon, white salmon etc. and in Zaysan-Irtysh basin the trout and the white salmon are no longer found. This has resulted in these species being recommended for inclusion into the Red Book (Anonymous, 2006). There is also an ongoing invasion of alien fish species via transboundary rivers (vice-versa). Five new species of fish have migrated from China to Kazakhstan waters in the last decade, specifically to Balkhash-Alakol basin. Their numbers are increasing rapidly, which can lead to destabilization of native Kazakh ecosystems (Asylbekova et al. 2002).

Impacts of changes on water quantity

Monitoring transboundary effect on fish populations, such as introduction of other species, provides evidence of adverse changes in many fish waters. In recent years hydrological regime of the Ural-Caspian basin is affected by dramatic changes in natural factors such as reduced runoff volumes. Reproduction efficiency of sturgeons is directly dependent on the water regime of the Ural River, whose annual run-off volume is not constant and has fluctuated over the years from 12 to 5 km³. Figure 5.9.1 shows that the maximum water levels recorded in the lower reaches of the river Ural over the last 7 years.

recent years, river flow is reduced in the Black Irtysh from an annual average flow of 9 km^3 to 4-6 km^3. Water storage capacity in the Irtysh cascade is such that it can partially compensate for the loss of water (associated with increased water use in China). Figure 5.9.2 shows changes in water level over the period of 2002-2012. There

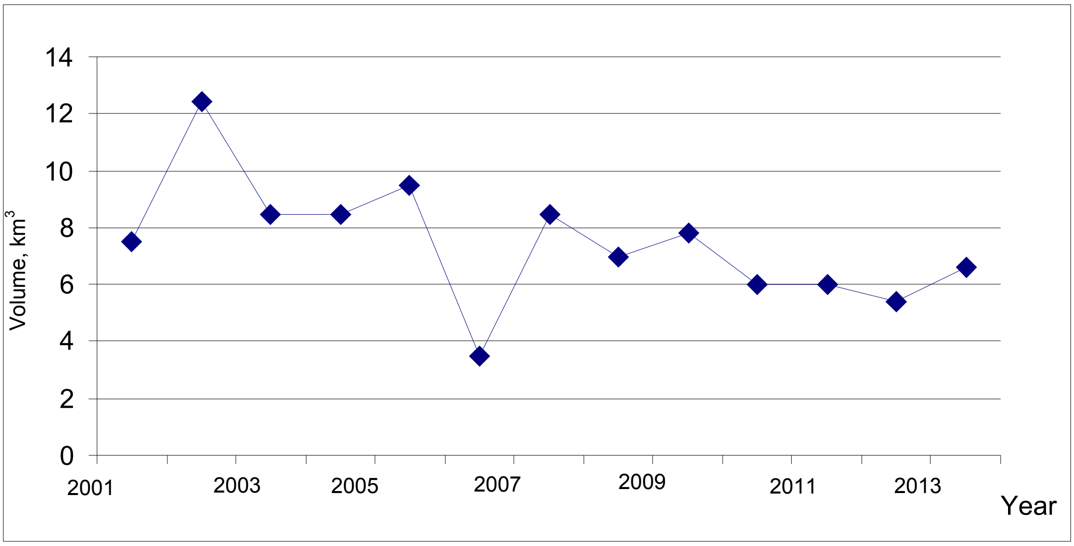

Figure 5.9.1 Maximum water level recorded in the river Ural over the last 7 years

Carp spawns when water temperature goes above 25 °C, which occurs in spring. However, by this time of the year, the water level goes down in the river and coastal spawning grounds are non-productive. The flow characteristics of the upper zone of the Ural River towards the lower zone is not conducive to late spawning, and hence the lower spring water levels have led to reduction of spawning areas for Ural River sturgeon (KazRiF, 2014). In the Zaysan-Irtysh basin, the most productive and important water bodies for fisheries are the Buhtarma Reservoir and Zaysan Lake. Hydrologically these two water bodies function as a single reservoir. It is predicted that reductions in water intake of 1 km^3 in this basin would lead to water levels decrease by 32 cm over a 170 km^2 area. In these conditions, spawning grounds tend to disappear. Under a scenario where water intake is reduced by 3 km^3, the water body ceases to exist as a single reservoir, and is split into two water bodies. If water intake reductions of 1km^3 results in significant fishery losses then a 3km³ reductions will have catastrophic consequences for biocoenosis. Bukhtarma Reservoir will be divided into two separate water bodies resulting in the loss of almost all fish spawning grounds (Kulikov 2010)

Fluctuations in water levels of up to 5m have been registered in Bukhtarma Reservoir and Zaysan Lake in years with differing flow conditions. In were notable low water periods in 2008-2009 and 2012. The reason of these low water years is not yet established. However, data suggests that their frequency is increasing, with such low-water periods reported in 1983-84, 1992, 1999-2000, 2008-09 and 2012.

Whilst the natural cycle of water availability plays an important role in ensuring water for the region, it is also heavily influenced by the Irtysh River hydroelectric dams. In recent decades this river has suffered from the lack of water, not only for energy and agriculture, but also for fisheries. At the same time, against the background of inefficient management of fish stocks and their protection in low rainfall years, there was a sharp growth of uncontrolled fish catches. This was primarily due to the concentration of fish in localized areas and subsequent increases in its catch (Zarkenov, 2011). The fish fauna of the Irtysh River below the cascade of hydroelectric stations is the most diverse in terms of variety of species, including both native and invasive species. The latter come either from the upstream reservoirs and/or the middle reaches of the river. In case of variations in water level and in temperature within the range which occur on an interannual basis, fish fauna of the Balkhash-Alakol basin will stabilize over a period of 4-6 years.

