






Water resources of Kazakhstan in conditions of uncertainty

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Abstract: The exceptionally high spatial-temporal variability of the river runoff and the significance of its transboundary component considerably worsen the problem of the water supply of the republic. Due to the disadvantageous geographical location in the lower reaches of transboundary river basins, the Republic of Kazakhstan is largely dependent on water economy activities taking place in neighbouring countries. In the article the modern change of the resources of river runoff in Kazakhstan, taking into account climatic and anthropogenic influences is considered. For the assessment of the impact of economic activities on the river runoff and changes in climatic-related runoff, the complex of integral methods was used, and appropriate methodologies were developed. The obtained results of the modern influence of a complex of factors, as well as their significance for the future (till 2030), can be used for the development of scientifically based solutions for sustainable management and protection of water resources. An assessment of the anthropogenic activity of this study shows that the water resources of the river runoff of the Republic of Kazakhstan have decreased by $16.0 \text{ km}^3 \cdot \text{y}^{-1}$. According to our forecasts, there will be a further decrease in the water resources of the republic due to the expected decrease in transboundary flow to $87.1 \text{ km}^3 \cdot \text{y}^{-1}$ by 2030, in dry years less than $50.0 \text{ km}^3 \cdot \text{y}^{-1}$. We propose a set of measures to prevent the negative impact of possible reduction of river runoff resources in the future in the water basins of Kazakhstan.

Keywords: anthropogenic influences, river runoff, transboundary water problems, water resources

INTRODUCTION

The use of water resources in Central Asia today is a complex of interrelated problems: social, political, and economic. Lack of effective management in the field of water resources plays the role of a deterrent mechanism in their use and protection from pollution. The national legislation of the countries of the region concerning water resources is “one-sided” and takes into account only the interests of national states. Although this issue is being actively investigated by many experts and organisations and numerous recommendations are accepted on how and what is better to do, there are no real changes for the better in the field of water relations on the regional scale. There are some examples of

successful cooperation between countries (for example, Kazakhstan–Kyrgyzstan), and effective management in this area (measures to save the Malyi Aral). But that is not enough. This issue directly affects all countries of Central Asia, and interaction on it is extremely important for the social-economic development of all Central Asian countries. Only collaboration of all countries of the region, taking into account the interests of all participants, is the way to solve the problem of water resources.

As a result of climate warming in the arid regions of Central Asia, there is a stable reduction of the Tien Shan glaciers and a decrease in their glacial coefficients, which show the relation of the areas of glacial accumulation to the entire area of glaciers. In the mountain systems of Kazakhstan, there is also a decrease in

the number and size of glaciers. According to certain studies, in the next decades, due to global warming, the water resources of the main rivers of Kazakhstan may decrease by 20–40% [GAGLOYEVA 2016; NYSANBAYEV *et al.* 2016; SEVERSKIY *et al.* 2016].

The problem of water deficiency in Central Asia becomes more acute as the population grows. Currently, 100–120 mln people live in the region, and by 2050 this number may increase to 150 mln. In the context of shortage of water resources, water security should be considered as one of the components of the national security of the Republic of Kazakhstan, this problem was already discussed in 2003, and it does not lose its actuality today [MEDEU *et al.* 2012a].

The World Meteorological Organisation (WMO) has identified four levels of stress associated with water deficiency. According to this gradation, the fourth, highest stress level includes territories where more than 40% of available water reserves are used, where water is consumed with an intensity that exceeds natural recharge [UNESCO 2018]. In Kazakhstan, this gradation is exceeded in five out of eight water economic basins (WEBs), and in Shu-Talas and Nura-Sarysu WEBs, this index is 0.98 and 1, i.e. all river runoff is in use. The exceptionally high spatial-temporal variability of the river runoff and the significance of its transboundary component considerably worsen the problem of water supply in the republic. Due to the disadvantageous geographical location in the lower reaches of transboundary river basins, the Republic of Kazakhstan is largely dependent on water economic activities in neighbouring countries: China, Uzbekistan, Kyrgyzstan, and Russia [DOSTAI 2012; MEDEU *et al.* 2012a; MEDEU *et al.* 2015].

Due to the forecasted decrease in the river runoff in Kazakhstan, noticeable changes in the values and structure of water consumption may occur. The conflicts and contradictions between certain water consumers could intensify, including an increase in water consumption for the development of sectors of the economy of Kazakhstan, and a worsening of interstate water relations in transboundary basins. The main threats and challenges in the field of water supply are global and regional climate changes, use of water-consuming technologies, imperfection of technical means of water regulation and water distribution for economic sectors in the republic, and disagreement of interstate water relations. A shortage of water resources can cause interstate water conflicts to worsen, the development of new regions of environmental instability, and disruption of social-economic development programs [MEDEU *et al.* 2015; NYSANBAYEV *et al.* 2016].

Observations of the river runoff and its main characteristics are carried out by the Hydrological Service – one of the main units of the Republican State Enterprise (RSE) “Kazhydromet” (Rus. Respublikanskoe Gosudarstvennoe Predpriyatie “Kazgidromet”), where in 2021 the hydrological monitoring is carried out at 377 hydrological stations (329 river stations; 38 lake stations; 10 sea terminals and stations). In the period from 1970 to 1990, the hydrological network was more developed, and according to the WMO recommendations, this number of observations is not enough for the reliable assessment of the volume of water resources.

Previous studies of many scientists and authors both on the territory of Kazakhstan and Central Asia (DOSTAI [2012], GALPERIN [2012], MEDEU *et al.* [2015; 2020], ALIMKULOV *et al.* [2018; 2019], BISSENBAJEVA *et al.* [2019; 2021]) mostly concern only the problem

of water security in the basins of large rivers in regard to certain country importance, without assessing the current condition within the macro-basins of certain rivers. In this work, we aim to determine the volume of river runoff for the period from 1974 to 2015 that is formed in the transboundary territory, which more accurately shows the inflow and outflow of water in each water basin in Kazakhstan. The authors also make an attempt to forecast all elements of water resources for the near future (until 2030), taking into account changes in the global, and accordingly, regional climate and human impacts on water use. All these calculations and assessments are carried out in such a form for the first time for the territory of Kazakhstan. For the previously mentioned calculations and assessments, a number of methods are used that are adopted in classical hydrological calculations, in accordance with the regulatory documents SNiP 2.01.14-83 and SP 33-101-2003, especially for poorly studied regions, where the monitoring net and gauging stations are practically absent. Also, new approaches have been generated to assess the anthropogenic impact on the river runoff, in particular, the use of water balance calculations to assess water consumption in the territories of macro-areas of certain basins and along the main river beds.

