Review Report on the Doctoral Dissertation of Lyazzat Muratbekovna Birimbayeva

PhD Programme: *8D05203 – Hydrology*

Dissertation title: *"Current changes and prospective assessment of minimum flow of rivers of the Zhaiyk-Caspian water management basin"*

1. General Assessment of the Dissertation

The dissertation addresses one of the most pressing issues in modern hydrology: the variability and prospective evolution of minimal river runoff under conditions of climate change and increasing anthropogenic pressure. The focus on the Zhaiyk–Caspian water management basin is of high relevance, both nationally and internationally, as this region is characterized by severe water scarcity, strong economic dependence on water (oil and gas industry, irrigated agriculture, fisheries), and complex transboundary challenges.

The work is timely and significant. Kazakhstan is experiencing warming rates higher than the global average, which makes the study particularly necessary for sustainable water resources management. By combining historical hydrometeorological data, modern statistical methods, geoinformation technologies, and climate change scenarios (CMIP6), the author provides a comprehensive picture of current trends and plausible futures of low-flow regimes.

2. Structure and Content

The dissertation is clearly and coherently structured, following a logical sequence that begins with a comprehensive literature review and continues through methodological design, data analysis, presentation of results, and practical recommendations. From the outset, the candidate formulates the research problem with precision, setting out well-defined objectives and hypotheses that guide the entire work.

The first part of the dissertation provides a critical and well-contextualized review of scientific literature and regulatory frameworks related to the assessment of minimal runoff. This review not only situates the study within the international context of hydrological and climatic research but also highlights the specific challenges faced in

Kazakhstan, particularly in the Zhaiyk–Caspian basin. By doing so, the author establishes a strong conceptual and methodological foundation for the subsequent analyses.

The central chapters present an extensive analysis of long-term hydrometeorological series covering the period 1940–2021. Through the systematic examination of data from hydrological posts and meteorological stations, the candidate identifies significant patterns and changes in the behavior of river runoff over time. This long-term perspective is particularly valuable for understanding both gradual trends and abrupt changes in hydrological regimes under conditions of climatic variability and increasing anthropogenic impact.

The dissertation then addresses in depth the dynamics of hydrological droughts and the variability of minimum flows, making it possible to establish robust links between climatic drivers—such as air temperature, precipitation, and soil freezing depth—and the response of river systems. The analysis distinguishes between summer–autumn and winter low-flow periods, thereby capturing the strong seasonal contrasts that characterize the hydrology of the region.

Building on these findings, the author develops and applies a scenario-based methodology for forecasting minimal runoff under future climate conditions, employing the latest CMIP6 models for two relevant socio-economic pathways (SSP3-7.0 and SSP5-8.5). This part of the work represents a clear methodological innovation, as it adapts global climate model outputs to regional hydrological conditions, offering forecasts for 2040, 2060, and 2080. The results reveal strong seasonal asymmetries, with projected increases in winter flows and sharp decreases in summer–autumn flows, and they highlight the growing vulnerability of southern basins.

Finally, the dissertation provides practical recommendations for water management in the context of climate uncertainty. These include proposals for developing early warning systems, improving efficiency in industrial and agricultural water use, and implementing adaptive strategies to mitigate risks associated with hydrological droughts. Such recommendations are firmly grounded in the empirical findings of the research and demonstrate the applied relevance of the work.

Taking together, these elements confirm that the scope of the dissertation is fully adequate for a doctoral thesis. The work demonstrates both depth and originality, while maintaining a balance between scientific innovation and practical applicability, and thus represents a substantial contribution to the field of hydrology and climate change adaptation.

3. Scientific Publications

The dissertation is defended on the basis of three core international journal articles, published in reputable international journals indexed in Scopus and Web of Science (Q1–Q2). These articles form a coherent and complementary body of scientific evidence and include contributions from researchers affiliated with international institutions such as the Universitat Politècnica de València (UPV, Spain) and the National Technical University of Athens (Greece), highlighting the international dimension of the work. Importantly, the foreign supervisor preparing this review is also coauthor of the three publications, ensuring continuous scientific collaboration and mentoring throughout the research process.

