

Study of Water Stress in Plains Rivers: Climate and Human Influence

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Abstract: The study aims to assess recent changes in water consumption, stress, and supply in Northern and Central Kazakhstan amidst significant climate and socio-economic shifts. The study used methods of analysing long-term changes in annual and seasonal runoff, statistical analysis, and assessment of the anthropogenic impact on water resources. The article presents new data on the assessment of the multi-year dynamics of water resources formed in the basins of the Yesil, Tobyl – Torgai and Nura – Sarysu rivers and the multi-year dynamics of water used.

Keywords: water resources; minimum flow; winter low water

1. Introduction

Water is the basis of the health and well-being of society, its economic prosperity, a source of vitality. The Core Principles for Sustainable Development, identified for implementation by 2030, expand the approach to sustainable water management, focusing on drinking water supply and ensuring compliance with sanitation standards. Water use in the framework of sustainable development includes effective integrated water resources management, wastewater treatment, high requirements for environmental flow parameters and the priority of ecosystem conservation. The main task within the framework of the program to achieve the sustainable development goals, with regard to efficient water use and water stress, is the priority provision of fresh water and increasing the efficiency of water use in all vectors of industrial and social activities. To achieve this goal, specific indicators are used that determine the level of water stress and the dynamics of changes in water use efficiency.

The indicator of water stress for 32 countries of the world community ranges from 25-70%, and for 22

countries it exceeds 70% (severe water shortage)¹⁾. Compared to a global average of 13% water stress, high rates indicate the uneven distribution of water resources in the world, as well as not always rational use²⁾. For Kazakhstan, the value of the water stress indicator is 30%, which corresponds to high water stress. Optimization of water use in economically developed regions involves an integrated approach to rational water consumption in various industries, with the obligatory consideration of the characteristics of the hydrological and climatic component of the ecosystem. This approach can have a significant impact on the conditions of run-off formation, transforming the existing water regime. This concept is especially relevant for basins with a low level of water supply.

The priority of the water management system is the stability of supplying consumers with water in the required quantity and quality. In this regard, the main problem is the solution of the issue of scarcity of water resources. In addition, the water resources management system implies strict requirements for the parameters of water bodies and limiting changes in qualitative and

quantitative parameters. Firstly, it is all about the minimum allowable water discharge in rivers, which is a proportion of the discharge of a certain probability and is calculated using probability distribution curves and calculation of parameters and quantiles from actual data. Limiting and maintaining indicators of the minimum allowable flow in rivers makes it possible to optimize the processes of water use and regeneration of aquatic ecosystems. Also, an important characteristic of the local and regional water system is the indicator of the average annual run-off. Based on this value, the calculation of the main parameters of the regulation of the water management system is carried out³⁾.

The traditional approach to water resources management involves the use of a stationary hypothesis of fluctuations in river flow, hydrological calculations for water resource assessment and forecasting. This approach is based on the concept of stationarity of fluctuations in river run-off. At the same time, it does not take into account the influence of the growing anthropogenic impact and climate change processes, which entail significant changes in run-off characteristics and lead to the need to change the modern paradigm of hydrological calculations. There is a need to optimize existing and develop new methods for assessing run-off characteristics and systems for predicting water use. It is worth noting the scientific research in this industry, which actualize the problem of assessing hydrological characteristics against the background of global climate change and substantiate the need to develop fundamentally new forecasting methods^{4),5)}.

The hydrological regime of the river basin is based on the seasonal specifics of the inflow of seasonal water, the consequence of which is a stable sequence of floods and low water⁶⁾. The less noticeable the fluctuations in the indicators of the annual and extreme consumption of water resources, the more real the possibility of organizing an environmentally safe and economically feasible water use regime becomes⁷⁾. Thus, the actual goal of managing the water management system is to stabilize the water supply of the population and the economy under conditions of significant run-off fluctuations.

For Kazakhstan, a characteristic trend of the modern water regime of lowland rivers is a decrease in the share of spring run-off and an increase in the share of low-water run-off^{8),9)}. These processes lead to the transformation of the annual runoff, aligning its values. The main reason for

this is climate change, which is reflected in the long-term increase in surface air temperatures in the cold season, and, as a result, in a regular increase in the frequency of thaws and winter low water flow^{10),11)}. The duration and stability of low water are determined by run-off-forming factors. At the same time, the key role is assigned to atmospheric precipitation and groundwater, which are directly involved in the formation of the inflow part of the flow¹²⁾.

The defining indicators of the hydrological regime in the water use management system are the minimum run-off and the average annual run-off. In this regard, the assessment of changes in the parameters of the minimum run-off is one of the most urgent problems of hydrology today. Its calculations are related to the solution of practical important problems of planning measures in the water management industry, regulating the flow of regional water supply, and territorial distribution of water resources. The phenomenon of minimum water content should be regarded as an extreme phenomenon, since the problems of water scarcity and its poor quality are associated precisely with the minimum flow¹³⁾.

The purpose of this scientific study is to study the features of modern changes in the minimum run-off and the average annual run-off of lowland rivers, as well as the possibility of their effective use in assessments and forecasts, taking into account climate change and the level of water stress.

2. Methods and Materials

Multi-year data from hydrological observations of the Kazhydromet network were used to solve the research tasks. The main methods of analysing the initial data were standard hydrological calculations according to the recommendations^{14),15),16)}. To analyse multi-year changes in annual and seasonal flow in the considered area, the following gauging stations were identified as reference hydrological posts: Tobyl (Kostanay), Ayat (Varvarinka), Toguzak (Toguzak), Siletly (Pirrechnoye), Shagalaly (Pavlovka), Yesil (Petropavlovsk), Nura (Balykty), Nura (Koshkarbayeva), Sarysu (junction No. 189). The choice of hydrological gauging stations is based on differences in the physical and geographical conditions of the formation of flow and the degree of anthropogenic impact on it. The flow in the basins of the Tobyl, Yesil, Nura rivers is regulated by reservoirs of multi-year regulation (Fig. 1).