In case of the presence of transboundary and natural-related threats to the river flow change in the future, the authors propose a set of measures to prevent the negative impact of a possible reduction in river flow resources in Kazakhstan.

METHODS

In almost all countries of the world, the value of renewable water resources, their dynamics in time, and distribution by the territory are estimated by the characteristics of river runoff. The runoff of river systems provides the main volume of water consumption in the world, determines the level of the water supply of the territory and population, and the level of overflow and deficit of water resources. River runoff in the process of circulation restores the quality of freshwater mostly due to the natural self-purification that river systems have [MEDEU *et al.* 2012a].

The water resource potential of river waters can be characterised by the following three indicators: natural (climatic) resources, available resources, and actual (transformed under the influence of anthropogenic load) resources.

Natural means the annually renewable potential resources of river runoff of any territory. Part of the catchment basins of the rivers of Kazakhstan is located in the territory of neighbouring countries. Therefore, despite the annual renewal, it is impossible to count on the inflow of natural runoff from outside the country. And in such conditions, we need to operate with available resources, which means annually renewable local natural resources and the actual inflow of river runoff from outside the country, transformed under the influence of anthropogenic impact. Thus, the available resources characterise the country's annual water potential.

Apart from that, for a sufficiently clear understanding of the resource conditions, knowledge about anthropogenic changes in the local and total runoff is required. In this case, the indicator is actual resources – resources transformed under the anthropogenic impact, both inflows from outside the country and local, own, as well as the transformation of the total runoff in the

channels of the main transboundary rivers on the territory of the Republic of Kazakhstan.

Global climate change and anthropogenic activities contribute to significant changes in the ecological and hydrological characteristics of river runoff around the world. Identifying their role is extremely important for understanding the genesis of already occurred and possible future hydrological changes, as well as for taking measures to reduce or even completely neutralise their undesirable consequences. The difficulty of solving this problem lies in the fact that climatic and anthropogenic changes in river runoff are closely interrelated and often affect runoff not directly, but indirectly (through the relief, soil, and biota).

Currently, by determining the change in the quantitative characteristics of water resources, the concept of “water stress” or the coefficient of use of water resources is widely used. Water stress is determined by the relation of water intake from the surface water sources to available renewable water resources [KORONKEVICH 2003; McLELLAN 2014; UNESCO 2015]. The coefficient of water resource use, which has found an implementation in the works of scientists from Russia and the former Soviet republics [GALPERIN *et al.* 2008; SHIKLOMANOV 2004, 2008], is calculated as the relation of the water consumption volume to water resources of the corresponding supply.

For the assessment of the anthropogenic load, a methodology based on the complex application of various techniques, with a detailed study of the condition of irreversible water consumption in sectors of the economy was developed [BERGSTRÖM *et al.* 1995; GALPERIN *et al.* 2008; SHIKLOMANOV 2004, 2008].

Assessment of changes in water resources for the long-term prospective is a key problem in hydrology. However, the “water” issue here is somewhat complicated by certain natural and anthropogenic factors. Due to its position in the global water exchange system, the region’s moisture content is highly dependent on the degree of its incoming from outside. The main amount of precipitation in Kazakhstan, as is known, comes from the south, southwest, west, and northwest (cyclones from the south of the Caspian Sea, from Tejen and Murghab valleys, and polar air masses). By passing through the region of southern cyclones in mountain areas, in winter falls up to 400–450 mm of precipitation (70–80% of the annual amount) [BERGSTRÖM *et al.* 1995].

At present, a large number of works are devoted to the study of climate change [BATES *et al.* 2008; DOLGIKH *et al.* 2006; DUETHMANN 2020; GRUZA, MESHCHERSKAYA 2008; HUNTINGTON 2010; IBATULLIN *et al.* 2009; MEEHL *et al.* 2007; PACHAURI, MEYER 2014; TAYLOR *et al.* 2012]. So the well-known Intergovernmental Panel on Climate Change (IPCC) released its Fifth Assessment Report in 2014. The conclusions of the report are definite: climate change is real, human activity and an increase in the concentration of the “greenhouse” gas (CO₂) in the atmosphere is its main reason. By the end of this century, the average global temperature is very likely to rise by 1–2°C in comparison to the 1990 level and by 1.5–2.5°C in comparison to the pre-industrial epoch. The warming of oceans and melting of ice will continue. It is estimated that by 2065 the world average sea level will rise by 24–30 cm, and by 2100 – by 40–63 cm compared to the level of 1986–2005. Most of the effects of climate change will remain for several centuries, even if greenhouse gas emissions stop completely [GRUZA, MESHCHERSKAYA 2008].

Ultra-long-term forecasts can also be made based on empirical dependences of river runoff from meteorological factors, in particular from the expected values of precipitation and air temperature obtained on the basis of general circulation models (GCMs), runoff forecasts based on the runoff formation model [DOSTAI 2012; GALPERIN *et al.* 2008; GOLUBTSOV 2010; GRUZA, MESHCHERSKAYA 2008; MOREIDO 2015; PABAT 2006]. In these works, runoff-forming factors are taken into account in accordance with the physical-mathematical model of runoff formation, developed in the Institute of Water Problems of the Russian Academy of Sciences and RSE “Kazhydromet”, there is also an experience in the forecasting of water resources of certain regions of Kazakhstan within the water economic basins using GCMs based on the forecasted values of precipitation and temperature [DOSTAI 2012; KISHKIMBAYEVA *et al.* 2016]. In works of DAVLETGALIYEV and MEDEU [2017], ALIMKULOV *et al.* [2018; 2019], the results of the assessment of climate variability and river runoff based on calculations of the complex of global climate models from the Coupled Model Intercomparison Project phase 5 (CMIP5) project are presented. However, the advance time of such forecasts is limited and does not take into account the possible changes of runoff forming factors as a result of global climate change.