1. Birimbayeva L., Makhmudova L., Alimkulov S., Tursunova A., Mussina A., Tigkas D., Beksultanova Z., Rodrigo-Clavero M.-E., Rodrigo-Ilarri J. (2024). "Analysis of the Spatiotemporal Variability of Hydrological Drought Regimes in the Lowland Rivers of Kazakhstan." Water, 16, 2316.
   DOI: https://doi.org/10.3390/w16162316

This article investigates long-term drought variability across four major water management basins of Kazakhstan. Using standardized indices (SPI, SDI), it reconstructs drought dynamics over several decades (up to 2021). Results show a marked increase in the frequency and intensity of hydrological droughts in recent decades, with shorter recurrence intervals and a higher prevalence of extreme events. These findings are of high importance for agriculture, ecosystems, and water security. The collaboration with European partners (NTUA, UPV) strengthened the methodological framework and international dissemination.

2. Birimbayeva L., Makhmudova L., Alimkulov S., Tursunova A., Tigkas D., Abayev N., Dostayeva A., Birimbayev Zh., Alzhanov O., Rodrigo-Clavero M.-E., Rodrigo-Ilarri J. (2025). "Reaction of Minimal Streamflow to Natural Factors in the Context of Climate Uncertainty." Water Resources Management.
   DOI: https://doi.org/10.1007/s11269-025-04238-y

This study develops a novel methodological framework for understanding minimal streamflow dynamics, linking hydrological processes with soil freezing depth, thaw frequency, and climatic drivers. Based on hydrometeorological records from 1940–2021, it reveals contrasting patterns: winter flows increase up to 5.2 times due to shallower frost depth and more frequent thaws, while summer–autumn flows decline in several rivers due to rising air temperatures and precipitation deficits. The paper

highlights the importance of season-specific drivers of low flows and provides tools for adaptive water management. The participation of UPV researchers, including the foreign supervisor, ensured rigorous methodological standards and strengthened the international perspective of the study.

3. Makhmudova L., Alimkulov S., Tursunova A., Birimbayeva L., Talipova E., Alzhanov O., Rodrigo-Clavero M.-E., Rodrigo-Ilarri J. (2025). "Seasonally Contrasting Sensitivity of Minimal River Runoff to Future Climate Change in Western Kazakhstan: A CMIP6 Scenario Analysis." Water, 17, 2417. DOI: https://doi.org/10.3390/w17162417

This article develops long-term projections of minimal runoff for 2040, 2060, and 2080 under two climate scenarios (SSP3-7.0 and SSP5-8.5). The results show a clear seasonal asymmetry: winter runoff is projected to increase due to higher winter precipitation, more frequent thaw events, and enhanced infiltration; conversely, summer–autumn runoff is projected to decline dramatically (up to 60–70% by 2080 in southern basins under SSP5-8.5) due to increased evapotranspiration and soil moisture deficits. These projections provide a robust scientific basis for seasonally differentiated, climate-resilient water management strategies. The inclusion of UPV coauthors underscores international collaboration and the scientific quality of the study.

Together, these three publications reflect the candidate's ability to produce internationally relevant research, to work in interdisciplinary and multicultural teams, and to contribute original insights to the study of hydrological droughts and minimal runoff in arid and semi-arid regions. The fact that the foreign supervisor has been directly involved as coauthor in all three papers guarantees the high academic quality of the outputs and their close alignment with international standards.

4. Novelty and Scientific Contribution

The novelty of this dissertation lies in the way it systematically addresses the issue of minimal runoff in an arid and climatically vulnerable region, applying both retrospective analyses and prospective forecasts. For the first time in the Zhaiyk–Caspian water management basin, a comprehensive assessment of spatial and temporal changes in minimal flows has been carried out, based on more than seventy years of hydrometeorological observations. This long-term perspective has allowed the candidate to detect patterns that were previously undocumented, such as the progressive increase in winter flows associated with reduced soil frost depths and the

higher frequency of thaw events, as well as the simultaneous decline in summer–autumn runoff driven by rising temperatures and precipitation deficits.

Another important contribution is the detailed characterization of hydrological droughts, including the identification of their duration, frequency, and intensity, and the classification of low-water years in different sectors of the basin. By doing so, the dissertation demonstrates that drought processes in the region have intensified significantly in recent decades, with more frequent zero-flow events in smaller rivers and a general flattening of annual hydrographs. These findings not only enrich the scientific understanding of drought mechanisms in arid and semi-arid contexts, but also provide a basis for designing adaptive strategies tailored to the seasonal dynamics of the rivers.