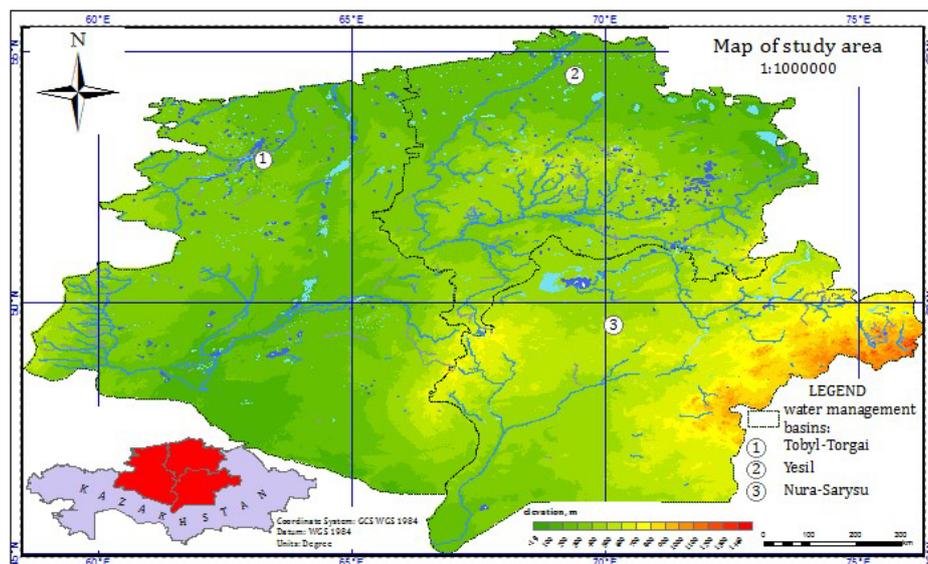


Fig. 1. Study area, comprising estimated water management basins in Kazakhstan.

Analysis of multi-year changes in annual and seasonal flow in basins of plain rivers is based on the use of difference-integral curves, the features of multi-year dynamics in different river sites, including the synchrony of observed changes, are identified by normalized values (matrices of pair correlation coefficients are built, coefficients of linear determination are calculated). All available series were analysed for stationary (uniformity) using the Student and Fisher criteria. Chronological graphs and differential integral curves in combination with statistical analysis of the series make it possible to analyse changes in the series of observed values of the flow of plain rivers and determine the dates of transition to new conditionally stationary states. The dates of the stationary violation are generalized by territory, taking into account the physical and geographical features of the considered region. To determine the flow rate, the calculation period of 1932-2018 was adopted, including full cycles of flow fluctuations (the Tobyl river basin – 1940-1989, 1990-2018; the Yesil river basin – 1940-1982, 1983-2013; the Nura River basin – 1940-1982 and 1983-2014; the Sarysu river basin – 1940-1979 and 1980-2014). A comparative analysis of the minimum flow parameters was performed for three periods – when assessing the representativeness of a number of observations, the presence of the lowest water years or a group of years in the statistical series is of great importance.

When analysing the initial materials on the minimum flow of the plain rivers of Central and Northern Kazakhstan, the period from 1932 to 1940 belongs to the category of the most low-water years. The distinctive feature of low flow characteristic series of plain rivers is the presence of zero values in many of them; this is observed in low-water years when river feeding sharply decreases up to the complete suspension of groundwater flow into the channel. In such cases, rivers dry up or freeze

over for varying, sometimes very long periods. The calculation of the characteristics of the minimum monthly flow in the presence of observational data was carried out using statistical methods. When calculating the characteristics of the monthly minimum flow during the statistical processing of the observation series, authors strived to include this low-water period. In the absence of data, the statistical series were reconstructed using river-analogues. The construction of empirical probability curves of the characteristics of the minimum monthly flow was carried out using the Kritsky-Menkel formula. The value of the coefficient of variability required to construct an analytical probability curve was determined from the available actual series or reconstructed using the formula of the method of moments, the method of maximum likelihood and the graph-analytical method¹⁷⁾.

Assessment of anthropogenic loads on water resources. In this study, at the first stage, an assessment of anthropogenic changes in river flow was carried out according to the main reference points of observations based on the method of hydrological analogy. The method gives quite reliable results, while the integral values of changes are limited to assess the role of individual industries or types of economic activity (the estimates obtained from reference hydrological gauging stations and estimates obtained on the basis of the channel water balance give a complete picture of the anthropogenic transformations of the river flow of plain rivers in water management areas and water management basins). An approach based on independent reconstructions of flow by regression relationships with the flow of the river-analogue was used to assess the anthropogenic contribution to multi-year changes in seasonal flow. To assess the availability of water resources in various regions and countries in the world, an approach is used based on the use of the indicator of the water stress (the

coefficient of use), which is equal to the ratio as a percentage of the total water consumption to renewable water resources. Renewable water resources represent the sum of local water resources formed within the considered region and the inflow of river waters from neighbouring territories. This approach to assessing the availability of water resources has been applied in the works of various researchers^{18),19)}. The degree of the load on water resources, in accordance with the proposed approach, is determined by a classification having five categories (Table 1).

Table 1. Classification by degree of water stress.

| Category | C _{use} , % | Characteristics |
|----------|----------------------|--|
| I | <10 | Low load – regions do not experience serious problems with water supply |
| II | 10-20 | Moderate load – level of water supply becomes a factor limiting regional development |
| III | 20-40 | High load – for sustainable development, it is necessary to regulate the demand and supply of water |
| IV | 40-60 | Very high load – there is a serious deficit of water and an urgent need to regulate and limit water consumption, to attract additional sources of water supply. Water resources' scarcity becomes a factor restraining economic growth and welfare improvement of the population |

This approach does not allow authors to fully characterize the shortage of water resources in a particular region, because it does not take into account the number of people living in its territory. In order to take into account this factor, it is proposed to additionally use the indicator of specific water supply, calculated as the ratio of real water resources minus irretrievable water consumption to the size of the population. Classification of water resources according to this indicator includes the following gradation (Table 2).

Table 2. Classification of water resources status by specific water supply.

| Characteristics | Gradation |
|-----------------------------------|-----------|
| Catastrophically low water supply | <1 |
| Very low water supply | 1.01-2 |
| Low water supply | 2.01-5 |
| Average water supply | 5.01-10 |
| High water supply | 10.01-20 |
| Very high-water supply | >20 |

The water stress and water supply are determined in relation to the total average annual water resources, which allows authors to assess the necessary measures to regulate or redistribute the river flow, and eliminate existing or potential water shortages. There is another point of view according to the scientific researches of A. P. Demin et al.²⁰⁾ and E. A. Korobkina et al.²¹⁾, the coefficient of use is calculated as the ratio of water withdrawal for economic needs to the minimum water availability of rivers in the limiting winter period.