In the Central Asian republics, the lack of legal documents regulating internal and external water relations has not yet been repaired, there is no general water legislation in the countries. Evidence of this is the existence of a small number of laws regulating water relationships. For example, in Kyrgyzstan, there is one main law “On Water” [Zakon ... 1994], a private Law on Tariffs [Zakon ... 1998], and in Kazakhstan, at the legislative level, the code “On Water Resources” [Vodnyi kodeks ... 2003] was adopted. A similar situation is observed in other countries of the region. For comparison: in the US, about 50 laws regulate water relations. When developing general water legislation, countries should rely on international water law and should be based on the idea of integrated water resources management (IWRM). The main goal of IWRM is sustainable and, most importantly, equitable provision of water resources for all countries of Central Asia. At this time, Turkmenistan is the most problematic country in the region since this country is not participating in developing common water projects. In addition, the Turkmen authorities are planning to build a number of reservoirs, which may later practically leave Khorezm and Karakalpakstan without water. Representatives of Turkmenistan do not make compromises and connections with neighbouring countries [BERDYGULOVA 2002].

In the policy sector, it is also the dogmatic understanding of sovereignty that is almost the main obstacle to resolving international river sharing disputes. In the presence of one or another choice, states nevertheless prefer independent actions to joint cooperation, since multilateral or even bilateral agreements generally limit sovereignty and independence, as well as the possibilities of developing inland waters. For example, in this regard, multilateral agreements are disadvantageous to Tajikistan and Kyrgyzstan, while to Uzbekistan and Kazakhstan – bilateral ones. Nevertheless, Kazakhstan has signed a bilateral agreement with Kyrgyzstan on the use of water facilities on the Chu and Talas rivers. Not taking Uzbekistan’s counterstep, Kyrgyzstan has tightened its water policy, motivating it with a sovereign right. In addition to this water also becomes the subject of political trade between the countries of the region. Water problem, in some cases, is used as a method of pressure on one or another country

to resolve conflicts. Considering that almost all drinking and irrigation water is concentrated in two countries of the region (Kyrgyzstan and Tajikistan), this all can lead to undesirable political implications [BERDYGULOVA 2002].

Water availability and water allocation have become pressing problems and caused political conflict over the past two decades. A strong joint research effort is required to understand the current changes in the climatic and hydrological systems, the socio-economic processes, and the interactions between them, including feedback mechanisms. This understanding is crucial to developing mitigation and adaptation strategies for climate and hydrological change and managing the regional water resources in a sustainable way. The research effort must inevitably be supported by strengthening the database (climatological, hydrological, land, and water use) in the Central Asian region and by creating infrastructures and policies for data provision and exchange among partners. Especially, homogeneous large-scale data products are required to inspire trustful relationships among stakeholders across sectors and political borders [UNGER-SHAYESTEH *et al.* 2013].

In our case, the assessment of water resources means the entire annual volume of surface river runoff formed in the region and recorded by hydrological stations, expressed in km³ per year, excluding groundwater, and water reserves in lakes and seas. River runoff per year is an objective indicator for determining the full flow of the river, and as for the territory of Kazakhstan, the share of river runoff is the largest and it characterises almost the entire volume of the country's water resources. Assessment of water resources in Kazakhstan is associated with such problems as lack of hydrological information, differences in the conditions of the formation and use of water resources, difficulties in combining physical-geographical, administrative-territorial, and water management boundaries, as well as heterogeneity of the analysed information. These and other difficulties in performing calculations reduce the quality of the assessments carried out in the regions.

To assess the volume of river runoff, a number of methods are used, adopted in classical hydrological calculations, in accordance with the regulatory documents SNiP 2.01.14-83 and SP 33-101-2003. The assessment of water resources was carried out according to the data of the nearest gauging station for the entire observation period, the so-called analogy method. In the absence of hydrological stations or their remoteness from the boundaries of the sites, for poorly studied regions, where there is practically no monitoring network and no gauging stations, we used the data of the river runoff module, which were obtained in our previous studies [SNiP 2.01.14-83; SP 33-101-2003].

A reliable quantitative assessment and forecast of the impact of economic activities on the river flow is a very difficult task. This is due to the fact that many factors of economic activity act simultaneously in the catchments, often changing the runoff in opposite directions. In addition, unidirectional anthropogenic changes are superimposed on the natural runoff fluctuations, the amplitude of which often exceeds artificial changes. It is far from always that accounting of water intakes for various economic needs and discharges of used water is kept, and information characterising the time, scale, and intensity of economic activities within the catchments is either insufficiently complete or absent.

Various calculation methods are used to quantify and forecast anthropogenic changes in river runoff. In this case, first

of all, the occurred changes in runoff are assessed, and then future changes are forecasted, taking into account the plans and trends in the development of economic activity in different climatic situations.

By the statistical method, the assessment of anthropogenic impact is carried out in the following sequence: the runoff for the natural (conditionally natural) period is determined; the value of natural runoff is restored during the period of disturbed water regime; its change under the influence of economic activity is estimated by the difference between the observed (household) and restored runoff.

In our work, we aimed at an approximate assessment of irreversible water consumption and differentiated it by certain districts and sectors of the economy, which in the future would allow obtaining relatively reliable scenarios of the future impact of anthropogenic loads on the water resources.

For the assessment, there was developed methodology based on the complex application of the methods of hydrological analogy, water balance, and method of determining irreversible water consumption by the economy branches. According to our assessment, the average (for the territories of WEBs of the Republic of Kazakhstan) values of anthropogenic load to the total water resources in the medium by high-water volume years reach 62.8%, and in dry years – up to 69.6% [MEDEU *et al.* 2020].

The comparison of the available data on water intakes and results of anthropogenic changes in the river runoff makes it possible to approximately assess the value of irreversible water consumption in each region and the ratio between the volumes of irreversible and total water consumption. The data obtained in this way by the values of irreversible water consumption is extremely indicative, nevertheless, some regularity can be noted in the values of indicated ratios, which vary by the regions within very large limits depending on the structure of water consumption and climatic conditions.

