STARS4Water

Manuscripts of STARS4Water results for special issue in peer-reviewed journal

Deliverable 6.9

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Manuscripts on STARS4Water results for special issue in peer-reviewed journal

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Dissemination Level		
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SEN	Confidential, only for members of the consortium and the granting authority (including other EU institutions and bodies)	
CI	Classified, as referred to EU Decision 2015/444 and its implementing rules	

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Disclaimer

Summary

This deliverable compiles the manuscripts produced within the STARS4Water project and submitted to a dedicated collection in an international peer-reviewed journal. Its primary objective is to document and disseminate some of the main scientific outputs generated by project partners, while ensuring open access through the provision of links to preprints hosted in the project's Zenodo community. Although originally conceived as a contribution to a traditional special issue, the collection aligns with the journal's transition toward a more flexible Article Collection format, enabling continuous publication and improved visibility of individual contributions.

The document outlines the process followed to define the scope, target a journal, and coordinate manuscript submission and review. An editorial team was appointed to guide these activities, working in close collaboration with the project consortium. The thematic scope was deliberately broad and interdisciplinary, reflecting the core objectives of STARS4Water: integrating advanced modelling approaches, stakeholder engagement, and water governance frameworks to support adaptive and resilient water management. The selected scope emphasizes the translation of data into decision-making, highlighting the importance of co-creation processes and stakeholder-driven research.

A structured journal selection process was undertaken, considering criteria such as thematic alignment, scientific visibility, publication model, timelines, and costs. Following evaluation and discussion among partners, the International Journal of River Basin Management was chosen as the most suitable outlet. The manuscript submission process adhered to the journal's standard procedures, including editorial screening and independent peer review, with STARS4Water members contributing as Associate Editors to facilitate coordination while ensuring impartial evaluation.

The final part of the deliverable consists of a compendium of manuscript abstracts submitted to the journal. This includes links to the full manuscripts, which have been uploaded to the project's Zenodo community as preprints. These contributions cover a wide range of topics relevant to river basin management under changing environmental conditions. Key themes include the application of machine learning and hybrid modelling approaches for hydrological forecasting, assessment of climate change impacts on water availability and hydropower production, groundwater resource evaluation and contamination analysis, and the development of frameworks such as safe operating spaces to balance competing water uses. Several of them also demonstrate the integration of stakeholder input into modelling and decision-support tools, highlighting the project's emphasis on co-produced knowledge.

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1. Introduction

1.1. The STARS4Water project

The STARS4Water (Supporting Stakeholders for Adaptive, Resilient and Sustainable Water Management) project is a collaborative research initiative funded by the European Union's Horizon Europe programme. Launched in October 2022 and running through September 2026, the project aims to improve understanding of how climate change affects water availability and the vulnerability of ecosystems, communities, and economic sectors at the river-basin scale. By combining advanced scientific research with stakeholder engagement, STARS4Water seeks to help water managers and policymakers develop more effective strategies for adapting to climate-related water challenges.

STARS4Water operates through seven River Basin Hubs, which function as living laboratories where researchers, water authorities, and local stakeholders collaborate to test and validate new approaches (Figure 1). The project focuses on capacity building, knowledge sharing, and the creation of an international community of practice for water management. By connecting scientific advances with stakeholder expertise, STARS4Water aims to accelerate climate adaptation efforts and support long-term, sustainable management of freshwater resources.