From a methodological point of view, the work is particularly innovative in the adaptation and integration of global climate scenarios (CMIP6) into a regional hydrological framework. The candidate develops a forecasting methodology that combines trend analysis, statistical modelling, and climate scenario projections to estimate future minimal runoff for the horizons of 2040, 2060, and 2080 under SSP3-7.0 and SSP5-8.5. This methodology represents a valuable contribution, as it takes into account the uncertainty inherent in climate models while producing results that are directly relevant to water management decision-making. The projections clearly indicate a divergence between seasons, with increased winter flows and decreasing summer–autumn flows, a contrast that underscores the urgent need for seasonally differentiated management approaches.

Equally novel is the explicit incorporation of soil freezing depth and thaw dynamics into the analysis of minimal flows. While such factors have often been overlooked in regional hydrological studies, this dissertation demonstrates that they play a decisive role in shaping winter runoff and in conditioning groundwater recharge processes. By linking hydrological behavior with cryogenic processes, the candidate provides a fresh perspective on the mechanisms of minimal runoff formation under changing climatic conditions.

The scientific contribution of the work is not limited to its methodological advances. The dissertation also broadens the theoretical understanding of hydrological processes in arid regions, offering insights that are applicable not only to Kazakhstan but also to other Central Asian basins and even to similar environments worldwide. At the same time, it has direct practical relevance, since the results can inform national water policies, transboundary negotiations with Russia, and local strategies for adaptation to climate change. The originality of the research is further confirmed by the publication of its main findings in high-quality international journals, co-authored with researchers

from leading institutions such as the Universitat Politècnica de València and the National Technical University of Athens, thus ensuring that the work is recognized and validated within the global scientific community.

The dissertation makes a dual contribution: it advances scientific knowledge on the drivers, variability, and future evolution of minimal runoff in a vulnerable basin, and it provides innovative tools and forecasts that can guide sustainable and adaptive water management under climate uncertainty.

5. Methodology and Data

The dissertation employs a rigorous methodological framework that combines hydrological, statistical, and geoinformation approaches. The analysis is based on an extensive dataset of hydrometeorological observations covering the period 1940–2021, including long-term river discharge series from multiple hydrological posts and meteorological data on precipitation and air temperature from a wide network of stations. The candidate applies well-established statistical techniques, such as the Mann–Kendall trend test, Fisher's F-test, and Student's t-test, to detect and validate changes in minimal runoff characteristics.

Geoinformation systems are used to process and represent spatial patterns of hydrological variables, allowing for the creation of maps that illustrate drought-prone areas, soil freezing depths, and the spatial distribution of runoff variability. In addition, the study integrates climate change projections derived from the CMIP6 ensemble of global climate models, focusing on two scenarios (SSP3-7.0 and SSP5-8.5). These projections are dynamically downscaled and adapted to regional conditions to generate scenario-based forecasts of minimal runoff for 2040, 2060, and 2080.

This methodological combination—long-term observational analysis, statistical trend testing, GIS-based spatial interpretation, and climate scenario modelling—ensures both the robustness and the originality of the results. It also reflects the international collaborative framework of the research, with methodological input from coauthors affiliated with institutions such as the Universitat Politècnica de València and the National Technical University of Athens.

6. Results and Discussion

The results of the dissertation reveal profound changes in the hydrological regime of the Zhaiyk–Caspian basin over the last decades, with a strong seasonal differentiation in the dynamics of minimal runoff. By analyzing long-term series of hydrological and

climatic data, the candidate demonstrates that the stability of low-flow periods traditionally assumed in hydrology can no longer be maintained under current climatic and anthropogenic pressures.

The first set of findings concerns the **increasing frequency and intensity of hydrological droughts**. As shown in the article published in *Water* (2024), droughts have become more frequent and severe since the 1970s, with recurrence intervals significantly shortened and extreme droughts affecting a larger number of rivers. The application of indices such as SPI and SDI provided clear evidence that drought processes are not only intensifying but also spreading geographically, with southern and eastern basins proving especially vulnerable. These findings highlight the systemic nature of drought under climate change and the urgent need for integrated management strategies.