Water balance methods, which were also used to calculate and identify the anthropogenic component of river runoff, are based on taking into account direct water intakes and discharges, and on studying the processes that occur in catchment areas or river channels (on irrigated and drained lands, urban areas, etc.) based on the sources of the RSE “Kazhydromet”, schemes for the integrated use and protection of water resources, statistics on water intakes, etc. They make it possible to identify the physical essence of the processes occurring in the catchment, and to assess the role of each type of economic activity. At the same time, however, it is necessary to have observation data for runoff, precipitation and evaporation, and reliable materials for water consumption and irretrievable consumption accounting, which also caused certain difficulties.

Anthropogenic changes in river runoff were determined by reference points in the channels of the main rivers draining waters of a certain catchment area; channel water balances were determined; transformations of water balance elements (volume of river runoff, average annual precipitation values for the period, groundwater runoff, evaporation from the water surface) were studied for each section, comparing them with real water intakes; the shares of irretrievable water consumption have been determined for the certain sectors of the economy.

In more detail, the assessment of the anthropogenic impact on the river runoff in Kazakhstan was analysed based on statistical data of water intakes and water consumption by economic

sectors within the water basins of the Republic of Kazakhstan in our previous publication, where methods and calculations of anthropogenic impact to the water resources are presented in detail [MEDEU *et al.* 2020].

The economy's water consumption on average is $32.5 \text{ km}^3 \cdot \text{y}^{-1}$. If we talk in the context of economic branches, the largest consumer is agriculture – 75%. More than half of this volume is used in the Aral-Syrdarya basin – 53%, that is in the area, where irrigated agriculture is traditionally developed. The largest industrial consumers of water are the objects of the Ertis basin – 38%, Nura-Sarysu basin – 29%, Zhayik-Caspian – 21%, that is the industrially developed regions of the country. The municipal-domestic sector uses only about 5% of water.

In the long-term forecast of anthropogenic impacts on water resources, two scenarios for the development of water use, inertial and water-saving, were considered, they were developed taking into account early studies [MEDEU *et al.* 2012b] and their actual implementation.

The first scenario – “inertial”, is based on current trends in the development of the economy and the level of water use in the Republic of Kazakhstan. By inertial we mean not the tendency of sustainable growth of water use in a “pure” form, but the achievement of full satisfaction of the demand formed over the modern period, regardless of the water content of the years. This approach is prompted, on the one hand, by the climatic features of the dynamics of water resources observed in recent years, and on the other hand, by the realities in the country's water sector.

The “water-saving scenario” considers an increase in the coefficient of irreversible water consumption in the future, due to the introduction of advanced water use technologies with a reduction in unproductive water loss, in this regard, while maintaining the same values of water intake, the overall impact to the water resources increases. Here, an increase in the coefficient of irreversible water consumption is considered by 2025 by 5%, by 2030 – by 10%, by 2035 – by 15%. These two scenarios are developed taking into account many conventions.

Apart from the above-mentioned methods, the anthropogenic impact was additionally assessed by calculating the existing load to water resources, i.e. coefficient of use of water potential in a particular water basin.

Many scientists in the Commonwealth of Independent States (CIS) water industry widely use the classification based on the coefficient of use of the C_{use} or the load on water resources. Thus, according to studies of SHIKLOMANOV [2004; 2008], and UN/WMO/SEI [1997], the following classification can be applied to analyse the state of anthropogenic changes in water resources in any region of the world. Category I: $C_{\text{use}} < 10\%$ to Category V: $C_{\text{use}} > 60\%$ – critical load. If the water resource capacity factor is up to 20% (I and II categories of anthropogenic load), it is possible to plan for increasing the use of water resources. Above category III, territories already have a high load on water resources and require special attention for future development, it is recommended to introduce effective water-saving technologies everywhere, but it is best to limit non-direct water intakes from natural objects. For sustainable development, it is necessary to regulate the supply and demand for water. Special attention should be paid when developing water resources for regions where the capacity factor exceeds 40% (IV, V). With an anthropogenic load of 40–60% (IV), there is serious water scarcity and it is strongly recommended to regulate demand and

limit water consumption, and attract additional sources of water supply. Water scarcity becomes a factor that hinders economic growth and increases the level of well-being of the population. If the use of 60% of available resources is exceeded (V), water scarcity becomes a critical factor in the development of the economy and life [MEDEU *et al.* 2020].

In the territory of Kazakhstan, further increases in surface air temperature are expected in all months of the year. The expected increase of the average annual temperature by 2030 in almost all regions of the country is up to 2°C , only in the northern part, there can be an increase of temperature up to $3\text{--}4^\circ\text{C}$. By 2050, the increase of the average annual temperature in the Republic of Kazakhstan is almost 3°C ; in the northwest, north, and central regions of the country it can reach up to 4°C . The increase in precipitation by 2030 will be, in general, about 10%. An increase of more than 10% is possible in the north, central, and mountain regions of the southeast, as well as in the districts of the Balkash region [IBATULLIN *et al.* 2009].

The data is presented for two scenarios of greenhouse gas emissions, so-called Representative Concentration Pathways (RCP). The numbers indicate the radiation effect, i.e. change of the radiation balance of the Earth's surface by 2100 in $\text{W}\cdot\text{m}^2$.

In the study in order to increase the scale (regionalisation) of the output data of the ocean-atmosphere general circulation model (OAGCM) and to bring to unified latitude-longitude net, there was used statistical method [WOOD *et al.* 2004], the results of which are presented on the NASA NEX platform (National Aeronautics and Space Administration, NASA Earth Exchange) [NCCS undated], designed for scientific cooperation of the world scientific community, exchange of knowledge and research results. The regionalisation of the calculated data of each of the global climate models was carried out using the maximum and minimum daily air temperature, as well as the daily amount of precipitation in the grid points of $0.25 \times 0.25^\circ$ (or $25 \times 25 \text{ km}$). For the territory of Kazakhstan, the number of grid points is about 10.000, which significantly improves the spatial detailing of climatic data and its use in assessing the impact of climate change.