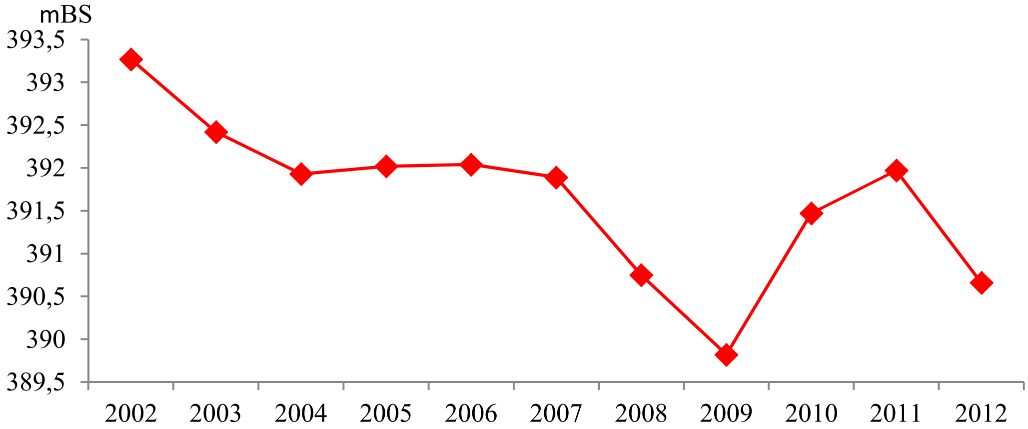

Figure 5.9.2 Changes in the average annual water level of Bukhtarma Reservoir (including Zaysan Lake) 2002-2012 (m)

The stabilization of water levels in recent years has created good conditions for the reproduction of commercial fish species. Fish stocks in the Kapshagay Reservoir depend on water level and the level of fishing. For some species of fish (e.g. carp, bream etc.) there have been marked negative trends whereby populations are dominated by older fish. In addition, the most valuable commercial fish species in Alakol Lake - especially carp and perch – have reduced in number due to overfishing. An important outcome of research studies undertaken by KazRIF is the selection of two types of bream; fast growing and slow growing sub-species. Under the recently implemented fishery management plan, the rapidly growing type has been withdrawn and replaced by the slow growing ones (Danko and Skakun 2008)

Reducing the volume of the Ili River flowing into Lake Balkhash will significantly increase the mineralization and, as a consequence, there will be a significant reduction in the biomass of fish stocks as a result of a change from freshwater species to brackish water species. In the worst case, it is predicted that this may lead to a subdivision in fish population characteristics within the two separate reservoirs. Deterioration of water availability is reflected in the upper portion of the Ili River and Kapshagay Reservoir as well, where research has established that fish breeding efficiency largely depends on the volume of the transboundary river flows.

The changes in contributing runoff levels as a result of both global warming and increasing water intake in China cause serious concerns regarding sustainability of fishery stocks. Of particularly worry is the status of sturgeon populations, given that their size and weight

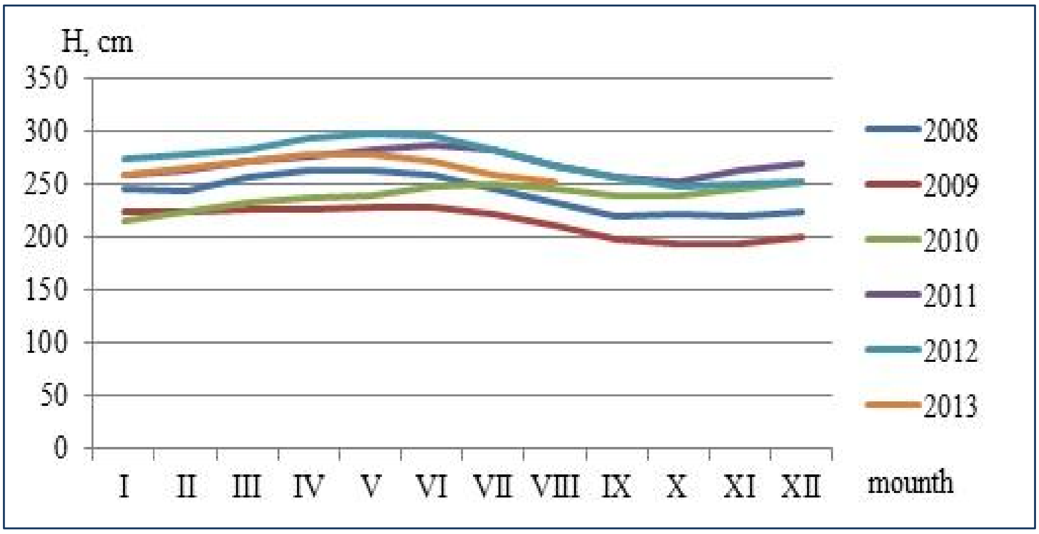

Figure 5.9.3 Variations in the height of the surface water levels of Balkhash Lake over the last years 2008-2013 (cm)

indicators report a sharp decrease, destruction of the natural age features of fish populations and reduction in the number of females. These changes are more apparent and widespread in the Ural River in relation to the stellate sturgeon *(Acipencer stellatus*) (Koishibaeva and Baimukanov 2006). Over the past few years, the number of stellate sturgeon migrating to spawn in the river Ural has decreased by 35,000 individuals (equivalent to 39% of the population). The numbers of migrating fish such as beluga/ great sturgeon (*Huso huso*) and sturgeon (*Acipenser gueldenstaedtii*) have, in recent years, fallen to quite a low level. The minimum catch of other species such as thorn fish (*Acipenser nudiventris)* also continue to decline suggesting an overall reduction in the habitat. The average number of sturgeon in the eastern North Caspian is also reduced (Bokova et al. 2013)

With the construction of the Kokaral dam, the non-salt area of the Aral Sea has increased significantly, expanding the range of native fish species. Comparative stabilization of the hydrological regime and, more importantly, reduction in salt levels of the Small Aral Sea has become the foundation for the restoration of populations of some commercially valuable species of fish e.g. carp, bream, pike perch (Ermahanov et al. 2013). According to data provided by the Kyzylorda regional Centre of Hydrometeorology (2013) the volume of river flow in the Aral Small Sea over the past seven months was 2816 million m^3. This is a reduction in its volume and is associated with an overall reduction in annual run-off within the river Syrdarya which fed into the Aral Small Sea within Kazakhstan (Table 5.9.1).

Conclusion

Almost all fishery waters in Kazakhstan are transboundary in nature. Their hydrological regime and fish production are largely dependent on the water management policies and practices implemented by neighbouring countries (e.g. the Russian Federation, Uzbekistan and China). In this context, sustainable use of transboundary bioresources is possible only in case all Border States undertake concerted actions towards integrated water resource management on the basis of international agreements. Conservation of fish biodiversity of in transboundary basins and its sustainable use is impossible unilaterally.

Table 5.9.1 The actual volume of the river Syrdarya flow-off (million m^3)

year	month							sum
	January	February	March	April	May	June	July	flow-off
2010	534	926	606	814	967	730	801	5378
2011	1045	554	800	641	258	134	63	3495
2012	488	637	755	581	97	72	70	2700
2013	500	670	765	620	110	83	68	2816

5.10 Biological indication and screening of polluted water systems in Kazakhstan

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Introduction – General state of the research

This article provides research data that the use of bio-indicators, not only expands the research area of water monitoring, but also supports the development of a more detailed understanding of the effects of pollution on biota. Data were gathered during a 2013 study conducted on the river Chaglinka, Kaszakhstan, using the methodology outlined in the textbook (Makrushin, 1974), generally referred to as the biotic index, developed by English scientist F. Woodiwiss (1964).

