

## ABSTRACT

Dissertation work for the degree of Doctor of Philosophy (PhD) in the educational programme '8D05203-Hydrology'

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### **'Current changes and prospective assessment of minimum flow of rivers of the Zhaiyk-Caspian water management basin'**

**General description of the work.** The dissertation research is devoted to assessing contemporary changes and scenario forecasting of the minimum flow of rivers in the Zhayik-Caspian water management basin under conditions of climate uncertainty and is presented in a series of papers published in journals indexed in the Scopus and Web of Science databases.

**Relevance of the research topic.** In the context of intensifying climate change and growing anthropogenic impact on aquatic ecosystems, a scientifically sound assessment of minimal runoff of rivers is of particular importance for the arid and economically significant Western region of Kazakhstan, where water resources are extremely limited. Reliably determining the characteristics of minimal runoff in such conditions is not only an important scientific task, but also a practical necessity related to ensuring sustainable water use, developing adaptation measures, minimizing the risks of hydrological droughts, and forming a long-term water management strategy for water resources.

Recent studies confirm that climate change is significantly transforming river water regimes: above-average temperature increases, precipitation variability and more frequent extreme events have led to a loss of understanding of the stability of river flow. Kazakhstan's climate is changing faster than the global average: while the global trend of average annual temperature increases in the period 1976-2021 was 0.18 °C per decade, it reached 0.32 °C per decade across the country and up to 0.54 °C per decade in the West Kazakhstan region. This requires a review of approaches to calculating and forecasting minimal runoff.

Minimal runoff reflects the most vulnerable periods of the water management system and determines water use opportunities. In conditions of water scarcity, it becomes a critical factor for industry, agriculture and the municipal sector, and a decrease below the ecologically acceptable level leads to ecosystem degradation, loss of biodiversity and increased environmental risks.

The industrial sector of the Western region of Kazakhstan occupies a dominant position in the country's economic structure, which makes uninterrupted water supply to the region particularly important. The key areas of the region's economy are oil and gas field development, agriculture and fisheries. The country's largest oil and gas fields are concentrated here – Tengiz, Karachaganak, Kashagan – whose operation requires significant amounts of water to support technological processes. The combination of high-water consumption by these industries, population growth and natural aridity increases the region's vulnerability to water shortages.

The transboundary nature of the Zhaiyk-Caspian water basin adds further significance to the study. The region's main river, the Zhaiyk, originates in the Russian Federation, while its lower reaches and tributaries are located within Kazakhstan, with some of the tributaries having transboundary flows. In these conditions, the assessment of minimal runoff takes on an international dimension, requiring coordinated action on water resource management and the fulfilment of international obligations within the framework of sustainable transboundary water use.

Thus, the study of contemporary changes and the prospective assessment of minimal runoff of the rivers of the Zhaiyk-Caspian water management basin has comprehensive scientific and practical significance. It allows us to identify the response of river systems to a combination of climatic and anthropogenic factors, justify the parameters of sustainable water use, reduce environmental and socio-economic risks, and form a scientific basis for the development of effective strategies for adapting water management to climate change.

**The aim of the work** is to assess current changes and provide a scenario forecast of the minimum flow of rivers in the Zhaiyk-Caspian water management basin in the long term under conditions of climate uncertainty.

**Research objectives.** To achieve the set goal, a number of tasks were considered in the dissertation:

- review of scientific literature and regulatory documents on the assessment of minimal runoff and scenario forecasting for the long term in the context of a changing climate;
- collection and analysis of hydrometeorological data for the entire period of observations at hydrological posts and meteorological stations in the study area to identify long-term trends in hydrometeorological characteristics;
- assessment and analysis of current changes in the minimal runoff of rivers in the study area;
- assessment and analysis of climatic factors affecting the formation of the minimal runoff in the study area;
- scenario-based forecast of minimal runoff for 2040, 2060 and 2080 based on CMIP6 climate scenarios.

**Research object.** The territory of the Zhaiyk-Caspian water management basin, covering four regions of the Republic of Kazakhstan: West Kazakhstan, Atyrau, Mangistau and most of the Aktobe region.