For each cell, its own value is provided, which shows how many degrees the air temperature will change or by how many percent the amount of precipitation will change, for example, for the period of 2006–2035 relative to the base period of 1981–2000 according to RCP 4.5 or RCP 8.5 scenario in a certain month, season or year. Base climate values of 1981–2000 are also provided for each square. These values show the amount of precipitation per day in a certain month, season, for the year ($\text{mm}\cdot\text{day}^{-1}$) in the average for the period of 1981–2000, as well as average monthly values of air temperature in a certain month, season, for the year ($^\circ\text{C}$), averaged for the period of 1981–2000. The initial data of the expected changes in temperature and precipitation are calculated for the periods of 2006–2035 relative to the base period of 1981–2000 with the intervals of every five years.

We roughly estimated the forecasted water balances of the basins to assess the amount and degree of development of available for use water resources within the boundaries of river basins, which represent an assessment of the needs of water users in comparison with the water resources available for the use within the boundaries of river basins under different water volumes conditions, taking into account the uneven distribution of surface runoff in different periods. The forecasted water

balance of the basins for the future until 2030 for certain WEB consists of:

- 1) actual values of the inflow into the territory of WEB;
- 2) river runoff formed in the territory of WEB, i.e. local resources;
- 3) part of the river runoff that leaves (outflow) and returns (return) to the territory of the WEB;
- 4) water consumption in the WEB (anthropogenic influence);
- 5) available resources in the river mouth of the main rivers;
- 6) natural losses in the river net;
- 7) available resources i.e. those that can be counted on in water economy planning.

Thus, it is necessary to focus on the available resources, which means annually renewable local natural resources of river runoff of the territory of the Republic of Kazakhstan.

We must not forget about the natural and climatic factors: the issues of hydrometeorology, hydrology, and water resource use must be considered as a whole. The accuracy of monitoring the condition of water bodies depends entirely on their record, which should become systematic and form the basis for their maintenance, and safe use, in order to take measures in advance to avoid disasters and emergencies.

Ecosystem capabilities have their limits that require much better understanding. For example, the concept of “points of no return”, beyond which the negative ecosystem changes become irreversible, is well developed theoretically, while the quantitative determination of such points is much less common. Therefore, it is necessary to accept the limited potential capacity of ecosystems and determine the thresholds beyond which any additional pressure (for example, the addition of pollutants and toxic substances) will cause irreparable damage to the ecosystem. The high degree of variability of the impact of ecosystems on hydrology (depending on the type or subtype of the ecosystem, its location and condition, climate and management) warns against the generalisation of ideas regarding natural solutions. Natural systems are dynamic and their roles and impacts change in time.

The necessary responses to these threats and challenges are essentially about creating favourable conditions for natural

solutions to be considered on an equal basis with other water management options [UNESCO 2018].

In economic terms, water problems are associated with a huge complex of development issues: the work of public utilities and municipal services, in particular the provision of drinking water and sanitation services; irrigation; energy, including the construction of hydroelectric power plants; navigation, etc. In political and legal terms, transboundary water resources, especially rivers, are a type of resource that is difficult to divide between countries. At the same time, the political and legal regimes of the functioning of transboundary water resources in crisis zones, as a rule, are not clearly defined or *de facto* not respected by the interested parties [ORLOV *et al.* 2011].

RESULTS AND DISCUSSION

The river runoff of Kazakhstan, however, like in other regions of the planet, makes up a significant part (about 85–95%) of annually renewable water resources, and their share in the use in the economy reaches 95%. In fact, the annually renewable resources of fresh surface waters of the country are represented by the river runoff [ALIMKULOV *et al.* 2019; BISSENBAYEVA *et al.* 2019; DOSTAI 2012; MEDEU *et al.* 2012a, 2015].

Table 1 and Figure 1 show the factual indicators of river runoff resources. The factual total resources of surface waters of Kazakhstan for the modern period are 90.1 km³·y⁻¹, 54.5 km³·y⁻¹ of which is a local runoff, 50.8 km³·y⁻¹ came from neighbouring countries (3.70 km³·y⁻¹ of which are returnable resources): from China – 21.4 km³·y⁻¹ (the Ile River – 12.8 km³·y⁻¹, the Emel River – 0.27 km³·y⁻¹, the Yertis River 8.32 km³·y⁻¹), from Uzbekistan – 16.9 km³·y⁻¹ (the Syrdariya River – 15.0 km³·y⁻¹, transfer channels – 1.90 km³·y⁻¹), from Kyrgyzstan – 3.14 km³·y⁻¹ (Shu, Talas, Assy rivers – 2.77 km³·y⁻¹, the Karkara River – 0.37 km³·y⁻¹), from Russia – 9.31 km³·y⁻¹ (Zhaiyk, Volga, Shagan, Saryozen, Karaozen – 8.86 km³·y⁻¹, the Tobyl River – 0.45 km³·y⁻¹).

Table 1. Factual resources of the river runoff in the Republic of Kazakhstan, km³·y⁻¹

Water economic basins	Local resources		Inflow		Total	
	total	including outflow outside the Republic of Kazakhstan (returnable)	total	including formed on the territory of neighbouring countries	total	taking into account anthropogenic changes in the main river bed
Aral-Syrdariya	2.16	0.38	16.9	16.5	18.7	14.5
Balkash-Alakol	16.5	0.96	13.5	12.5	29.0	26.5
Ertis	26.5	1.36	8.32	6.96	33.4	29.4
Esil	2.68	–	–	–	2.68	2.68
Zhayik-Caspian	3.13	0.99	8.86	7.87	11.0	10.3
Nura-Sarysu	0.87	–	–	–	0.87	0.87
Tobyl-Torgay	1.68	–	0.45	0.45	2.12	2.12
Shu-Talas	0.94	–	2.77	2.77	3.71	3.71
Total for RK	54.5	3.70	50.8	47.1	102	90.0

Explanations: RK = Republic of Kazakhstan.

Source: own study.