Context of the research methodology

Currently, environmental assessments is traditionally carried out by determining the concentration of potentially harmful effects of substances in the environment, and comparing the results with the legally established maximum permissible concentrations, according to the legal document of the Ministry of Environmental protection of RK on sanitary requirements for water sources, water intake places for drinking purposes, drinking water supply and places of cultural and household water use and security of water bodies (RK, 2012). It is possible to forecast the effects of contaminated water on humans if the evaluation of toxicity includes not only analytical methods, but also the biological diagnosis of impact on living organisms. Makrushin (1974) states that the biological analysis of water quality, with respect to organic pollution, is suggested to offer an advantage in comparison to conventional chemical techniques, in that it is a direct assessment of the status of aquatic ecosystems and their individual components. The main idea underpinning bio-monitoring is that aquatic organism reflecting the prevailing environmental conditions in the water body. Hence those species for which conditions are not favorable reduce in number or die-out, and are replaced by species with different types of needs. Bio-monitoring is widely used for the classification of rivers on benthic macro invertebrates.

The basis behind the International Organization for Standardization (IOS) system of river classification is the comparison between the behaviour of benthic macro invertebrates in a clean unimpacted environment and that in the environment being assessed. The IOS systems identifies five classes of water quality based on an analysis of the structure and relative abundances of benthic macro invertebrates identified (Table 5.10.1).

The use of bio-indicators

Bio-indication of water pollution is a system to support an evaluation of the level of pollution of a body of water based on the state of its aquatic organisms and their ecological communities. Aditionally, the quality of the receiving waters is estimated on the bases of the functional characteristics of bio-cenosis. The use of bio-indicators involves assessments of organisms, species population and community, characterized by specific features of the habitat which can point to specific changes in environmental conditions. Water quality is then judged according to the prevalence of such organisms within the target

Table 5.10.1 Biological classification of rivers

Classification of water quality on benthic macro invertebrate	*Characteristic*
High	Natural vital activity of benthic macro invertebrates.
Good	Biological community not affected
Moderate	Several affected biological communities
Poor	Moderately affected biological community
Bad	Strongly affected biological community - extreme reaction to anthropogenic pollution.

water body (Kaplin, 2001).

When selecting bio-indicators, Odum (1975) offers the following guidelines:

1) Senotopic species (i.e. those able to tolerate a narrow range of environmental changes only), are typically better indicators than eurytopic species;
2) Large species in size are usually a better indicator than smaller species as they cannot get into the water at the moment of sampling taken for the research;
3) Choosing the species (or group of species), used as an indicator of the impact of various factors, it is necessary to have a field and experimental data on the limiting values of this factor in view of possible compensatory reactions and tolerance type (group of species);
4) The use of numerical relationships between various species (populations or communities) is more revealing and provides a more reliable indicator than the number of one type of species.

Bio-indication methods are divided into two types: firstly, the assessment of the presence (or absence) of specific species of bio-indicators; and secondly, the levels of specific pollutants bio-accumulated by bio-indicator species. Recording the numbers or community structure of bio-indicator species gives an indication of the impact of environmental factors on the state of a species or population in comparison to an unimpacted reference state. Bioaccumulation by indicator species is based on an assessment of the level of pollutants accumulated by bio-indicator plants and animals (e.g. the lead content in fish liver that are at the end of the food chain can reach 100-300 MPC). Maximum permissible concentrations of harmful substances are those for which for a certain time of exposure does not affect human health or the components of the ecosystem and natural community as a whole. During the research on the river Chaglinka, Kazakhstan MPC is presented in mg/dm3.

Recording indicators' responses to changes of environmental conditions, by change in, for example, the number, tissue damage, somatic symptoms and change in growth rate. Accumulative indicators concentrate polluting substances in the tissues, organs and body parts of various species. Comparison of pollutant concentrations in target species, considering the value of MPC, is then used to determine the degree of contamination of the environment.

Laboratory or field testing?

However, research that uses living organisms *in situ* has a series of drawbacks in comparison with research using laboratory methods e.g. carrying out research in strictly regulated conditions and under permanent control. For example, field studies do not allow marking of specific contaminants reacting immediately to whole complex substances. In contrast, physico-chemical methods in a laboratory provide direct quantitative and qualitative characteristics of specific pollutants of concern (e.g. its presence and its concentration), but only indirectly allow judgements to be made about its biological impacts in an actual living context.

In most unimpacted water bodies, i.e. water bodies containing low concentrations or insignificant content of impurities of organic matter and nutrients, the number of aquatic species and their abundance is usually lower than in water bodies where the concentrations of organic matter, such as nitrogen and phosphorous compounds, are present in moderate concentrations. For many aquatic organisms living in meso- and eutrophic waters, a moderate level of contamination is the allowable state of the environment. Species which can only be found within a narrow range of environmental conditions and cannot withstand even minor increases in concentration of selected pollutant are good indicators of low levels of contamination (Chibilev, 1998).

Characteristics of a water body's contamination status

One of the major characteristics of the state of a water body is the level of its saprobity. The term saprobity relates to the physiological and biochemical properties of the organism (saprobionts) which determines its ability to live in waters with a specific content of organic substances.

The following zones of saprobity are given by Dolgov, Nikitinskiy (1927). (Table 5.10.2).

Oligosaprobic zones are considered to be clean waters: zones where nitrogen is present in the form of nitrates; the water is saturated with oxygen; insignificant content of carbon dioxide; and hydrogen sulfide is not detected.

Oligosaprobic waters typically contain many species of golden and dinoflagellate algae. Algal blooms do not happen.

Beta mesosaprobic zones contain nitrogen in the form of ammonium compounds, nitrates and nitrites. Oxygen supersaturation is frequently observed. Alluvium is typically yellow. Oxidative processes occur and there are much detritus i.e. dust mites in the water column of dead organic matter.

Alpha mesosaprobic zones are characterized by active self-cleaning, the characteristic biochemical process in redox, and hydrogen sulfide is present. Such waters contain blue-green algae, diatoms and green algae. Alluvium is gray and organisms adapted to low oxygen content are present.

