

# Projected Hydrological Regime Shifts in Kazakh Rivers Under CMIP6 Climate Scenarios: Integrated Modeling and Seasonal Flow Analysis

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## Abstract

The article presents an analysis of current (during the period 1985–2022) and projected (during the period 2025–2099) changes in the hydrological regime of the Buktyrma, Yesil, and Zhaiyk river basins in Kazakhstan under the conditions of global climate change. This study is based on the integration of data from General Circulation Models (GCMs) of the sixth phase of the CMIP6 project, socio-economic development scenarios SSP2-4.5 and SSP5-8.5, as well as the results of hydrological modelling using the SWIM model. The studies were carried out with an integrated approach to hydrological change assessment, taking into account scenario modelling, uncertainty analysis and the use of bias correction methods for climate data. A calculation method was used to analyse the intra-annual distribution of runoff, taking into account climate change. Detailed forecasts of changes in runoff and intra-annual water distribution up to the end of the 21st century for key water bodies in Kazakhstan were obtained. While the projections of river flow and hydrological parameters under CMIP6 scenarios are actively pursued worldwide, few studies have explicitly focused on forecasting intra-annual flow distribution in Central Asia, calculated using a methodology appropriate for this region and using CMIP6 ensemble scenarios. There have been studies on changes in the intra-annual distribution of runoff for individual river basins or local areas, but for the historical period, there have also been studies on modelling runoff forecasts using CMIP6 climate models, but have been very few systematic publications on the distribution of predicted intra-annual runoff in Central Asia, and this issue has not been fully studied. The projections suggest an intensification of flow seasonality (1), earlier flood peaks (2), reduced summer discharges (3) and an increased likelihood of extreme hydrological events under future climatic conditions. Changes in the seasonal structure of river flow in Central Asia are caused by both climatic factors—temperature, precipitation and glacier degradation—and significant anthropogenic influences, including irrigation and water management structures. These changes directly affect the risks of flooding and water shortages, as well as the adaptive capacity of water management systems.

Given the high level of water management challenges and interregional conflicts over water use, the intra-annual distribution of runoff is important for long-term planning, the development of adaptation measures, and the formulation of public policy on sustainable water management in the face of growing climate challenges. This is critically important for water, agricultural, energy, and environmental planning in a region that already faces annual water management challenges and conflicts due to the uneven seasonal distribution of resources.

## **Keywords**

hydrological modelling; CMIP6; climate scenarios; water resources; Kazakhstan; Central Asia; SWIM; intra-annual flow distribution; climate change.

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