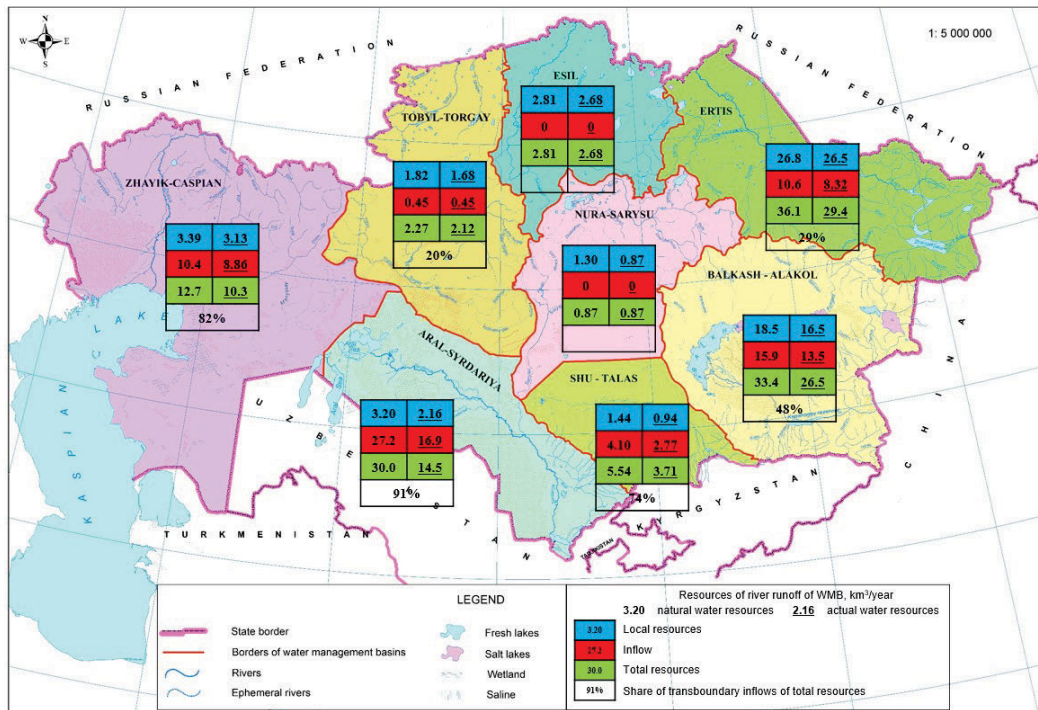


Fig. 1. The current condition of the river runoff resources in the Republic of Kazakhstan; source: own study

Today in Kazakhstan there are both external and internal threats of change in the river runoff, which will be worsening in the near future [DOSTAI 2012; MEDEU *et al.* 2012a, 2015; NYSANBAYEV *et al.* 2016] and can be subdivided as follows:

- External threats for transboundary water resources.
 1. The decrease in the inflow volume of transboundary rivers:
 - because of the global and regional climate changes, due to the expected increase of evaporation from all types of surfaces, and as a result, ecological losses in the hydrographic net.
 2. Changes in the runoff regime of transboundary rivers:
 - due to the regulated inflow of water in transboundary rivers, there is an increase in water inflow during the winter low-water period, and a decrease – during the flood period, associated with the conditions of water use in the upper reaches;
 - extreme increase in water inflow during the periods of extreme hydrometeorological phenomena.
- Internal threats of decrease of river runoff resources.
 1. Decrease of river runoff volume:
 - due to global and regional climate changes decrease in runoff is expected in the long term period;
 - due to reduced inflow of water in transboundary rivers;
 - due to the transformation of the water balance elements, in particular, an increase in evaporation from all types of surfaces is expected, and as a result, ecological losses in the hydrographic net.
 2. Change of river runoff regime:
 - due to the global and regional climate changes – intensification of intra-annual and interannual variations in river flow;
 - due to the regulated inflow of water along the rivers there is an increase in the water inflow during the winter low-water period and a decrease during the flood period, associated with the conditions of water use in the upper reaches; extreme increase in water inflow during periods of extreme hydrometeorological phenomena.

3. Decrease of river runoff resources. Economic demand for river water in the Republic of Kazakhstan is satisfied by the local and total runoff.

The economy's water consumption is on average 32.5 km³·y⁻¹. If we talk in the context of economic branches, the largest consumer is agriculture – 75%. More than half of this volume is used in the Aral-Syrdarya basin – 53%, area, where irrigated agriculture is traditionally developed.

The largest industrial consumers of water are the objects of Ertis basin – 38%, Nura-Sarysu basin – 29%, and Zhayik-Caspian basin – 21%, which are the industrially developed regions of the country. The municipal-domestic sector uses only about 5% of water [DOSTAI 2012; MEDEU *et al.* 2020].

It is known that seven of the eight water economic basins (WEBs) of Republic of Kazakhstan (RK) are transboundary and obviously the role of transboundary inflow in the total resources of river waters in Kazakhstan is very high, accounting for 55% (taking into account the runoff from RK – 52%). In this regard, the most vulnerable are basins of Aral-Syrdarya (91%), Zhayik-Caspian (82%), Shu-Talas (74%), Balkash-Alakol (48%), and the least vulnerable are Tobyl-Torgai and Ertis WEBs.

At present, the inflow from outside the country (transboundary rivers) has decreased to 50.8 km³·y⁻¹, the anthropogenic reduction, according to our assessment, amounted to 17.9 km³·y⁻¹ (68.7–50.8), i.e. due to anthropogenic influence in the territory of neighbouring countries, the river inflow into Kazakhstan has decreased by 26%.

In Aral-Syrdarya (the most stressful in water balance) WEB, the decrease reached 38% (10.3 km³·y⁻¹) from Uzbekistan, Shu-Talas 32% (1.33 km³·y⁻¹) from Kyrgyzstan, from Russia the runoff of Ertis decreased by 21.5% (2.28 km³·y⁻¹), Zhayik-Caspian WEB by 15% (1.56 km³·y⁻¹), in Balkash-Alakol basin the river inflow decreased by 15.3% (2.44 km³·y⁻¹) due to anthropogenic activities in the territory of China.