Polysaprobic zones are characterized by low oxygen conditions. This water is characterised by decomposition of organic matter processes with the formation of iron sulfide in sediments and hydrogen sulfide.

Table 5.10.2 Water quality assessment of saprobity (Dolgov, Nikitinskiy, 1927

Degree of saprobity	Condition of reservoirs	Water quality class	Ammonia nitrogen, mg/dm^3	Nitrate Nitrogen, mg/dm^3	Phosphates mg/dm^3	Oxygen	BOD, mg/dm^3	Coli-index (cells per cm^3)
Oligosaprobic zone	Clean	1-2	<<0,04	<0,03	<0,05	90-100	0-3,3	<50
Beta mesosaprobic area	Moderate-contaminated	3	0,04-0,08	0,03-0,05	0,05-0,07	80-90	3,3-5	50-100
Alpha mesosaprobic area	Contaminated	4	0,08-1,5	0,05-1,0	0,07-0,1	50-80	5-7,7	100-1000
Polysaprobic zone	Dirty, grimy	5-6	1,5-5,0	1,0-8,0	0,1-0,3	5-50	7,7-10	1000-20000

Many of the key indicators of aquatic life are absent from oligosaprobic zones to the polysaprobic zone: reduced dissolved oxygen contents; nitrates are converted into the more toxic nitrites and ammonium compounds; sulfites are passed to sulfates then to sulphide till forming hydrogen sulphide.

For hydrobiological analysis all groups of organisms e.g. planktonic, zooplanktonic and benthic can potentially be used. Each group of organisms as a biological indicator has its own advantages and disadvantages, which determine the limits of its application as a bio-indicator. An overview of a several methods of bio-indication is given in Table 5.10.3:

The Woodiwiss method

One of the most reliable and widely used methods of biological water quality assessment is the Woodiwiss biological index (Patin, 1981). The Woodiwiss index takes into account two parameters of a benthic community in parallel: the overall diversity of invertebrates, and the presence of specific indicator organisms in a receiving water body. These groups combined animals characterized by their particular degree of saprobity. To assess the state of water bodies using the Woodiwiss method involves the following steps:

1. Identify the presence of any indicator groups in the investigated water body. This process starts with an examination of waters for the species which are more sensitive to contamination such as stoneflies (Plecoptera), and mayflies (Ephemeroptera) followed by caddis flies (Trichoptera), etc. If the investigated water body contains the nymphs of stoneflies (Plecoptera) - the most sensitive bio-indicator organisms (see Figure 5.10.1) further work is done on the first or second row of Table 5.10.4. If there are several species of stoneflies, we should work on the first row of the table. If there is only one species, we work on the second row.
2. If nymphs of stoneflies are not present in the collected samples, samples are examined for

mayfly nymphs (*Ephemoptera spp.*) the next most sensitive indicator group. If these are found we work with the third or fourth row of the table 5.10.4. In the case of the mayfly nymphs absence, the presence of caddisworms (*Trichoptera spp.*) are sought.

Table 5.10.3 Characteristic of biological methods of assessment of contamination of water

Name	Advantages	Disadvantages
Woodiwiss Biotic index	Predefined sequence of the order of extinction of indicator organisms with associated increasing of levels of pollution.	Not suitable for lakes and ponds.(low species richness of benthos index values are directly dependent on the presence of indicator groups: larvae of mayflies, stoneflies, caddisflies).
Goodnight - Uotleya index	This method is used to determine water pollution by organic substances (this is very simple methodology: calculated as the number ratio of oligochaetes to the total number of organisms in the sample)	Is used for the analysis of materials of bottom grab samples only
Shannon index	Suitable for the purposes of comparison, in cases where separately diversity components is not interested.	Impossible to include all kinds of community in the sample.
Mayer index	Suitable for all types of water bodies.	Accuracy of the method is low (it is not necessary to determine the invertebrate up to species).

3. Assess the overall diversity of benthic organisms.This technique does not require all species collected to be identified to the level of species. It is enough to determine the amount found in samples of benthic organisms. For example, for each group a more general level of classification is accepted e.g. presence or absence of any kind of flatworms, oligochaetes, shellfish, leeches, crustaceans, water mites, stoneflies, lacewings, beetles, mayflies etc..
4. 4. At the intersection of the row and column in the table we find the value of the index of Woodiwiss characterizing an analyzed water body (Table 5.10.4).

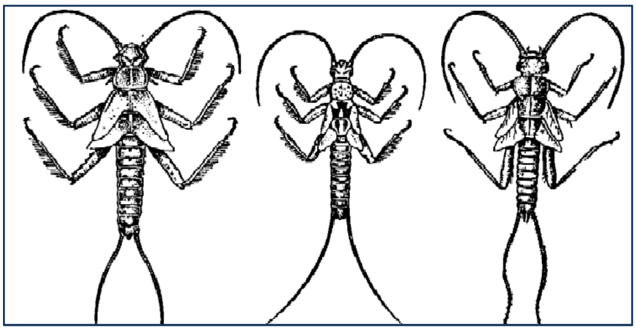

Figure 5.10.1 Larva of stoneflies

Based on the above analysis, if water scores from 0-2 points, it is classified as very dirty. This designation means waters are polysaprobic and the water body's ecology is strongly depressed in reference to an unimpacted state. A score of 3-5 points defines the water body as having an average degree of contamination (i.e. a alpha mesosaprobic status). A score of 6-7 indicates a slight level of contamination of the water body (e.g. a beta mesosaprobic status).

A designation of clean (or oligosaprobic) waters requires a score of 8-10.

Case study from the Chaglinka River

During a field study which monitored the average flow of the river Chaglinka, in September 2013, the Woodiwiss method was applied to 3 water samples. Representatives of sensitive to contamination-tolerant indicator group - mayfly nymphs were found in 1 sample. Therefore, we need to work with the third row of the table 5.10.4. Among the benthic organisms collected, representatives of ten different groups were observed. We need to choose the column "Total number of groups 6-10". At the intersection of this column and the third row we find the index - 7 points, i.e. there is a slight contamination of the receiving water. The data obtained give an idea about the pollution level of the river Chaglinka, on the basis of which we can conclude about the need for water treatment activities.

