ANNOTATION

Dissertation for the degree of Doctor of Philosophy (Ph.D.)
in the educational program 8D07303 - Cartography

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Modeling and forecasting of seasonal fluctuations in river flow in the Lake Balkhash basin based on remote sensing

By the mid-21st century, advancements in technology have created new opportunities for studying and managing water resources. The development of digital technologies has facilitated the application of Earth Observation (EO), machine learning, and Geographic Information Systems (GIS). These technologies are used for analyzing hydrological processes, forecasting river flow, and modeling water systems. These methods assist in managing water resources effectively, maintaining ecological balance, and developing strategies for adaptation of climate change.

Relevance of the Research Topic. The Balkhash Lake Basin is a vital region in Central Asia, playing a key role in supplying water resources for agriculture, industry, and domestic needs. However, climate change, global warming, and anthropogenic factors threaten the region's ecological sustainability and water security. Increasing pressure on water resources disrupts the hydrological balance and exacerbates water scarcity issues.

The transboundary nature of the Balkhash Basin creates additional challenges in water resource management, including the need for coordinated policies between neighboring countries, complexities in water allocation agreements, and potential conflicts over shared water usage. Effective water distribution requires international negotiations between Kazakhstan and China, impacting regional stability and ecosystem development.

The Intergovernmental Panel on Climate Change (IPCC) 2021 report emphasizes that rising global temperatures and seasonal precipitation fluctuations lead to reduced snow cover, decreased river flow, and ecosystem degradation. Climate scenarios (SSP2-4.5 and SSP5-8.5) predict an increased winter runoff and decreased spring and summer runoff, posing new challenges for water resource management.

In the 2023 Address by the President of Kazakhstan, Kassym-Jomart Tokayev, the necessity of implementing modern technologies and developing a new Water Code to reduce water scarcity and enhance ecological and national security was highlighted. The development of scientifically grounded solutions for the efficient use of water resources and adaptation to climate change is becoming increasingly relevant.

Research Subject. The study of the seasonal dynamics of river flow in the Balkhash Lake Basin, as well as the improvement of modeling and forecasting methods based on the integration of EO and hydrological models.

Research Aim and Objectives. To analyze and forecast the seasonal fluctuations of river flow in the Balkhash Lake Basin based on EO data and hydrological models. The following objectives were set to achieve this aim:

- Comprehensive analysis of the hydrological and climatic features of the Balkhash Lake Basin, including the study of seasonal dynamics of temperature changes, precipitation, soil moisture, and snow cover with high precision.
- Development of spatial thematic maps reflecting the distribution of snow cover, land use changes, and drought indicators using EO data (MODIS, Sentinel, Landsat).
- Regionalization of the HBV hydrological model and its integration with EO data processing algorithms to improve the accuracy of river flow forecasting and identify extreme events.
- Assessment of the impact of temperature and precipitation on hydrological processes using climate scenarios SSP2-4.5 and SSP5-8.5.
- Development of an algorithm for the operational identification of extreme hydrological events, such as floods and droughts, based on EO data, hydrological models, and machine learning algorithms.

Research Methods. The study is based on the application of modern methods for analyzing the seasonal dynamics of river flow in the Balkhash Lake Basin. EO data was used to study the spatiotemporal dynamics of runoff, snow cover, and land use changes. The HBV model was applied for runoff modeling and forecasting, considering climate scenarios (SSP2-4.5, SSP5-8.5).

GIS technologies facilitated the visualization of hydrological processes and regional spatial features. Mathematical and statistical methods (correlation, regression, R^2, NSE, PBIAS) were used to improve result accuracy. A script based on machine learning algorithms was developed for the rapid assessment of floods and droughts. The integration of methods enhanced the study's accuracy and provided a basis for water resource management strategies and climate change adaptation.