**Subject of the study:** the formation, dynamics and change in the minimal river runoff of the rivers of the Zhaiyk-Caspian water management basin under the influence of climatic factors in a historical retrospective and in the long term.

**Sources of information and research materials.** The study used official cadastral materials from the Kazhydromet State Agency: daily data from stationary observations of water flow at hydrological stations, daily meteorological data on precipitation and air temperature. The ISIMIP Project database on precipitation and air temperature was used for scenario forecasting. The following were used for a comprehensive analysis: scientific articles from foreign and Russian scientific databases, scientific articles from Kazakh scientific journals, reports from international structures and regional organizations, etc.

**Research methods:** includes a set of modern methods and approaches based on a combination of climate scenarios, climate models, statistical analysis, and geoinformation methods. Among the methods and approaches proposed for solving the tasks set, the following are used as the main ones: the systemic method, the comparative method, the quantitative (mathematical) method, the statistical method, the cartographic method, the method of computer processing of information and logical modelling, and the concept of sustainable development. Hydrological changes over time are determined based on the analysis of hydrometeorological series. Spatial changes in hydrological characteristics and the processing of cartographic materials are performed using geoinformation technologies.

**Description of the main results of the study.** The dissertation presents the results of modern changes and a prospective assessment of the minimum flow of rivers in the Zhaiyk-Caspian water management basin. A multidirectional flow behavior has been established: the summer-autumn period is characterized by a significant reduction in minimum flow (up to 28% on the rivers Ulken Kobda and Shyngyrlau rivers), up to the complete drying up of individual watercourses, while for the winter low water period, a steady increase in minimal runoff has been identified, associated with an increase in the number and duration of thaws, a decrease in soil freezing depth and an increase in underground recharge.

It has been found that hydrological droughts have intensified in the modern period: their frequency, duration and intensity have increased, and for the first time, a long series of low-water years (11–13 years in a row) has been recorded. Extreme values of the SPEI index (up to  $-2.39$ ) have been established, confirming the high climatic vulnerability of the region.

Forecast calculations indicate a decrease in minimal runoff during the warm period to 64% by the end of the 21st century (especially in the southern part of the basin – the Zhem, Oiy, and Temir rivers) with a simultaneous increase in winter flow against the backdrop of rising winter air

temperatures (up to +7.2 °C) and an increase in the number of low-water years. Zhem, Oiyl, Temir) with a simultaneous increase in winter runoff against the backdrop of rising winter air temperatures (up to +7.2 °C) and increased precipitation (up to 71%).

**The validity and reliability of the data** obtained have been confirmed by the application of a combination of various statistical and analytical methods, such as the criterion of applicability and quality of the methodology, correlation analysis, etc. A detailed description of the data and methods used allows the research results to be reproduced.

**Scientific novelty of the work:**

➤ Spatial-temporal changes in the minimum flow of rivers in the Zhaiyk-Caspian water management basin have been assessed;

➤ For the first time, a comprehensive assessment of the influence of climatic factors on the formation of minimum flow has been carried out;

➤ For the first time for this region, modern trends in the duration and frequency of hydrological droughts have been established, and groups of low-water years have been identified;

➤ Areas most vulnerable to hydrological droughts have been identified;

➤ A methodology for scenario forecasting of minimal runoff, adapted to the specifics of the region, has been developed;

➤ For the first time, a prospective assessment of minimal runoff for the years 2040, 2060 and 2080 was carried out using the CMIP6 model ensemble.

**Scientific and practical significance of the work.** The scientific significance of the study lies in the fact that it substantiates the impact of modern climate change on the formation of minimum flow in the rivers of the Zhaiyk-Caspian water management basin under conditions of increasing climate acidization and intensifying anthropogenic impact, and identifies patterns of its spatial and temporal variability. The work applies new methodological approaches to the assessment and forecasting of minimal runoff, which increases the reliability of hydrological calculations in the context of a changing climate and water management situation. The results obtained expand scientific understanding of the hydrological regime of rivers in arid zones, the mechanisms of minimal runoff formation and its variability, which is important for further research in the field of hydrology of arid territories.