The second line of results focuses on the **reaction of minimal streamflow to natural drivers**, developed in the article published in *Water Resources Management* (2025). The dissertation identifies soil freezing depth, thaw frequency, and precipitation variability as decisive factors for low-flow regimes. Winter flows show a general tendency to increase, in some cases up to five times higher than in the mid-20th century, due to shallower frost depth and more frequent thaws that favor groundwater contributions. Conversely, summer–autumn flows show marked reductions in several rivers, often linked to higher air temperatures, reduced rainfall, and depletion of groundwater reserves. The analysis also reveals a rise in zero-flow events, particularly in smaller tributaries, which is of great concern for both ecological stability and water supply.

Finally, the third publication in *Water* (2025) extends the analysis into the future by applying **CMIP6 climate scenarios**. The projections show a striking seasonal asymmetry: while winter minimal runoff is expected to increase due to higher precipitation and enhanced infiltration, summer–autumn minimal runoff is projected to decline sharply, particularly under the high-emission scenario SSP5-8.5. By 2080, southern basins could experience reductions of 60–70% in summer–autumn flows, threatening water security for agriculture and ecosystems. These results confirm that climate change will not affect all seasons equally and that management strategies must account for this duality.

Taken together, the findings indicate that climate change is reshaping the intra-annual distribution of river flows in Western Kazakhstan. The flattening of hydrographs, the intensification of droughts, and the increasing frequency of zero-flow events are already visible in observational records, while future projections confirm the persistence and worsening of these trends. The discussion situates these results within

the broader scientific literature, showing consistency with international research on hydrological changes in arid and semi-arid regions, while also emphasizing the unique features of the Zhaiyk–Caspian basin.

The dissertation thus provides a robust and multi-layered understanding of the mechanisms that govern minimal runoff, linking historical evidence with forward-looking forecasts, and offering a clear scientific basis for the design of adaptive and seasonally differentiated water management policies.

7. Practical Significance

The dissertation has clear and direct practical relevance for water resources management in Kazakhstan and Central Asia. By providing reliable assessments of minimal runoff under both current and future climate conditions, the work offers tools for planning and decision-making in a region where water scarcity is a critical constraint. The results can be used to design **early warning systems for low-flow periods**, to improve the **efficiency of water use in agriculture and industry**, and to guide the **selection of adaptive practices** such as drought-resistant crops or optimized irrigation schedules.

Moreover, the findings have implications beyond the national scale. Given the transboundary character of the Zhaiyk–Caspian basin, the dissertation provides valuable evidence for international water negotiations, especially with the Russian Federation. Its methodological approach can also be applied in other arid basins of Central Asia, strengthening regional cooperation on climate adaptation.

The research bridges the gap between scientific knowledge and practical application, contributing to the development of sustainable strategies that can enhance water security and ecological resilience under conditions of increasing climate uncertainty.

8. Compliance with Doctoral Requirements

Work fully meets the requirements for degree of Doctor of Philosophy in Hydrology:

- Original scientific contribution.
- International peer-reviewed publications.
- Methodological rigor.
- Practical applicability.

The candidate shows capacity for independent research, teamwork, and international collaboration.

9. Final Recommendation

The dissertation of **Lyazzat Muratbekovna Birimbayeva** represents a **substantial and original contribution** to the field of hydrology and climate change impacts on water resources. The research combines methodological innovation, solid empirical basis, and practical recommendations of high relevance for Kazakhstan and beyond.

I therefore **strongly recommend** the dissertation for public defence and the award of the degree of **Doctor of Philosophy (PhD) in Hydrology**.

Certification

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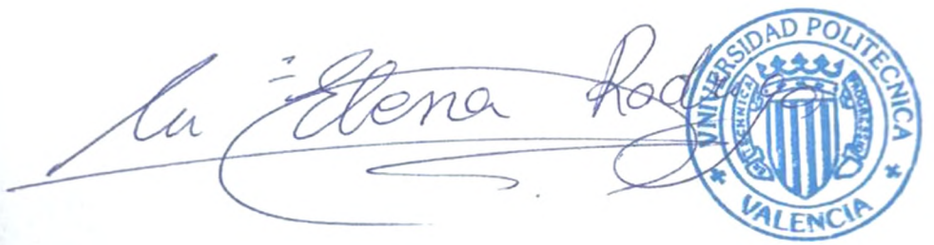

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