3. Results

Scientific research in the area under study indicates the beginning of the modern period in the formation of climate and run-off approximately in the 60-70s of the twentieth century. The intensification of economic activity in Kazakhstan also occurred during this period. Since the 70s of XX century, a new phase in changes in water resources of vast territories began, and some slowdown of the process or even groupings of years with the opposite sign of anomaly since the late 90s do not give grounds to consider that this phase has ended and was replaced by a new one; these are just random groupings against the established trend^{21, 22)}. The period from the mid-70s of the last centuries can be considered as the modern period in the multi-year course of water supply of the rivers of the considered territory. As a result of the analysis of multi-year data, phases of different water supply were identified, and it was noted that within long homogeneous phases, years, or series of years (up to two or three years) characterized by anomalous water supply for a given phase are quite often observed. The features of the nature of long-term fluctuations in the river run-off of lowland rivers are reflected in the dynamics of the values of modular coefficients (Fig. 2)²³⁾.

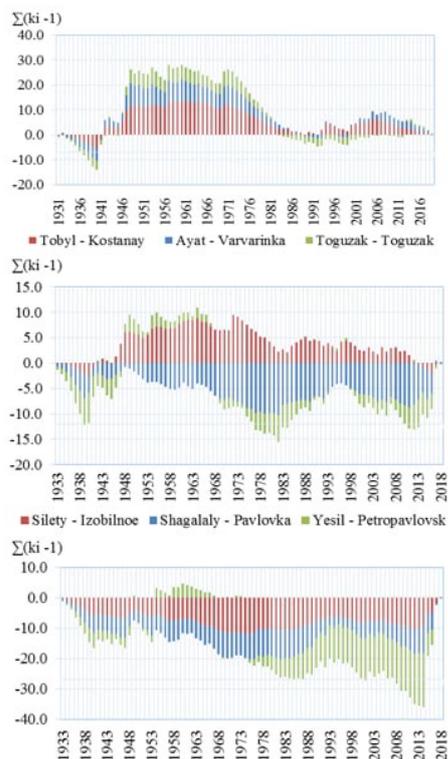


Fig. 2. Dynamics of water supply in plain rivers.

Rivers of the Kazakh type are characterized by specific features of the run-off distribution dynamics during the year. Its main share falls on the period of the spring flood, and after the depletion of the latter, a common characteristic feature of the rivers of the Kazakhstan type is observed – a decrease in flow, until the beginning of the next flood. The rivers of the Tobyl river basin are characterized by a flow cycle from 8 to 14 years, the Yesil

river is characterized by a flow cycle with a period of 10-23 years, for the Nura River basin from 5 to 15 years, and for the rivers of the Sarysu river basin flow cycle from 4 to 15 years is typical. In the Tobyl river basin from 1932 to 2018, there are eight low-water periods lasting from two to eleven years; in the Yesil river basin, there are six low-water periods lasting from four to seven years; in the Nura River basin, there are nine low-water periods lasting from two to ten years; in the Sarysu river basin, there are ten low-water periods lasting from two to nine years. Most of the rivers of the studied basin are characterized by a pronounced decrease in the share of spring run-off and an increase in the share of run-off during dry periods. It should be noted that rivers with a regulated regime are characterized by even more significant changes. For example, the share of the spring run-off of the Yesil river (Astana) decreased from 95% in 1932–1973 to up to 52% in the modern period. At the same time, the share of winter run-off increased from 2% to 16%. The same dynamics is observed for the Tobyl river (Kostanay): the reduction in the share of spring run-off occurred from 77% in 1932–1973. to 42% today, while there was an increase in the share of winter run-off from 3% to 18%. The minimum run-off is characterized by specific conditions and formation factors. They do not appear in other periods. At the same time, for the winter low water there is a dependence on the duration of the period of low temperatures, and the summer-autumn one is more dependent on the characteristics of atmospheric precipitation, mostly on their intensity^{24, 25, 26}). Thus, the duration of low-water phases depends, firstly, on the stability of low-water periods. Multi-year dynamics of minimum flow in the considered basins show stable growth of values for the majority of the studied rivers (Fig. 3).