The practical significance of the research results lies in providing a scientifically sound basis for effective water management planning in conditions of climate uncertainty, using the example of the Zhaiyk-Caspian water management basin. The developed scenario assessments of minimal runoff allow for possible low-water periods to be taken into account when allocating water resources among economic sectors, especially in dry years, which helps to reduce the risk of water shortages and conflicts in a transboundary context.

In the long term, the implementation of effective water management strategies will allow ecosystems to adapt to changing climatic conditions, reduce the risk of environmental disasters and ensure the rational use of water resources, contributing to environmental sustainability and the conservation of Kazakhstan's natural resources.

The proposed methodology of combining climate scenarios, trend analysis and uncertainty assessment is applicable for estimating minimal runoff in other basins of Kazakhstan and Central Asia, which broadens its scope of application. In addition, the results can be integrated into national water resource monitoring systems, used in the preparation of regulatory documents and strategies aimed at sustainable water resource management, and serve as a scientific basis in international negotiations on transboundary waters with the Russian Federation.

The results obtained can be used by government agencies, international organizations and research centers in developing national and regional programmes for adaptation to climate change and improving water resource and natural risk management systems.

**Practical recommendations.** Proposed preventive measures for adapting water resource management:

1. Improving water resource management in conditions of low water availability: developing and implementing an early warning system for low water periods based on hydrological and climatic models; implementing water conservation measures and improving water use efficiency; preparing action plans to minimize the negative impacts of water shortages on the population, the economy and ecosystems.

2. Adaptation to climate risks and droughts: development of climate risk management strategies, integration of hydrological and climatic model results with long-term forecasts to create a comprehensive adaptation strategy; introduction of modern technologies for the rational use and redistribution of water resources; reducing the vulnerability of the region's economy to periods of drought.

3. Sustainable development of the agro-industrial sector and ecosystems: developing and implementing recommendations for the restoration of degraded ecosystems and the application of sustainable land and water use practices; introduction of adaptive approaches in agriculture, including the selection of drought-resistant crops, adjustment of sowing and harvesting dates, and improvement of irrigation methods to increase efficiency and reduce the burden on water resources.

**Connection of the topic with the research plan and various state programmes.** The work was carried out within the framework of funding for projects by the Ministry of Education and Science of the Republic of Kazakhstan: ‘Sustainable development of natural, economic and socio-economic systems in the West Kazakhstan region in the context of green growth: comprehensive analysis, concept, forecasts and scenarios’ for 2023-2025 (BR21882122-OT-24).

**Main provisions put forward for defense:**

I. Current trends in changes in minimal runoff have been established based on the analysis of long-term hydrological time series and seasonal flow-forming climatic characteristics of the Zhaiyk-Caspian water management basin.

II. Current trends in the duration, frequency and spatial-temporal changes in the occurrence of hydrological droughts have been established and groups of low-water years have been identified based on the analysis of long-term hydrometeorological data.

III. A methodology has been developed for scenario forecasting of minimal runoff under conditions of climate uncertainty based on data from the CMIP6 ensemble of global climate models for scenarios SSP3-7.0 and SSP5-8.5. Scenario changes in minimal runoff for summer-autumn low-flow and winter low-flow have been forecast for the horizons 2040, 2060, and 2080.

**Author's contribution to scientific work.** In order to achieve the goals and objectives of the research work, a comprehensive review of scientific research was conducted and the information necessary for the study was collected. The scientific problem was formulated independently, the goals and objectives of the study were defined, and a comprehensive methodology for assessing changes in minimum river flow under conditions of climate uncertainty was developed. A full cycle of systematic scientific analysis was carried out, including:

- collection and critical processing of long-term hydrometeorological data and climate forecasts (including CMIP6 models);
- reconstruction of minimal runoff taking into account anthropogenic and natural factors;
- adaptation of trend analysis, climate modelling and scenario uncertainty assessment methods to the conditions of the Zhaiyk-Caspian water management basin;
- development of a methodology for scenario forecasting of prospective changes in low water conditions, taking into account climatic and water management influences;
- interpretation of the results obtained and formulation of practical recommendations for adapting water resource management.