Table 5.10.4 Biotic index of Woodiwiss

Presence of indicator species	Amount of indicator species	Total amount of groups of bottom dweller					
		0-1	2-5	6-10	11-15	16-20	20+
Nymphs of stoneflies (Plecoptera)	More 1	-	7	8	9	10	11+
	1 species	-	6	7	8	9	10+
Mayfly nymphs (Ephemeroptera)	More 1	-	6	7	8	9	10+
	1 species	-	5	6	7	8	9+
Caddisworms (Trichoptera)	More 1	-	5	6	7	8	9+
	1 species	4	4	5	6	7	8+
Amphipods		3	4	5	6	7	8+
Water louse		2	3	4	5	6	7+
Oligochaete or larva chironomids		1	2	3	4	5	6+
Absence of all groups		0	1	2	-	-	-

Conclusion

Ecological assessment assumes long-term monitoring of the water body, which allows obtaining a number of observations required in statistical processing of information. This work requires considerable time and effort. However, it is difficult to overestimate the advantages of the Woodiwiss method for small river water quality assessment on organisms. The Woodiwiss method is versatile enough and simple. It does not require cumbersome mathematical calculations. The research results of the Chaglinka river condition, using the method of bioindication, showed that water quality could be determined by the species diversity of aquatic invertebrates. Water quality in water bodies depends on the level of anthropogenic load on them. Water quality and sustainability of natural ecosystems reduced in the areas most impacted by the humans' activities.

5.11 Integrated water resources management on irrigation systems in Kazakhstan

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Introduction

An important element of agro-industrial activities in Kazakhstan is irrigation farming. The sustainability of its application and further development depends mainly on the availability of water resources, the sources of which are primarily generated in transboundary regions of Central Asia outside of Kazakhstan e.g. China, Russia and Uzbekistan. Being located upstream, these countries have the first access to this finite resource. In most cases, the amount of water abstracted for the use in irrigation is high (about 70% of Kazakhstan water resources are used in irrigation). High levels of irrigation have led to degradation of several river basins, especially in the lower reaches of the rivers Syrdarya, Shu, Talas and Ili in Kazakhstan. Consequently, in the current situation increasing the availability of water for irrigation systems can only be achieved by developing methods of integrated water resources management. In developing such methods, integrated management must take into account a range of factors including soil and climatic conditions of irrigation systems, ecological-reclamation condition of irrigated soils, technical condition of canals and collector drainage systems of various orders, technology and crop watering regime and the quality of water resources (surface water, groundwater and drainage).

Surface water resources

This section aims to assist students (Bachelor, Master and PhD students) to become familiar with the characteristics of irrigation systems in Kazakhstan, ecological-reclamation situations and methods of rational use of water and land resources. Key drivers are to reduce costs, ensure optimal use of water per unit mass of crop and increase environmental sustainability in river basins. In general, Kazakhstan is characterized by an exceptional variety of natural conditions such as steppe, dry steppe and desert zones. These natural zones may be subdivided into the following categories: main steppe, desert, transitional steppe and dry steppe zone ecosystems.

In Kazakhstan, water scarcity is increasing. This is confirmed by a comparative analysis of natural and domestic river flows; the term natural flow refers to the annual volume of water in rivers whereas the term domestic flow refers to the annual river water volume minus water withdrawals for agricultural and industrial purposes. When water withdrawal for domestic needs in Kazakhstan was comparatively low (e.g. up to 1960), natural and domestic flow volumes were approximately equal. However, with increasing water withdrawals for irrigation and industrial purposes, domestic water volumes started to decrease sharply (see Table 5.11.1). As a result, the magnitude of the river natural flow volume was calculated theoretically, as the difference between the natural and domestic flow volumes used as the basis for establishing the magnitude of the flow reduction occurring within a specific river. Currently in Kazakhstan, there are not single large rivers, in which natural flows have not been severely affected by human activities. For example, according to Kazgiprovodkhoz (2010) the average domestic and natural flow volumes of the major rivers in Kazakhstan for the period 1935-2008 were 80.67 and 91.37 km^3, respectively (Table 5.11.1). Therefore, the average flow reductions of the largest rivers in Kazakhstan for the period 1935-2008 as a result of domestic activities made up 10.7 km^3.

In the late 1980's, the total volume of water used for agriculture, industry and communal-domestic economy was 30-35 km^3/year. The maximum amount of water used for irrigation was 20-25 km^3/year. Since 2000, water abstraction for irrigation has been stabilized at an annual withdrawal of 12 km^3. Irrigation systems in Southern Kazakhstan are mainly located on the territory of Aral-Syrdarya, Balkhash-Alakol and in the Shu-Talas river basins. According to the data of the Institute of Geography (Dostay**,** 2009) the average water flow within these basins is currently 49,9 km^3/year.The hydrographic network of Southern Kazakhstan is divided into three natural basins - the Caspian, Aral Sea and Balkhash. Basin Balkhash, which contains the rivers Karatal, Ayaguz, Lepsy, Aksu, Tentek and Ili as well as their tributaries, covers the whole Almaty region. In relation to natural and economic conditions, the Balkhash basin is divided into two water economy districts: the Ili district and the river Karatal, Aksu, Lepsy and Tentek district. The Aral Sea Basin covers Zhambyl, South Kazakhstan and Kyzylorda region and includes the rivers Shu, Talas, Asa Sarusy and tributaries of Syrdarya: Arys, Keles, Chirchiq, etc. The flow volume of the river Shu on the border with Kyrgyzstan ranges from 1,5 to 4 km^3. In the Kazakhstan part of the Syrdarya basin, the main use of water is that for the irrigation of crops.

Irrigation systems

In the early 1990s, the area of land irrigated for agricultural production in Kazakhstan was 2.36 million hectares. 5% of the total arable land contributes more than 30% of the total agricultural output in value terms. However, since the 1990s, due to the economic crisis, a steady decline in the amount of agricultural products obtained from irrigated lands has been observed. For example, since 1991, the area of irrigated land has reduced in total by1 million hectares, to the current value of 1.3946 million hectares for the year 2010 (Table 5.11.3). Today more than 90% of irrigated lands are located in the southern regions of Almaty, Zhambyl, South Kazakhstan, and Kyzylorda. The largest areas of irrigated lands are situated in the basin Syrdarya.

Crops cultivated in the irrigation systems located in the middle reaches of the Syrdarya (South-Kazakhstan region) include cotton, vegetables and melon cultures. On the lower reaches of the Syrdarya River (Kyzylorda oblast), rice, melons and fodder crops are primarily grown (Figure 5.11.2).

The area of rice cultivation in Kyzylorda region varies from 71.4-77.4 thousand ha, and in Almaty region from 11-13.2 thousand ha with irrigation waters applied at a rate of 20.000-25.000 m^3/ha. These rice crops are grown mainly on saline soils and on soils prone to salinisation. The large volume of irrigation water provides desalinization of saline soils. Recent rice yields are in the range of 4,29-4,78 ton/ha (Table 5.11.3).