Therefore, the impact of economic activity on the runoff in the territory of the Republic of Kazakhstan can be assessed by the change of the available total resources, which under the modern conditions of water use makes $16.0 \text{ km}^3 \cdot \text{y}^{-1}$ (106–90.0). At the same time, in the territory of the Republic of Kazakhstan, the local runoff has changed by $4.8 \text{ km}^3 \cdot \text{y}^{-1}$ (59.3–54.5), and the runoff in the channels of transboundary rivers – by $11.2 \text{ km}^3 \cdot \text{y}^{-1}$ (16.0–4.8) [ALIMKULOV *et al.* 2019, MEDEU *et al.* 2020].

Based on the calculation results using prognosis relationships between river runoff and meteorological characteristics (temperature, precipitation), scenario forecasts of runoff changes were received in the context of eight water economic basins and administrative regions of the Republic of Kazakhstan. The results of scenario forecasts of climate-related changes in the river runoff are presented in Table 2.

increase in local runoff from 9.36 to 12%, of which an increase is expected in the southeastern and eastern regions of the republic (Shu-Talas, Balkash-Alakol, Ertis WEBs) from 0.18 to 10.0%, in Aral-Syrdarya WEB up to 27.4%, in Nura-Sarysu WEB almost doubled, the maximal increase in local resources is expected in the northwestern part of the country in Tobyl-Torgai WEB (increase in water resources is possible by almost 2–3 times).

The forecasted assessments of river runoff resources, taking into account climate and anthropogenic loads, are presented in Table 2 and Figure 2. Taking into account the implementation of possible climatic, anthropogenic, and transboundary hydrological threats in the future, a decrease in river runoff resources is forecasted: in the whole of Kazakhstan by 2030 up to $87.1 \text{ km}^3 \cdot \text{y}^{-1}$, including transboundary runoff – up to 46.4; local – up to $56.7 \text{ km}^3 \cdot \text{y}^{-1}$.

Table 2. Forecast values of the factual resources of river runoff of the Republic of Kazakhstan, taking into account the climate and anthropogenic loads (2030), $\text{km}^3 \cdot \text{y}^{-1}$

Water economic basins	Local resources		Inflow		Total	
	total	including outflow outside the Republic of Kazakhstan (returnable)	total	including formed on the territory of neighbouring countries	total	total, taking into account anthropogenic changes in the main river channel
Aral-Syrdariya	3.17	0.48	14.4	13.9	17.1	12.7
Balkash-Alakol	16.6	0.99	12.5	11.5	28.1	25.5
Ertis	26.5	1.31	7.13	5.82	32.3	27.7
Esil	2.47	–	–	–	2.47	2.47
Zhayik-Caspian	3.08	0.97	8.63	7.66	10.7	9.97
Nura-Sarysu	1.96	–	–	–	1.96	1.96
Tobyl-Torgay	1.88	–	0.59	0.59	2.47	2.47
Shu-Talas	1.01	–	3.21	3.21	4.22	4.22
Total for RK	56.7	3.75	46.4	42.7	99.4	87.1

Explanations: RK = Republic of Kazakhstan.
 Source: own study.

At present, a large number of works are devoted to the study of climate change. So in 2014, the well-known Intergovernmental Panel on Climate Change (IPCC) released its Fifth Assessment Report. In this work, the basis for meteorological forecasting for the territory of Kazakhstan is a program Climate Wizard, based on the IPCC 5.

Within the frames of various projects, Kazhydromet’s meteorologists have calculated the forecast monthly values of precipitation and air temperature for the periods of 2030–2050 and handed them over to us for the implementation and assessment of water availability forecasts [Ministerstvo energetiki Respubliki Kazakhstan 2017; III-VI natsional’noe soobshchenie RK ... 2013].

The expected water resources for the whole of Kazakhstan are calculated according to two scenarios RCP 4.5 and RCP 8.5 and show approximately equal results for the periods of 2020–2029, 2025–2034, and 2030–2039. Therefore, we present the forecasted runoff values as averaged for both scenarios. Deviations of the forecasted runoff values from the runoff norm for the calculated period of 1974–2015 for the whole Republic of Kazakhstan for all periods of 2025, 2030, and 2035 amount to an

The average annually renewable local natural resources of river runoff of the territory of the Republic of Kazakhstan for the future by 2030 are $105 \text{ km}^3 \cdot \text{y}^{-1}$, local water resources – $62.2 \text{ km}^3 \cdot \text{y}^{-1}$, inflow to the territory of the Republic of Kazakhstan – $46.4 \text{ km}^3 \cdot \text{y}^{-1}$, outflow from the territory of the Republic of Kazakhstan – $26.3 \text{ km}^3 \cdot \text{y}^{-1}$, anthropogenic influence – $17.9 \text{ km}^3 \cdot \text{y}^{-1}$, and the natural loss of the river net will be $25.6 \text{ km}^3 \cdot \text{y}^{-1}$, i.e. that much water is required for the existence of the ecologically stable balanced condition of the systems of Kazakhstan (Fig. 2).

To implement the general goal – to prevent a possible shortage of water resources in Kazakhstan, to ensure all sectors of the economy and ecological needs of water, we propose a number of tasks and a complex of specific measures:

- 1) preventing the expected reduction of transboundary inflow of water resources;
- 2) improving international cooperation in the sphere of transboundary water resources, organisation of mutually beneficial regulation of the river runoff of transboundary rivers between countries;