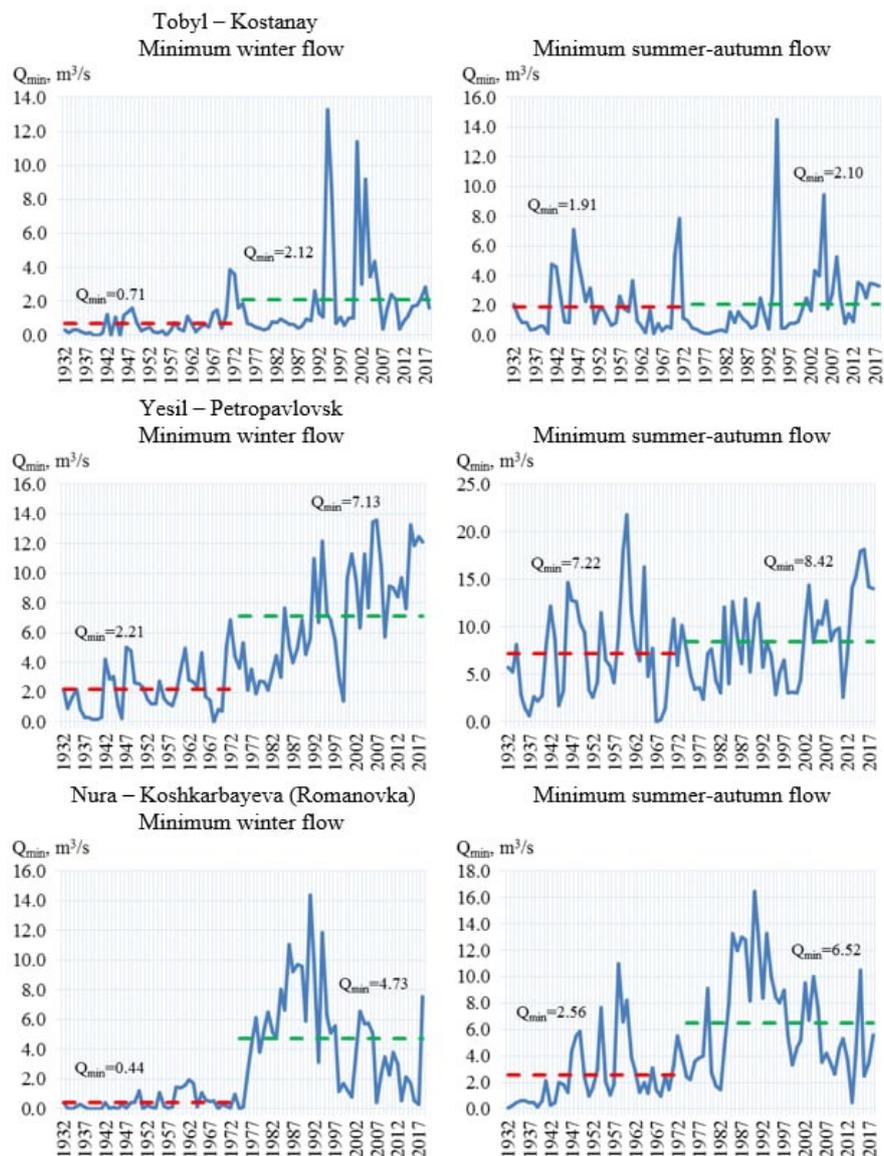


Fig. 3. Dynamics of minimum flow.

The values of the minimum run-off for the modern period differ significantly from the average long-term values of the conditionally natural period, which indicates a positive trend. In this case, the maximum deviations from the norm are recorded for the indicators of the winter

low-water flow. Statistical characteristics and discharges of different probability of the minimum monthly flow for the winter period and for the period of free-flowing channel of the main plain rivers are shown in Tables 4 and 5.

Table 4. Statistical characteristics of the minimum winter flow in the basins of the plain rivers.

| River – gauging station | Period | Q, m³/s (average, minimum) | Cv | Water discharges in years with different water availability, % | | |
|--|-----------|----------------------------|------|--|-------|-------|
| | | | | 80 | 90 | 95 |
| Tobyl – Torgai water management basin | | | | | | |
| Tobyl – Kostanay | 1932-1973 | 0.71 (0) | 1.2 | 0.1 | 0.041 | 0.017 |
| | 1974-2018 | 2.12 (0.31) | 1.34 | 0.36 | 0.3 | 0.28 |
| | 1932-2018 | 1.44 (0) | 1.55 | 0.15 | 0.13 | 0.11 |
| Ayat – Varvarinka | 1392-1973 | 0.1 (0) | 1.05 | 0.02 | 0.009 | 0.004 |

| | | | | | | |
|---|-----------|--------------|------|-------|-------|-------|
| | 1974-2018 | 0.34 (0) | 1.22 | 0.05 | 0.03 | 0.02 |
| | 1932-2018 | 0.24 (0) | 1.43 | 0.03 | 0.02 | 0.01 |
| Toguzak – Toguzak | 1932-1973 | 0.12 (0) | 0.93 | 0.03 | 0.017 | 0.011 |
| | 1974-2018 | 0.22 (0) | 1.35 | 0.05 | 0.022 | 0.016 |
| | 1932-2018 | 0.17 (0) | 1.35 | 0.04 | 0.02 | 0.014 |
| Yesil water management basin | | | | | | |
| Siley – Izobilnoye | 1932-1973 | 0.07 (0) | 0.92 | 0.02 | 0.012 | 0.009 |
| | 1974-2018 | 0.28 (0) | 1.02 | 0.057 | 0.023 | 0.009 |
| | 1932-2018 | 0.18 (0) | 1.3 | 0.016 | 0.005 | 0.001 |
| Yesil – Astana | 1974-2018 | 0.46 (0) | 1.01 | 0.098 | 0.042 | 0.019 |
| | 1932-2018 | 0.23 (0) | 1.76 | 0.007 | 0.005 | 0.003 |
| Yesil – Kamenny Karyer | 1932-1973 | 1.44 (0.018) | 0.92 | 0.41 | 0.25 | 0.18 |
| | 1974-2018 | 1.65 (0.063) | 0.54 | 0.9 | 0.69 | 0.54 |
| | 1932-2018 | 1.57 (0.018) | 0.69 | 0.67 | 0.44 | 0.3 |
| Yesil – Zapadnoye | 1974-2018 | 1.49 (0.081) | 1.01 | 0.32 | 0.14 | 0.06 |
| Yesil – Petropavlovsk | 1932-1973 | 2.21 (0.002) | 0.76 | 0.83 | 0.5 | 0.31 |
| | 1974-2018 | 7.13 (1.43) | 0.51 | 4.04 | 3.02 | 2.33 |
| | 1932-2018 | 4.76 (0.002) | 0.79 | 1.68 | 0.92 | 0.51 |
| Zhabai – Atbasar | 1974-2018 | 0.34 (0) | 0.86 | 0.11 | 0.071 | 0.053 |
| | 1932-2018 | 0.2 (0) | 1.4 | 0.012 | 0.003 | 0.001 |
| Nura-Sarysu water management basin | | | | | | |
| Nura – Balykty | 1974-2018 | 0.72 (0) | 1.03 | 0.16 | 0.077 | 0.042 |
| Nura – Koshkarbayeva (Romanovka) | 1932-1973 | 0.44 (0) | 1.27 | 0.05 | 0.018 | 0.005 |
| | 1974-2018 | 4.73 (0.029) | 0.73 | 1.9 | 1.21 | 0.83 |
| | 1932-2018 | 2.71 (0) | 1.22 | 0.34 | 0.15 | 0.076 |
| Sherybainura – Karamurun | 1932-1973 | 0.32 (0.046) | 0.54 | 0.17 | 0.13 | 0.11 |
| | 1974-2018 | 0.55 (0.18) | 0.5 | 0.32 | 0.24 | 0.19 |
| | 1932-2018 | 0.48 (0.046) | 0.55 | 0.26 | 0.19 | 0.14 |

Table 5. Statistical characteristics of the minimum summer-autumn flow in plain river basins.