Theoretical and Methodological Foundations of the Study. The scientific foundation of the study is based on the following key works: D. Jiang – “The Role of Satellite-Based Remote Sensing in Improving Simulated Streamflow: A Review” (2019) [1], A.A. Assylbekova – “Study of Landscapes on the Northern Slope of the Ile Alatau Using Remote Sensing Data” (2010) [2], A.A. Tursynova – “Water Resources of Kazakhstan Under Conditions of Uncertainty” (2021) [3], E.K. Talipova – “Impact of Modern and Future Climate Changes on the Water Resources of the Ili River Basin” (2023) [4], S.K. Alimkulov – “Assessment of Intra-Annual Distribution of River Flow

in the Northern Slope of the Zhetysu Alatau" (2022) [5], K.K. Duskaev – "Assessment of Maximum Water Discharges of Rivers in the City of Almaty" (2019) [6], V.S. Cherednichenko – "Climate Fluctuations in the Ili-Balkhash Basin and Their Relationship with Lake Level" (2009) [7], and V.G. Salnikov – "Climate Variability in General Atmospheric Circulation, Precipitation, and River Runoff Over the Territory of Kazakhstan" (2011) [8].

Additionally, the study utilizes works on hydrological modeling and the application of numerical methods: V.A. Shelutko – "Numerical Methods in Hydrology" (1991) [9], V.G. Andriyanov – "Intra-Annual Distribution of River Runoff: Basic Patterns and Their Use in Hydrological and Water Management Calculations" (1960) [10], as well as the textbook by S.K. Dauletkaliyev, D.K. Jusupbekov, and M.M. Moldakhmetov – "Methods of Mathematical Processing of Hydrological Information" (2012) [11].

Practical Significance. The scientific novelty of this study lies in the development of new methods and solutions for assessing the dynamics of climate change and water resources in the Balkhash Lake Basin. The research results include new approaches for accurate forecasting and analyzing seasonal river flow changes using integrated EO data and hydrological models.

Scientific Novelty. The scientific novelty of this study lies in the comprehensive analysis of the seasonal dynamics of water resources in the Balkhash Lake Basin based on EO data and the HBV hydrological model, conducted for the first time. The study identified the relationship between snow cover and river flow and developed predictive scenarios for 2030 and 2050 to assess the impact of climate change.

Main Provisions for Defense:

1. The E-Flow and HBV models, integrated with EO data (MODIS, Sentinel, Landsat) and hydrometeorological information, are identified as reliable analysis methods, providing high accuracy in assessing seasonal and spatial characteristics of water resources in the Balkhash Lake Basin.
2. The HBV model demonstrated effectiveness as an advanced modeling method for predicting the impact of climatic and anthropogenic factors on water resources and for developing management strategies through regional parameter calibration and the use of climate scenarios SSP2-4.5 and SSP5-8.5.
3. A specialized algorithm for the rapid identification and assessment of droughts and floods based on EO technologies and the HBV model was developed, proposed as an effective tool for water resource management, rapid response to natural disasters, and reducing climate risks.

Author's Contribution to Scientific Results. The research conducted within the dissertation is based on published articles and the author's personal scientific investigations without the participation of laboratory staff. The author formulated independent conclusions and conducted individual research.

Discussion and Approval of Research Work. The main research results were discussed at international and national conferences from 2021 to 2024 and received high recognition from the scientific community. The results were presented at conferences such as "Farabi Alemi" (Almaty, Kazakhstan), GARSS 2022, Youth Forum (Chiang Rai, Thailand, 2023), and the International Journal of Geoinformatics Conference (Kuala Lumpur, Malaysia, 2021), where they were highly evaluated in the fields of water resource management and climate change.

Publication of Research Results. Based on the research results, seven scientific papers were published in Kazakhstan and international journals and at international scientific-practical conferences. Among them, four articles were published in journals indexed in Elsevier, Web of Science, and Scopus databases. Additionally, the applicant's Hirsch index is 4 in Scopus and 2 in Web of Science.

Scope and Structure of the Dissertation. The dissertation consists of an introduction, four chapters, a conclusion, a list of references (198 sources), 15 tables, 51 figures, and 16 appendices. The number of pages is 148.