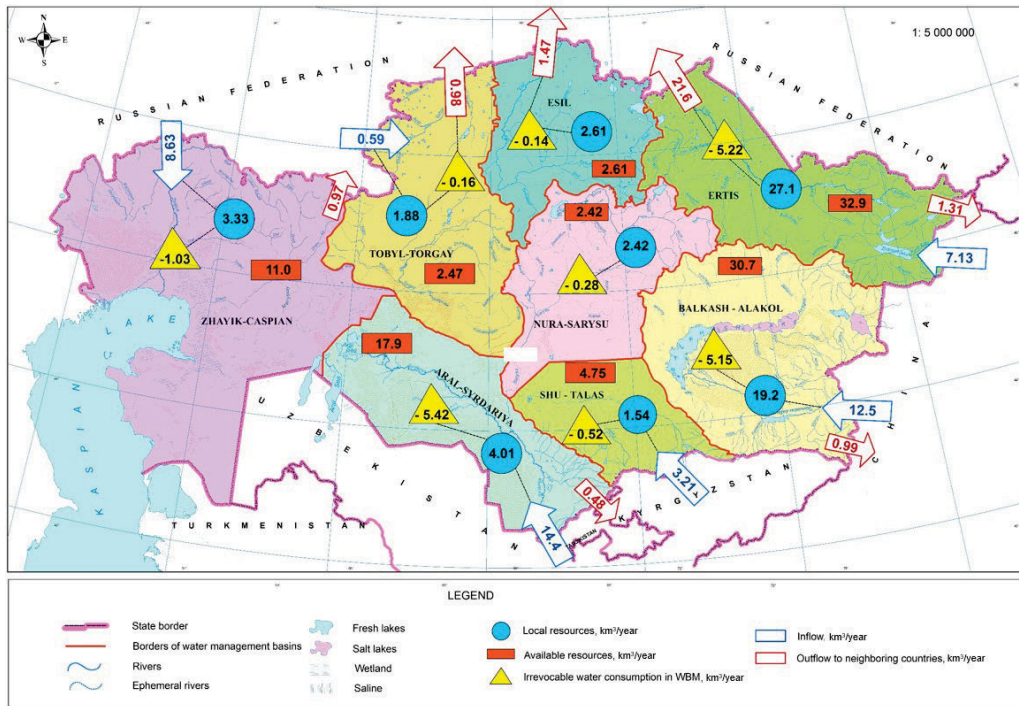


Fig. 2. Scheme of distribution of river runoff resources for 2030; source: own study

- cooperative development by the experts of countries of the enlarged schemes of distribution of water resources for various years of water availability;
- environmental cost management by introducing norms of water consumption.

The corresponding measures were developed:

- improvement of methods of hydrological regime assessment;
- improvement of methods of water balance assessment of water bodies and catchment basins;
- an accurate determination of anthropogenically and climatically caused changes of river runoff resources, improvement of methods for assessing hydrological transformations under the influence of anthropogenic impact;
- reducing the pressure on water resources – rationing ecological and economic demand, water-saving in sectors of the economy;
- an increase of freshwater resources – improvement of intergovernmental water relations, use of underground freshwater resources, desalination of saline and brackish waters, inter-basin redistribution of water resources, reduction of unproductive water losses in the natural hydrographic net.

Change of the river flow regime – regulation of river flow.

It is proposed to achieve the objectives according to the following indicators and parameters:

- the functioning of the automated information system of the state water cadastre based on the improvement of its organisational structure and maintenance procedure by 2030;
- equipping 80% of agricultural producers with measuring devices and automation of control at all stages of water intake and water supply by 2030;
- coverage by hydrological monitoring of all large and medium-sized, as well as small rivers, significant for the economic complex of the republic, and creating 1500 or more state hydrological gauging stations by 2030;
- introduction of geoinformation system for monitoring of water bodies, creation of computer models of river basins;

- development and creation of an automated assessment of water resources for the future prospective;
- securing the needs of natural objects in water to preserve their ecological condition, including Lake Balkash at least 12.0 km³·y⁻¹, Lake Aral – 3.6 km³·y⁻¹, the delta of the Syrdarya River – 2.7 km³·y⁻¹, the delta of the Ile River – 2.0 km³·y⁻¹ and other natural objects, included in the list of wetlands of international importance;
- international cooperation in the field of transboundary water resources;
- a creation of an infrastructure for monitoring the volume of water resources coming from the neighbouring countries, including jointly with them on their territory;
- development of forecasts and analysis of possible scenarios of changes in transboundary flows based on detailed computer models;
- strengthening of negotiating groups, and the negotiation process in general regarding transboundary water allocation for the preparation and making of agreements;
- development of complex negotiation strategies based on collected analytical information and taking into account international experience;
- development of the concept of the efficient use of water and energy resources of the Central Asian region;
- the making of long-term agreements on water allocation of transboundary rivers and creation of mechanisms for their implementation.

CONCLUSIONS

Water resources, or rather their rational use, determine the well-being of people, the maintenance of natural potential, and a significant part of the national income of the countries of the region.

The water resources of the river runoff in the Republic of Kazakhstan due to anthropogenic activity decreased by $16.0 \text{ km}^3 \cdot \text{y}^{-1}$. This is corresponding to the long-term forecast of climate change. Taking into account the expected decrease of transboundary runoff by 2030, there will be a further decrease in the republic's water resources to $87.1 \text{ km}^3 \cdot \text{y}^{-1}$, and in low water years – less than $50.0 \text{ km}^3 \cdot \text{y}^{-1}$.

This indicates the threat of severe water shortages at the turn of 2030–2050, which on the whole affects the national security issues.

Reducing the pressure on the water resources and increasing freshwater resources are the ways to eliminate the deficiency in Kazakhstan. The first group provides for the implementation of measures to reduce the rate of development of the main water consumers and the use of modern technologies to reduce the consumption of freshwater in industry, agriculture, and municipal economy. The second group assumes an increase in water resources available for use by regulating river flow, using ground freshwater resources; desalination of saline and brackish waters, and territorial redistribution of water resources.

As it is known, Kazakhstan is located in the lower reaches of large transboundary rivers; therefore water availability largely depends on the economic “position” of neighbouring countries, the development of their economies, and population growth. Consequently, the issues of regulating the use and protection of water resources are of strategic importance, as well as adequate state policy formation.

For the rational use and protection of water resources within the country, it is necessary to adopt a national plan for their integrated management and, on its basis, carry out complete rehabilitation and improvement of the existing water infrastructure.

In addition, new water-saving technologies, automated control systems for production processes, state and primary water accounting need to be established and introduced everywhere.

Improvement of interstate water relations is the second direction of state policy in this area. First of all, this means the establishment of legal and economic mechanisms for the joint use of water resources of transboundary watercourses.

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For the Project: 1 Rational use of water resources with an increase in the areas of regular and estuary irrigation in all water basins of the Republic of Kazakhstan until 2021.

For Activity: 1.1 Assessment and forecast of annually renewable water resources possible for use for irrigation purposes in water basins of the Republic of Kazakhstan.

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