| River – gauging station | Period | Q, m ³ /s (average, minimum) | Cv | Water discharges in years with different water availability, % | | |
|--|-----------|---|------|--|-------|-------|
| | | | | 80 | 90 | 95 |
| Tobyl – Torgai water management basin | | | | | | |
| Tobyl – Kostanay | 1932-1973 | 1.91 (0.12) | 0.99 | 0.34 | 0.21 | 0.11 |
| | 1974-2018 | 2.1 (0.14) | 1.23 | 0.37 | 0.28 | 0.26 |
| | 1932-2018 | 2.01 (0.12) | 1.13 | 0.35 | 0.27 | 0.22 |
| Ayat – Varvarinka | 1932-1973 | 0.68 (0.11) | 0.65 | 0.13 | 0.07 | 0.03 |
| | 1974-2018 | 0.77 (0) | 1.15 | 0.21 | 0.11 | 0.05 |
| | 1932-2018 | 0.74 (0) | 1.03 | 0.16 | 0.08 | 0.04 |
| Toguzak – Toguzak | 1932-1973 | 0.4 (0.06) | 0.67 | 0.17 | 0.12 | 0.08 |
| | 1974-2018 | 0.31 (0.01) | 0.93 | 0.08 | 0.04 | 0.03 |
| | 1932-2018 | 0.35 (0.01) | 0.79 | 0.13 | 0.08 | 0.05 |
| Yesil water management basin | | | | | | |
| Siley – Prirechnoye | 1932-1973 | 0.014 (0) | 1.53 | 0.001 | 0 | 0 |
| | 1974-2018 | 0.021 (0) | 1.59 | 0.002 | 0.001 | 0 |
| | 1932-2018 | 0.018 (0) | 1.61 | 0.001 | 0 | 0 |
| Siley – Izobilnoye | 1932-1973 | 0.62 (0.1) | 1.13 | 0.09 | 0.03 | 0.002 |

| | | | | | | |
|---|-----------|---------------|------|-------|--------|-------|
| | 1974-2018 | 0.47 (0) | 0.67 | 0.18 | 0.12 | 0.082 |
| | 1932-2018 | 0.42 (0) | 0.92 | 0.13 | 0.072 | 0.046 |
| Shagalaly – Pavlovka | 1940-1973 | 0.07 (0.01) | 0.92 | 0.018 | 0.009 | 0.004 |
| | 1974-2018 | 0.16 (0) | 1.07 | 0.03 | 0.02 | 0.009 |
| | 1940-2018 | 0.12 (0) | 1.17 | 0.02 | 0.005 | 0.001 |
| Shagalaly – Severnoye | 1940-1973 | 0.16 (0.008) | 1.15 | 0.02 | 0.01 | 0.004 |
| | 1947-2018 | 0.22 (0) | 0.91 | 0.06 | 0.03 | 0.02 |
| | 1940-2018 | 0.19 (0) | 1 | 0.04 | 0.02 | 0.01 |
| Yesil – Astana | 1932-1973 | 0.24 (0) | 1.52 | 0.014 | 0.006 | 0.005 |
| | 1974-2018 | 0.54 (0) | 1.59 | 0.02 | 0.01 | 0.003 |
| | 1932-2018 | 0.39 (0) | 1.73 | 0.012 | 0.005 | 0.004 |
| Yesil – Kamenny Karyer | 1932-1973 | 3.8 (0.036) | 0.81 | 1.31 | 0.81 | 0.54 |
| | 1974-2018 | 3.3 (0.29) | 0.74 | 1.28 | 0.72 | 0.42 |
| | 1932-2018 | 3.54 (0.036) | 0.78 | 1.3 | 0.81 | 0.54 |
| Yesil – Petropavlovsk | 1932-1973 | 7.22 (0.001) | 0.7 | 3.03 | 1.96 | 1.31 |
| | 1974-2018 | 8.42 (2.36) | 0.52 | 4.7 | 3.47 | 2.64 |
| | 1932-2018 | 7.84 (0.001) | 0.6 | 3.84 | 2.67 | 1.82 |
| Zhabai – Atbasar | 1932-1973 | 0.33 (0) | 0.99 | 0.08 | 0.04 | 0.02 |
| | 1974-2018 | 0.64 (0) | 1 | 0.14 | 0.006 | 0.03 |
| | 1932-2018 | 0.49 (0) | 1.08 | 0.09 | 0.05 | 0.03 |
| Akkanburluk – Privolnoye | 1932-1973 | 0.05 (0) | 1.24 | 0.006 | 0.002 | 0.001 |
| | 1974-2018 | 0.17 (0) | 0.82 | 0.06 | 0.03 | 0.02 |
| | 1932-2018 | 0.11 (0) | 1.11 | 0.02 | 0.01 | 0.006 |
| Imanburluk – Sokolovka | 1932-1973 | 0.11 (0.01) | 0.66 | 0.012 | 0.0006 | 0.005 |
| | 1974-2018 | 0.43 (0.023) | 1.34 | 0.049 | 0.033 | 0.023 |
| | 1932-2018 | 0.28 (0.01) | 1.62 | 0.038 | 0.013 | 0.006 |
| Nura – Sarysu water management basin | | | | | | |
| Nura – Besoba | 1932-1973 | 0.037 (0.005) | 1.08 | 0.007 | 0.003 | 0.002 |
| | 1974-2018 | 0.023 (0) | 1.19 | 0.003 | 0.001 | 0.001 |
| | 1932-2018 | 0.026 (0) | 1.18 | 0.004 | 0.002 | 0.001 |
| Nura – Sheshenkara | 1932-1973 | 0.34 (0.011) | 1.18 | 0.012 | 0.004 | 0.002 |
| | 1974-2018 | 0.39 (0) | 1.59 | 0.051 | 0.022 | 0.011 |
| | 1932-2018 | 0.36 (0) | 1.43 | 0.025 | 0.009 | 0.006 |
| Nura – Balykty | 1932-1973 | 0.37 (0) | 1.40 | 0.023 | 0.006 | 0.002 |
| | 1974-2018 | 2.08 (0.04) | 0.66 | 0.93 | 0.62 | 0.43 |
| | 1932-2018 | 1.25 (0) | 1.08 | 0.24 | 0.11 | 0.06 |
| Nura – Koshkarbayeva (Romanovka) | 1932-1973 | 2.56 (0.09) | 0.97 | 0.62 | 0.33 | 0.2 |
| | 1974-2018 | 6.52 (1.45) | 0.6 | 3.23 | 2.30 | 1.67 |
| | 1932-2018 | 4.63 (0.09) | 0.83 | 1.52 | 0.83 | 0.4 |
| Akbastau – Zhanaauyl | 1932-2018 | 0.022 (0) | 0.99 | 0.003 | 0.002 | 0.001 |
| Sharubainura – Karamurun | 1932-1973 | 0.6 (0.15) | 0.56 | 0.32 | 0.24 | 0.18 |
| | 1974-2018 | 0.63 (0.08) | 0.53 | 0.35 | 0.26 | 0.2 |
| | 1932-2018 | 0.61 (0.08) | 0.54 | 0.33 | 0.25 | 0.19 |
| Karamys – Karamys | 1932-1973 | 0.007 (0) | 1.48 | 0.001 | 0 | 0 |
| | 1974-2018 | 0.004 (0) | 1.12 | 0.001 | 0 | 0 |
| | 1932-2018 | 0.006 (0) | 1.43 | 0.001 | 0 | 0 |