In the Shu-Talas basin (located in the Zhambyl region) and Ili basin (the Almaty region), mainly winter wheat, sugar beet, alfalfa, maize for grain, vegetables and melons are cultivated (Figure 5.11.3). In the 1980s, the main crop in the Shu-Talas basin was sugar beets. In those years, the yield of sugar beet was within 35,0-40,0 t / ha. However, now sugar beet yields are 13,0-20,5 t / ha.

Table 5.11.1 Average volume of flow within the main rivers of Kazakhstan for the period 1935-2008 in km^3/year.

River	Post	Environmental flow		Reduction of environmental flow
		Natural	Domestic	
Syrdarya	Lower Tail-water Shardara reservoir	23,75	19,37	4,38
Ili	Kapshagai	14,97	14,15	0,82
Karatal	Karatal	2,84	2,84	0,00
Esil	Petropavlovsk city	2,10	1,82	0,28
Zhayik	Kushum village	11,14	9,53	1,61
Irtysh	Semiyarskoye village	30,31	28,61	1,70
Nura	Romanovskoye village	0,58	0,61	-0,03
Sarusy	Railwaystation Kyzul-Zhar	0,15	0,12	0,03
Tobol	Kostanay city	0,52	0,41	0,11
Turgai	Sands Tusum	0,32	0,32	0,00
Shu	Tasotkel village	3,47	2,08	1,39
Talas	Grodekovo village	1,25	0,83	0,42
Total		**91,37**	**80,67**	**10,7**

Table 5.11.2 Total of average perennial water resources of Kazakhstan, km^3

№	Waterworks basins	Flow formed outside Kazakhstan	Flow formed on the territory of Kazakhstan	Total
1	Aral-Syrdarya	14,630	3,360	17,990
2	Balkhash-Alakol	12,247	15,434	27,681
3	Irtysh	7,780	25,920	33,700
4	Ishim	-	2,588	2,588
5	Ural-Caspian	7,108	4,130	11,238
6	Nura-Sarysu	0	1,366	1,366
7	Tobol-Torgay	0	1,869	1,869
8	Shu-Talas	2,590	1,646	4,236
Total		**44,355**	**56,313**	**100,668**

Figure 5.11.1 Overview of the 8 Kazakh river basins (Kazgiprovodkhoz, 2010

Figure 5.11.2 a and b – a) Flooding of fields b) growth and development of rice (Syrdarya district of Kyzylorda oblast, 2012; Photo by: E. Zhaparkulova)

Figure 5.11.3 Growth and development of winter wheat and vegetables (pepper) in the basin of the Asa-Talas (2013; Photo: by R. Bekbayev)

Table 5.11.3 Sown area and yield of rice in Kyzylorda

Years	Sown area rice, ha	Yield, t/ha	Gross harvest, Ton
2009	71421	4,29	306396,1
2010	77459	4,71	364831,9
2011	77385	4,78	369900,3
2012	75427	4,77	359786,8

Compared with the 1980s, current crop yields for all crops have decreased by 25-50%. The reason for this is identified as on-going reductions in the efficiency of irrigation water delivery, related to a decrease in the technical level and the quality of the irrigation network as well as in the hydro-technical infrastructure. Other factors observed are (1) the deterioration of the ecological state of irrigated lands, (2) an increasing water resources deficit and the deterioration of their quality, (3) failure of farmers to strictly adhere to correct irrigation technology protocols and (4) in insufficient quantities of mineral fertilizers used and the failure to comply with good practices in terms of the timing of farming activities. Factors associated with the deterioration of the ecological state of irrigated lands are: increased salinity of soils, solonetzification and increased alkalization of the soils (Bekbayev and Dzaparkulova, 2013). Nowadays, approximately 50% of the irrigated land is saline and around 30% - solonetzic and alkaline (Figure 5.11.4).

Figure 5.11.4 Saline and solonetzic soils (Mahtaaral, 2009; Photo by: R. Bekbayev)

The use of saline and solonetzic soils for agriculture (both with and without irrigation)

Figure 5.11.5 Flushing and chemical reclamation of saline soils (Photo by: R. Bekbayev)

results in dramatically reduced crop production and water resources use (Vyshpolsky et. al., 2010). Therefore, such degraded lands should be meliorated, i.e., washed with water prior to their use for crop cultivation. Fertility enhancement of solonetzic and alkaline soils is achieved by chemical reclamation using phosphogypsum.

Technologies of watering agricultural crops

In increasing the efficiency of irrigated agriculture, a strong emphasis is placed on the technology used to irrigate the crops. Successful application of both water saving technologies and efficient technical watering means depends on the design and the technical equipment of the irrigation network. Widely used technologies include watering by (1) flowing water (2) deep constant furrows and (3) variable irrigation jets (Figure 5.11.6).

Under current production conditions, the length of irrigation furrows has increased from 50 to 500 m and, in some cases, up to 1000 m with the extended length of furrow achieved by their mulching with polyethylene film (Figure 5.11.7). The duration of watering depends on the mechanical and chemical properties of the soils and typically varies from 1-2 hours to 2-3 days. Closed irrigation network is recommended for sprinkling or drip irrigation systems. This is required to achieve the pressure necessary to enable sprinklers and drip irrigation systems to function centrally (Figure 5.11.8).

Figure 5.11.6 Watering sugar beet by flowing water and cotton plants by furrows (2010; (Photo by: R. Bekbayev).

On large irrigation systems (defined as > 20 thousand ha) a mixture of watering approaches (e.g. surface, sprinkler and/or drip irrigation) is often used. In such cases, a range of technologies is applied, involving the use of both open and closed channel pipelines as a way to enhance the efficiency of transportation of irrigation waters from their source to the plant. For this reason, any reconstruction of irrigation systems must specify the types of sprinklers (Figure 5.11.9), irrigation units and drip irrigation systems. The results of long-term experimental data measurements show that in furrow and strip irrigation the volumes of unproductive water losses during both transportation and irrigation range from 65-70% of water intake (Bekbayev and Zhaparkulova, 2013). However furrow irrigation remains the most promising technology. Use of this low-cost technology helps to reduce the amount of irrigation water loss to 30-35%.Whilst the use of modern drip irrigation technologies could lead to an even higher reduction in water consumption per unit mass of crop produced, it implies additional costs about 8000-10000 U.S. dollars for the purchase, construction and operation of drip irrigation system per ha.