The calculations, writing and formatting of the articles were carried out with the personal participation of the author.

**Approval of work results.** In 2023-2025, the author participated as an executor in the implementation of scientific project No. BR21882122-OT-24 within the framework of programme-targeted financing. ‘Sustainable development of natural, economic and socio-

economic systems in the West Kazakhstan region in the context of green growth: comprehensive analysis, concept, forecasts and scenarios' of the Ministry of Science and Higher Education of the Republic of Kazakhstan.

The main results of the work were presented at the International Conference 'Farabi Alem' (Almaty, 6-8 April, 2023):

- Birimbaeva L.M. Assessment of changes in the flow of the Zhem and Oiyil rivers // Materials of the international scientific conference of students and young scientists 'Farabi Alem'. – Almaty: Kazakh University, 6-8 April 2023. – pp. 104-105.

The results obtained on the research topic were tested in the form of two author's certificates of entry in the state register of rights to objects protected by copyright NIIS 'Kazpatent':

- Series of maps: maximum snow cover height, number of days with snow cover in the modern period, average annual value of water reserves in snow cover in the modern period. Authors: Alimkulov S.K., Birimbaeva L.M., Kulebaev K.M., Sailaubek A.M., Alzhanov O.M. Certificate No. 58888 dated 29 May 2025;

- Schematic map of average soil freezing depths in the Zhayik-Caspian water management basin for the period 1974-2024. Authors: Birimbayeva L.M., Alimkulov S.K., Makhmudova L.K., Tursunova A.A., Smagulov Zh.Zh., Dostaeva A.Zh. Certificate No. 58933 dated 29 May 2025.

**Publication of research results.** The results of the work are reflected in eight scientific articles, including four in peer-reviewed international journals indexed in Scopus and Web of Science: Water Resources Management (Q1 according to WoS, Impact factor 4.7, Percentile 84.7%), Water (Switzerland) (Q2 according to WoS, Impact factor 3, Percentile 64.1%), Water and Climate Change (Q2 according to WoS, Impact factor 3.1, Percentile 66.4%) and 4 in journals recommended by CQASE.

**Personal contribution of the doctoral student to the preparation of articles:**

Birimbayeva Lyazzat Muratbekovna is the first author of the articles 'Analysis of the Spatiotemporal Variability of Hydrological Drought Regimes in the Lowland Rivers of Kazakhstan' and 'Reaction of Minimal Streamflow to Natural Factors in the Context of Climate Uncertainty'. The calculations, writing and formatting of the articles were carried out with the personal participation of the author. The scientific problem was formulated independently, the goals and objectives of the research were defined, and a comprehensive methodology for assessing changes in minimal runoff of rivers under conditions of climate uncertainty and a methodology for identifying hydrological droughts were developed. The doctoral student conducted a review of the literature on the research topic, collected and critically processed long-term hydrometeorological data, reconstructed and assessed changes in minimal runoff taking into account anthropogenic and natural factors, assessed the spatial and temporal manifestations of hydrological droughts, identified groups of low-water years, and participated in the preparation of maps in the ArcGIS environment.

The doctoral student is one of the authors of the article 'Transformation of seasonal distribution of river flow in the Zhayik-Caspian water basin under changing climate conditions. In this work, the doctoral student participated in the calculations and interpretation of the research results, the preparation of maps in ArcGIS, the writing of the initial versions of the article, as well as its editing and refinement.

The doctoral student is one of the authors and correspondents of the article 'Seasonally Contrasting Sensitivity of Minimal River Runoff to Future Climate Change in Western Kazakhstan: A CMIP6 Scenario Analysis'. As part of the research, the doctoral student participated in the development of a methodology for scenario forecasting of minimal river runoff, calculations and interpretation of the results obtained, and the formulation of practical recommendations for adapting water resource management. The doctoral student participated in writing the initial versions of the article, as well as in its editing and refinement.