| | | | | | | |
|------------------------------|-----------|--------------|------|-------|-------|-------|
| Sarysu – junction No. 189 | 1932-1973 | 0.076 (0.01) | 0.66 | 0.016 | 0.007 | 0.005 |
| | 1974-2018 | 0.094 (0) | 1.1 | 0.034 | 0.023 | 0.016 |
| | 1932-2018 | 0.087 (0) | 1.11 | 0.016 | 0.008 | 0.003 |

The problem is especially urgent for Kazakhstan due to the poor network of observations of river flow and unreliable data on water withdrawals and discharges into

natural water bodies. Anthropogenic changes in the flow of plain rivers are shown in Table 6.

Table 6. Anthropogenic changes in the flow of plain rivers.

| No. | River – gauging station | Flow volume, mln. m ³ | | Change in flow volume, mln. m ³ | In % of the naturally-restored run-off |
|--|----------------------------------|----------------------------------|-----------------|--|--|
| | | Natural restored | Actual observed | | |
| Tobyl – Torgai water management basin | | | | | |
| 1 | Tobyl – Kostanay | 515 | 379 | -136 | -26.4 |
| 2 | Ayat – Varvarinka | 200 | 200 | 0 | 0 |
| 3 | Toguzak – Toguzak | 89.9 | 89.9 | 0 | 0 |
| 4 | Ubagan – Aksuat | 63.4 | 63.4 | 0 | 0 |
| 5 | Yi – Stepnoye | 124 | 124 | 0 | 0 |
| 6 | Torgai – Tosyn | 314 | 305 | -9 | -2.87 |
| Yesil water management basin | | | | | |
| 7 | Silety – Izobilnoye | 239 | 194 | -45 | -18.8 |
| 8 | Shagalaly – Pavlovka | 35.9 | 45.7 | 9.8 | 27.3 |
| 9 | Yesil – Astana | 186 | 153 | -33 | -17.7 |
| 10 | Yesil – Kamenny Karyer | 1354 | 1251 | -103 | -7.61 |
| 11 | Yesil – Petropavlovsk | 1718 | 1860 | 142 | 8.27 |
| 12 | Yesil – Dolmatovo | 2205 | 1994 | -211 | -9.57 |
| Nura – Sarysu water management basin | | | | | |
| 13 | Nura – Balykty | 220 | 259 | 39 | 17.7 |
| 14 | Nura – Koshkarbayeva (Romanovka) | 653 | 657 | 4 | 0.61 |
| 15 | Sarysu – junction No. 189 | 93 | 72.3 | -20.7 | -22.3 |

According to the results of Table 6, the greatest changes occurred in the basins of the rivers Tobyl, Sarysu, Silety, the least changes in the basins of the Yesil, Torgai rivers, which is quite consistent with the level of development of water resources in the territory of Kazakhstan. Comparison of available data on water intakes and results of anthropogenic change of river flow in water-management sites gives the opportunity to estimate approximately values of irretrievable water consumption in each region and ratios between volumes of irretrievable and total water consumption. The data on irretrievable water consumption obtained in this way are tentative, nevertheless, it is possible to note some regularities in the values of the specified ratios; they change within a very large range depending on the structure of water consumption and climatic conditions in the regions.

In order to consider water resources shortage, the study analysed the coefficients of specific water supply with respect to the adopted gradation, also in accordance with the classification based on the degree of water resources stress in the considered water management basins, the

coefficients of water stress were obtained. The value of the water stress coefficient for the considered period in the Yesil water management basin varies in a wide range from 4% (2002) to 50% (2006), the average value of the water stress coefficient is more than 20%, which corresponds to category III of the adopted classification (high load). The territory of the Yesil water management basin already has a high-water stress, special attention is required and the introduction of efficient water-saving technologies is recommended for further development of the territory, it is necessary to limit water withdrawals from natural objects. It is necessary to regulate water supply and demand for sustainable development of the region²⁷).

The value of the coefficient of specific water supply taking into account the population size living in the territory of the considered Yesil water management basin, during the considered period varies within the range from 0.16 (catastrophically low water supply), to 3.93 (low water supply), the average coefficient of specific water supply is 1.33, which corresponds to a very low water supply. The value of the coefficient of specific water

supply taking into account population size living in the territory of considered Tobyl – Torgai water management basin, during the considered period varies in the range from 0.13 (1996) (catastrophically low water supply), to 2.88 (2005) (low water supply), the average coefficient of specific water supply is 0.97, which corresponds to catastrophically low water supply. In the Nura – Sarysu

water management basin, the value of the coefficient of specific water supply varies from 0.24 (2000) to 2.99 (2017), the average is 0.75, which corresponds to the accepted gradation of catastrophically low water supply. The next approach considered in this study is the calculation of the coefficient of use (water stress) (Table 7)^{28,29,30}.