Identification and selection of the optimal type of irrigation network (in terms of utilizing surface irrigation, sprinkler and/or drip irrigation) should be based on the approach, which minimizes water loss during irrigation. Washing out salts from the soil, enhancing groundwater recharge and use of sub-irrigation methods are priority aims to address when planning the design of the irrigation network.

Figure 5.11.7 Mulching watering furrows for growing early cabbage and watermelon (Mahtaaral irrigation system, 2013; (Photo by: R. Bekbayev).

Figure 5.11.8 Drip irrigation of onions (Basin Rivers of Asa-Talas, 2012; (Photo by: U. Bekbayev).

Figure 5.11.9 Sprinkler technologies used for watering forage crops (Basin Rivers of Asa-Talas, 2012; (Photo by: R. Bekbayev).

Collector-drainage networks and the volumes of wastewater

One of the most effective and reliable ways to enhance levels of groundwater recharge is to increase the drainability of irrigated lands. For this, collector-drainage systems are constructed, which consist of open or closed drains and sewers. Drains from irrigated lands directly recharge groundwater. Collectors are intended to divert the drainage waters outside of irrigation systems. A collector is an open channel with a depth of 3.5 - 5 m. For example, the drainage network on the Mahtaaral irrigation system consists of a series of open collectors composed of earthen channels. The main components of this system are: the East discharge, West collector, North discharge, Tugas collector and End discharge (Figure 5.11.10). The water from these collectors falls into the Shardara reservoir and the collectors Sardoba, D-3, Zhetysay, Kyzylkum and Arnasay discharge collector waters. Central Golodnostepsky collector (CGC) waters come both from the territories of Uzbekistan and Kazakhstan and are discharged into the Arnasay. Key parameters of the main collectors are given in Table 5.11.4.

The use of these collector systems is especially important for irrigation systems in the Southern Kazakhstan, where water scarcity is relatively severe. Until the mid-1990s, the maintenance of groundwater levels above the critical depth and prevention of salinization of soils in the irrigation systems were addressed using horizontal and vertical drainage wells (Figure 5.11.11). Thus drainage waters are discharged mainly to sources of irrigation waters, which increase their mineralization. The main function of vertical drainage wells is regulation of the water-salt regime of irrigated lands. The collector-drainage system removes groundwater beyond the irrigation systems.

Drainage-reset waters - an additional source of irrigation

The analysis of the formation of drainage flows shows that the volumes of collector-drainage water generated depend on (1) the technical condition of the irrigation systems, (2) the efficiency of the drainage systems (3) the norms of irrigation and farming culture practices (Table 5.11.5)

Figure 5.11.10 Arnasay and Central Golodnostepsky collectors (Photo by: E. Zhaparkulova)

Collector-drainage water when entering a river increases its mineralization and degrades the quality of the irrigation water. Therefore, it is necessary to study and assess the quality and the salinity of drainage water. The availability of water for crop irrigation is estimated based on the assessment of the following indicators: (1) risk of soil salinization (2) level of soil alkalinization and (3) toxicity of the individual ions. In international practice (Yakubov et al., 1977 the sodium adsorption ratio (SAR) is used to assess the quality of irrigation waters and to determine the risk of soil alkalinization:

$$SAR = \frac{Na}{\sqrt{\frac{Ca+Mg}{2}}}$$

(1)

The assessment is made using the SAR classification system developed by Yakubov et al., 1977). In this system, SAR <10 refers to a small risk of soil alkalinization, the SAR value of 10-18 implies an average risk and SAR values of 18-26 and > 26 suggest o high and very high risks, respectively. In the USA the assessment of the quality of irrigation waters involves both calculation of the SAR* which also takes into account the additional effect of the presence of calcium in the soil:

$$SAR* = \frac{Na}{\sqrt{\frac{Ca+Mg}{2}}}[1+(8{,}4-pH_c)]$$

(2)

8,4 in this case is the approximate pH_c in the absence of sodium soils, depending on the soil calcium carbonate ($CaCO_3$) content.This indicator is determined by the formula:

$pH_c=(pK_2-pK_c)+(Ca+Mg)+pAl_k$;
(3)

The K_2, Ks - second constant H_2CO_3 decay with constant solubility of $CaCO_3$, respectively (Ca + Mg) and (CO_3 + HCO_3) - gram molecular concentration of the respective ions, P - refers to the negative logarithm. With SAR* <6, soil alkalinization does not occur; SAR* value of 6-9 indicates potential for the accumulation of sodium cations in the SAC (soil-absorbing complex); the SAR* value of > 9 indicates alkalinity altering.

The limiting factor of the use of collector-drainage water for crop irrigation is the risk of soil salinity. Therefore it is necessary to evaluate the quality of collector-drainage water for the possibility of soda salinization of soil. The risk of soda salinity is measured though the assessment of the normal soda water (Na_2CO_3) content. Under the classification scheme developed by Yakubov et al., (1977) the level of Na_2CO_3 <0,3 mEq/l implies the safety of water for irrigation but the level of Na_2CO_3, which is> 0,6 mEq/L is unsuitable for irrigation without amelioration. The result of this evaluation of the quality of collector-drainage waters gives the idea of their safety and possibility to use them for irrigating crops.

The use of water-saving irrigation technologies in different natural zones of Kazakhstan

The results of laboratory and field studies carried out by KazSRIWE in 2005-2013 led to the development of water resource saving irrigation technologies appropriate for use in various soil zones of Kazakhstan. In the chernozem and chestnut soil zones the regulation limit of soil moisture (SM) for prevention of the development of alkalinization processes and soda formation should not exceed (0.7-0.9) SM (minimum moisture capacity). This limit indicates the need of irrigation sprinkling and frequent watering regimes using relatively low volumes of water i.e. 200-500 m^3 /ha. In this zone, the irrigation norm is 3000-3500 m^3/ha. Watering crops is carried out using sprinklers to distribute waters transported by pipelines.In the south of Kazakhstan, where the irrigation rate is 5000-8500 m3/ha, the watering norm is 1000-1500 m^3/ha.This leads to high losses due to water infiltration, and resulting groundwater rise. Therefore, irrigation rate reduction is achieved by using alternate furrow irrigation and groundwater sources for sub-irrigation (Figure 5.11.12).

Table 5.11.4 The main collectors drainage water discharge from the Mahtaaral irrigation system (2012).

Units	Southern Kazakhstan	Kyzylorda region	South Kazakhstan region			Zhambyl region		Almaty region
			Region	Makhtaaral	Shardara	Asa-Talas	Shu	
km^3	1293,76	266,5	829,4	219,3	457,6	-	12,36	185,5
% of total	100	20,6	64,1	17,0	35,4		1,0	14,3

Table 5.11.5 The volume of drainage waters, by a district (SKGGME, 2012).

№	**Name of region**	**Drainage-reset runoff, mil.m^3**		
		2009	**2010**	**2011**
1	Arys	5,64	4,76	-
2	Baidibek	6,42	6,75	6,43
3	Kazigurt	19,02	44,79	41,44
4	Mahtaaral	235,4	169,51	208,1
5	Ordabasi	3,69	16,09	20,34
6	Otyrar	2,2	5,93	1,5
7	Sayram	22,0	19,7	21,4
8	Saruagash	58,98	105,87	84,92
9	Suzak	1,92	1,30	1,1
10	Tolebi	0,4	0,52	1,98
11	Turkestan	38,69	45,37	34,94
12	Tulkubas	1,4	0,7	0,63
13	Shardara	266,79	112,60	269,81
14	Lands of Shymkent city	8,1	5,7	6,2
	TOTAL:	670,65	539,59	698,79

Figure 5.11.11 Open collector D-3 and vertical drainage wells VDW–18 (Mahtaaral irrigation system, 2013; Photo by: R. Bekbayev)

The use of alternate furrow irrigation technology reduces irrigation water losses through filtration by up to a factor of 2 and discharge and evaporation losses by a factor of 1.5. By reducing these losses, the water availability of irrigated lands will be improved by 20-30% and their fertility will be increased by slowing the destruction of organic materials and removal of mobile forms of nutrients.The application of water-saving irrigation technologies (furrow length reduction, water flow in the furrow) will reduce the irrigation rates by up to 30% compared with the usual values. The increased coefficient of the efficiency length of the irrigation network (e.g. facing the channels with bentonite clays) will; (1) reduce the water intake norms by a factor of 1.5; (2) increase the productivity of irrigated agricultural landscapes; (3) enhance water conservation and (4) improve the water quality in the surface sources.

Technologies using collector-drainage water for irrigation and washing

Diversion of water from drainage systems for use in irrigation and washing is performed by a mobile or stationary pumping station (Figure 5.11.13).
The use of groundwater in irrigation is organized by pumping vertical drainage wells and diluting abstracted waters with irrigation water through its direct supply to the irrigation network (Figure 5.11.14).

The collector-drainage waters are diluted with irrigation waters which are then applied directly in the irrigated catchments. The volume of waters required to dilute irrigation waters to achieve the required reduction in mineralization levels can be determined following chemical analysis of water samples. Crop watering by recovered water (e.g. treated water discharged from industry agriculture, drainage etc.) is recommended in critical periods, i.e. in times of acute irrigation water shortages. The application of return waters during such periods ensures the provision of acceptable yields of agricultural crops. However, consistent application of mineralized return water for irrigation of agricultural crops increases the degree of the soil salinity and, reduces crop yields in the longer term.

Conclusion

Currently 60-70% of the water resources of Kazakhstan are used for agriculture. However, the low level of technologies frequently employed in irrigation systems contributes to the increased levels of water deficit at the national level. As a result, up to 70% of the water abstracted for the use in agriculture is lost as a result of infiltration and discharge. The growth in losses of irrigation water has led to increased levels of soil salinization and alkalinization. Currently, about 50% of irrigated land is degraded as a consequence of these processes. Hence a combination of soil degradation and water shortages has decreased the crop yields by 25-50%. To increase the productivity of irrigated lands it is necessary to develop integrated technologies for the management of surface-water, groundwater and drainage waters. Full adoption of such 'best practices' may reduce water withdrawals from rivers by a factor of 1.5-2.

Adoption of an integrated approach for managing water resources utilised in irrigation systems has the potential to reduce the pollution of water and land resources in river basins. For example, the current volume of drainage water discharge from irrigation systems of the Southern Kazakhstan exceeds 1200 million m3, and the average mineralization of these drainage waters is 2,5-3 g/l. The use of this water for irrigation of crops increases both the water availability of irrigation systems and hence the environmental sustainability of the regions of irrigated agriculture.


Figure 5.11.12 The effect of alternate furrow irrigation on soil moisture in intercropping (Photo by: R. Bekbayev)

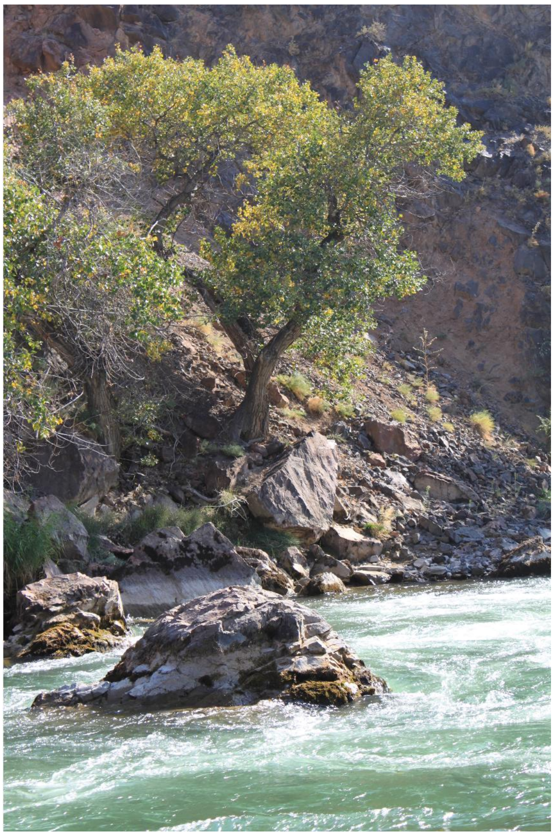

Figure 5.11.13 The fenced collector-drainage water of Arnasai and Sardoba collector in the Golodnostep array (Photo by: R. Bekbayev)


Figure 5.11.14 The use of groundwater in irrigation (Photo by: E. Zhaparkulova)

Integrated Water Cycle Management
in Kazakhstan

IB No. 7535
Signed for publishing 01.10.14. Format 60x84 1/8. Offset paper.
Digital printing. Volume 25,41 printer's sheet.
Edition: 100. Order No.1824.
Publishing house "Qazag university"
Al-Farabi Kazakh National University, 71 Al-Farabi, 050040, Almaty
Printed in the printing office of the "Qazag university" publishing house

E-mail: baspa@kaznu.kz



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