Table 7. Water stress coefficient

| River – site | Water resources (annual flow), mln. m ³ | | | Water stress, % | | | Water resources (minimum flow during the winter period), mln. m ³ | | | Water stress, % | | |
|---------------------------------------|--|------|------|-----------------------|------|------|--|------|------|-----------------------|------|------|
| | | | | Water stress category | | | | | | Water stress category | | |
| | 50% | 75% | 95% | 50% | 75% | 95% | 80% | 90% | 95% | 80% | 90% | 95% |
| Tobyl – Kostanay | 178 | 65.2 | 20.2 | 39.9 | 109 | 351 | 9.53 | 7.64 | 6.29 | 62.1 | 77.5 | 94.1 |
| | | | | III | V | V | | | | V | V | V |
| Ayat – Varvarinka | 138 | 74.9 | 26.2 | 14.9 | 27.5 | 78.6 | 0.6 | 0.58 | 0.52 | 85 | 87.9 | 98.1 |
| | | | | II | III | V | | | | V | V | V |
| Toguzak – Toguzak | 66.6 | 38.0 | 13.4 | 12.8 | 22.4 | 63.4 | 0.2 | 0.1 | 0.07 | 25 | 50 | 71.4 |
| | | | | II | III | V | | | | III | IV | V |
| Ubagan – Aksuat | 33.6 | 9.95 | 2.4 | 26.8 | 90.5 | 375 | - | - | - | - | - | - |
| | | | | III | V | V | | | | - | - | - |
| Torgai – Tosyn | 223 | 105 | 45.9 | 23.4 | 49.6 | 114 | - | - | - | - | - | - |
| | | | | III | IV | V | | | | - | - | - |
| Tobyl – Torgai water management basin | 873 | 525 | 222 | 24.2 | 40.2 | 95 | 14 | 8.65 | 6.63 | 133 | 215 | 281 |
| | | | | III | IV | V | | | | V | V | V |
| Silety – Izobilnoye | 101 | 43.5 | 19.1 | 10.2 | 23.7 | 53.9 | 1.95 | 1.01 | 0.59 | 22.6 | 43.6 | 74.6 |
| | | | | II | III | IV | | | | III | IV | V |
| Yesil – Astana | 95.2 | 49.5 | 14.3 | 16.2 | 31.1 | 108 | 3.02 | 1.42 | 0.71 | 42.7 | 90.8 | 182 |
| | | | | II | III | V | | | | IV | V | V |
| Yesil – Kamenny Karyer | 995 | 591 | 240 | 1.55 | 2.61 | 6.42 | 21.9 | 15.4 | 11.4 | 23.5 | 33.4 | 45.2 |
| | | | | I | I | I | | | | III | III | IV |
| Yesil – Petropavlovsk | 1535 | 832 | 291 | 4.01 | 7.39 | 21.1 | 127 | 95.3 | 73.5 | 16.1 | 21.5 | 27.9 |
| | | | | I | I | III | | | | II | III | III |
| Yesil water management basin | 1724 | 939 | 298 | 14.8 | 27.2 | 85.6 | 141 | 107 | 83.6 | 60.4 | 79.5 | 102 |
| | | | | II | III | V | | | | V | V | V |
| Nura – Balykty | 255 | 145 | 69.7 | 13.8 | 24.2 | 50.4 | 4.91 | 2.42 | 1.32 | 59.5 | 121 | 221 |
| | | | | II | III | IV | | | | IV | V | V |
| Nura – Koshkarbayeva (Romanovka) | 546 | 288 | 143 | 87.9 | 167 | 336 | 61.8 | 40.1 | 28.1 | 178 | 274 | 391 |
| | | | | V | V | V | | | | V | V | V |
| Sarysu – junction No. 189 | 14.5 | 4.34 | 3.85 | 95.9 | 220 | 361 | - | - | - | - | - | - |
| | | | | V | V | V | | | | - | - | - |
| Nura – Sarysu water management basin | 840 | 449 | 229 | 97.9 | 183 | 359 | 80 | 55.6 | 40.1 | 198 | 284 | 394 |
| | | | | V | V | V | | | | V | V | V |

According to the obtained results, if measures for effective water management are not implemented quickly in the region, and if industrial and agricultural institutions do not switch to water-saving technologies, then in Central and Northern Kazakhstan, in the city of Astana and adjacent areas in the coming decades, the indicator of already low water supply will be even lower, many times below the critical values.

4. Discussions

Analysis of calculation of minimum flow parameters for winter flow and summer-autumn flow made for three periods displayed the following:

- the long-term average annual value of minimum mean monthly water discharges (winter flow) for the period with disturbed flow (1974-2018) compared with the norm for the conditionally natural period (1932-1973) increased from two times (Sherubainura river – Karamurun village) to ten times (Nura River – Koshkarbayeva village);
- the long-term average annual value of the minimum mean monthly water discharge (summer-autumn flow) for the period with disrupted flow (1974-2018) compared with the norm for a multi-year period (1932-2018) increased from one and a half times (the Nura River – Koshkarbayeva village) to two times (the Nura River – Balykty village).

The conclusions obtained as a result of the analysis are consonant with the results of research by many scientists, including M. V. Bolgov et al.³¹⁾. The features of the parameters of the low-water phase reflect the trends in the long-term transformation of the intra-annual distribution of run-off, firstly, the dynamics of fluctuations in the level of the minimum run-off. At the same time, scientists focus on the fact that the long-term variability of summer-autumn run-off often exceeds the variability of winter run-off. This is due, firstly, to the impact of climatic factors, which in recent decades have had a significant impact on hydrological processes^{32, 33)}.

T. Tu et al. analysed the spatial patterns and drivers of environmental noise colour (temporal autocorrelation) in streamflow across the United States using data from 7,504 gages³⁴⁾. The researchers found that daily and annual streamflows are dominated by red (high autocorrelation) and white (low autocorrelation) noise spectra, respectively. Spatial variation in noise color was explained by a combination of geographic, hydroclimatic, and anthropogenic factors. Specifically, noise color at the daily scale was influenced by stream network position, while land use and water management explained around one-third of the spatial variation in noise color regardless of timescale. The results highlight the unique characteristics of environmental variability regimes in river networks and reveal a strong human influence on the stochastic patterns of streamflow. With the authors' results these studies highlight the complex and multifaceted nature of environmental noise in river systems, with both

natural and anthropogenic factors shaping the temporal and spatial patterns of streamflow variability. Such a constructive hydrological analysis also provides for the development of measures to improve the hydroecological situation, rationalize water use, and optimize the functioning of the water management complex^{35,36)}.

Special attention is paid to the impact of climate change on seasonal run-off and the hydrological regime of basins by modern scientists K. M. Whitney et al.³⁷⁾ and R. Zhao et al.³⁸⁾. Their researches lead to the same result as the current work: the most significant influence of the trend of climatic long-term transformations is felt on the indicators of winter low-water run-off. On the other hand, the trend towards a change in the structure of precipitation in recent decades has led to more frequent periods of low water in the summer-autumn season. Scientists note that in the years preceding the period of warming, the water levels of the summer-autumn low water were higher compared to the levels of the winter low water. Also, Despite the overall positive dynamics of precipitation amounts, the height of rain floods on most rivers has decreased, which can be explained by the morphological features of the river basins.

In addition, a significant impact on the formation of river run-off in today's conditions has a growing anthropogenic load on water basins. V. A. Dmitrieva and E. G. Nefedova³⁹⁾ are convinced that the hydrological regime of water bodies is directly related to human activity and its influence within local and regional ecosystems. Characteristic today are regular violations of the hydrological and ecological balance of water basins due to irrational water intake, the creation of artificial reservoirs, changes in run-off, land reclamation, a decrease in the number of forests, the development of degradation processes, and an increase in the degree of habitation. In their study, J. He et al. proposes a comprehensive framework and indicator system for evaluating urban water health (UWH) that integrates ecosystem health and water cycle health⁴⁰⁾. The analysis identified key weaknesses such as severe soil erosion, high domestic water use, and unsatisfactory water functional areas. To address these issues, the article recommends priorities including infrastructure upgrades, soil and water conservation, water quality improvement, and strengthened water management across resources, environment, ecology, security, and circulation. In connection with the authors' study, its highlight the importance of comprehensive water resource management, considering both water quality and quantity, to address the challenges posed by climate change and growing water demands. Changes in the hydrochemical composition of water, its physical and biological characteristics lead to pollution of drinking water sources. This is emphasized by A. G. Georgiadi et al.⁴¹⁾. In the works of these scientists, the proposal to develop an optimal classification of anthropogenic impact factors on water bodies, based on criteria such as intensity, method,

scale, duration of influence, is especially relevant.

According to the results of the current study, it is foreseen that it is optimal to carry out an assessment of the stability of the water body and its response to anthropogenic load in parallel with the classification. Thus, the study of anthropogenic influence, the degree of its manifestation and the directions of further changes in river basins are integral elements in the development of a further strategy for the regeneration, conservation, and management of aquatic ecosystems. In addition, to solve water management problems, it is necessary to identify time periods characterized by different water content, and further obtain the calculated hydrological characteristics of the river run-off, with the obligatory consideration of changes in climatic processes.

Anchita et al. identify that the dramatic desiccation of the Aral Sea has had significant health and socioeconomic impacts on the surrounding population in Kazakhstan⁴²⁾. The water level decrease has increased salinity, affecting biodiversity, and exposed lake beds have become a source of fine dust that is spread by storms, affecting people's health in the region. However, the study notes that the specific contaminants, rather than the dust storms alone, are the primary drivers of the public health problems in the region, and there is no clear evidence that the dust storms are the sole source of health deterioration. Combining the results of the analysed study and the current one, one can conclude that these works provide a comprehensive understanding of the complex and interconnected impacts of climate change on water resources and public health, emphasizing the need for a multifaceted approach to address these challenges.

In general, such processes provoke the deterioration of the ecological situation against the background of a shortage of water resources, especially in the spring^{43,44)}. Priority measures for the conservation and renewal of water resources should be the following:

- an effective comprehensive environmental assessment of the flow regulation process, optimally – the return of the channel complex to the reference conditions of the period before the onset of active anthropogenic load;
- adequate critical assessment of hydraulic structures, determination of the feasibility of their operation;
- optimization of the hydrological state of water bodies;
- streamlining of water protection territories and protective forests, control of their quality;
- rational management of water use in economic and industrial processes.

5. Conclusion

Climate change has a major impact on seasonal flow, especially the winter low-water flow has changed significantly. The increase in winter flow ranges from 2 percent to 18 percent. The identified specific features of the parameters of the low-water phase reflect long-term

processes of transformation of the intra-annual run-off distribution, primarily fluctuations in the minimum run-off in the summer-autumn and winter periods. In general, an increase in the values of the minimum flow leads to a decrease in the variability of river flow in the considered basins. According to the results of calculations, the greatest changes in the annual and low-water flow occurred in the basins of the Tobyl, Sarysu, Siletay rivers, the smallest changes in the basins of the Yesil, Torgai, which is consistent with the level of development of water resources in Kazakhstan. The load on water resources of the Tobyl – Torgai water management basin is generally characterized by category III in normal water years (load level 24%), category IV in low-water years (load level – 40%) and category V (load level – 95%) in very low-water years. In the water management basin of Tobyl – Torgai rivers, the load on water resources of winter low-water period is further aggravated by water scarcity.

In the upper reaches of the Yesil river, water resources on an annual basis are not exposed to relatively high loads. The load on water resources in normal water years is moderate, and in low-water years (75% availability) is a strong load, and in very low-water years, water resources are affected by critical loads. It should be noted that in the lower reaches of the Yesil river when the water content increases, water resources in the basin are less susceptible to stress. The degree of load on annual water resources in years of different water availability varies very slightly and is characterized by category I. The change ranges from 1.5 percent to 6.4 percent. In general, water resources in the Yesil water management basin are subjected from moderate to critically high load.

During the winter low-water period in the Yesil water management basin, water resources are subjected to critically high load of Category V. An acute shortage of water resources is becoming a limiting factor for the development of the economy and the improvement of the welfare of the population. The territory of the Yesil water management basin already has a high load on water resources, special attention is required and introduction of effective water-saving technologies is recommended for further development of the territory. It is necessary to limit water withdrawals from natural objects as well as regulate water supply and demand for sustainable development of the region. According to the obtained results, if measures for effective water management are not implemented quickly in the region, and if industrial and agricultural institutions do not switch to water-saving technologies, then in Central and Northern Kazakhstan, in the city of Astana and adjacent areas in the coming decades, the indicator of already low water supply will be even lower, many times below the critical values.

For further research on the impacts of climate change on water resources in Central and Northern Kazakhstan, it is important to consider the mechanisms that determine changes in winter and summer-autumn minimum flows. Research could focus on analysing the climatic and

hydrological factors that lead to changes in winter and summer-autumn minimum flows in the region. This may include analysing the impact of global warming, changes in precipitation, temperature regimes, and other climate parameters. Research can also aim to identify risks associated with changes in water resources and develop adaptation strategies to manage these risks. This may include developing water management plans, implementing water conservation technologies, and increasing storage capacity. Research can analyse the impacts of industrial and agricultural extraction on water resources and develop strategies to reduce these impacts. This may include analysing water use in different sectors and developing policies and regulations to ensure sustainable water use.

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