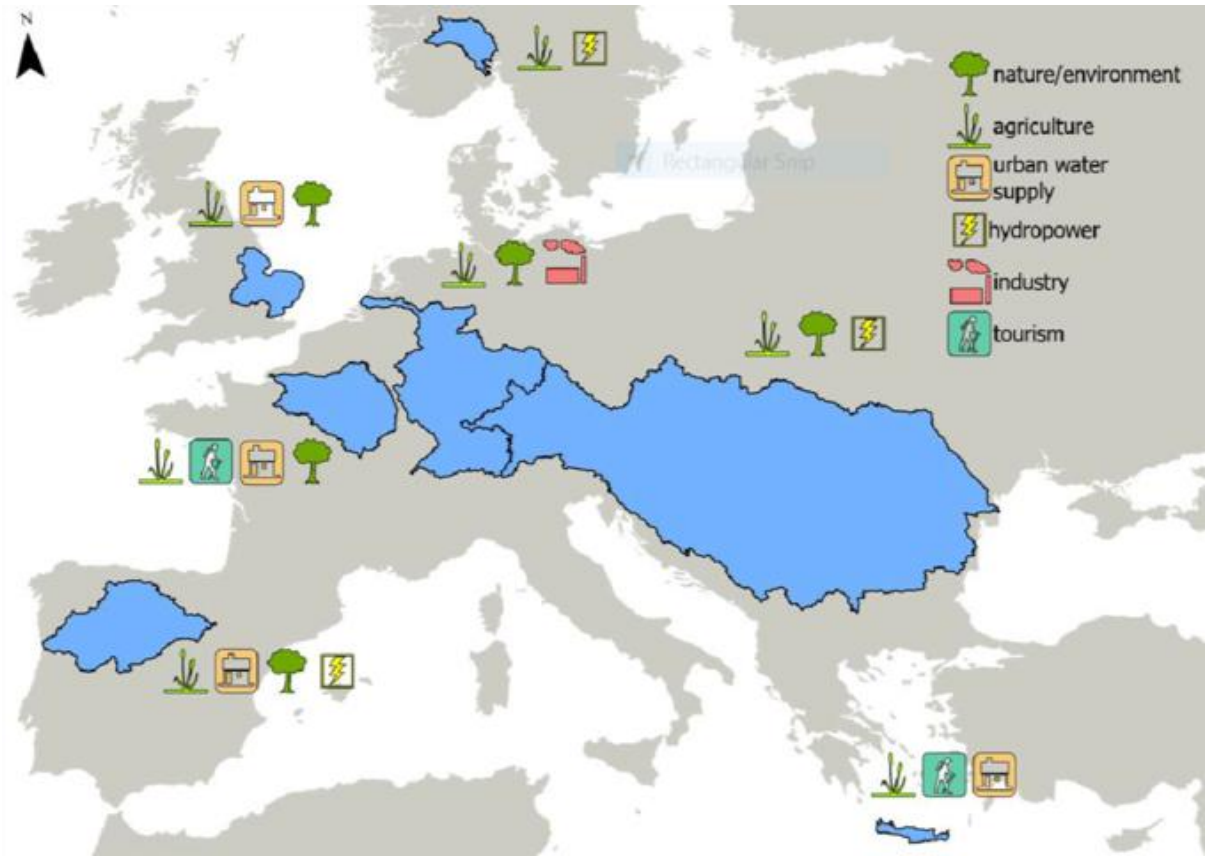

Figure 1. STARS4Water's river basin hubs.

A central feature of the project is the development of innovative data services, data-driven models, and decision-support tools that can improve water-resource planning and management. These tools are being co-designed with stakeholders to ensure they address real-world needs and can be integrated into existing decision-making processes. The project also aims to enhance the accuracy of regional water-resource projections, strengthen climate-risk assessments, and provide dashboards and information systems that support evidence-based planning for resilient and sustainable freshwater management.

1.2. About the deliverable

The original STARS4Water Description of Action establishes Deliverable D6.9 as the collection of manuscripts submitted to a project-related special issue in an international academic journal. The use of the term “manuscripts”, rather than “publications”, reflects the fact that the project is still ongoing and, consequently, some contributions may still be under review or in the publication process at the time of submission of this deliverable.

This deliverable thus compiles the manuscripts submitted by STARS4Water partners to a special issue of the International Journal of River Basin Management (Figure 2). Links are provided to all contributions, which in turn have been uploaded as preprints to the project's Zenodo community. This ensures open access to the submitted versions of the manuscripts and facilitates dissemination of project results in accordance with the project's open science commitments. Furthermore, uploading manuscripts as preprints is an authorized practice by the journal that prevents potential copyright breaches derived from including the full text in a project deliverable. For each contribution, the deliverable provides the manuscript title, author list, abstract, and a link to the corresponding Zenodo record. Upon being published, all papers will be available in open access form via the journal's website.

In addition to the contributions originating from STARS4Water partners, the special issue has attracted six manuscripts from authors not affiliated with the project. These external contributions demonstrate the broader scientific interest generated by the themes addressed by the Special Issue and contribute to enriching the overall collection. However, as Deliverable D6.9 is intended to report the scientific outputs generated within the STARS4Water project, only manuscripts led by project participants are included in the present document.

Readers should note that access to the Zenodo records may occasionally be affected by temporary platform performance issues. In some cases, links may load slowly or return a server error message. If this occurs, reloading the page or attempting access at a later time generally resolves the issue.

In keeping with the terminology of the original proposal, this deliverable will refer to the “special issue”. However, in recent times the International Journal of River Basin Management has transitioned from the traditional special issue format to an article collection model to better reflect the evolving landscape of scientific publishing. Unlike special issues, which are constrained by fixed timelines and publication bundles, article collections allow for greater flexibility, enabling papers to be published individually as soon as they are ready while still being thematically grouped. This approach improves visibility, accelerates dissemination, and accommodates a more dynamic and continuous flow of contributions, which is the reason why it was ultimately adopted in the STARS4Water context.

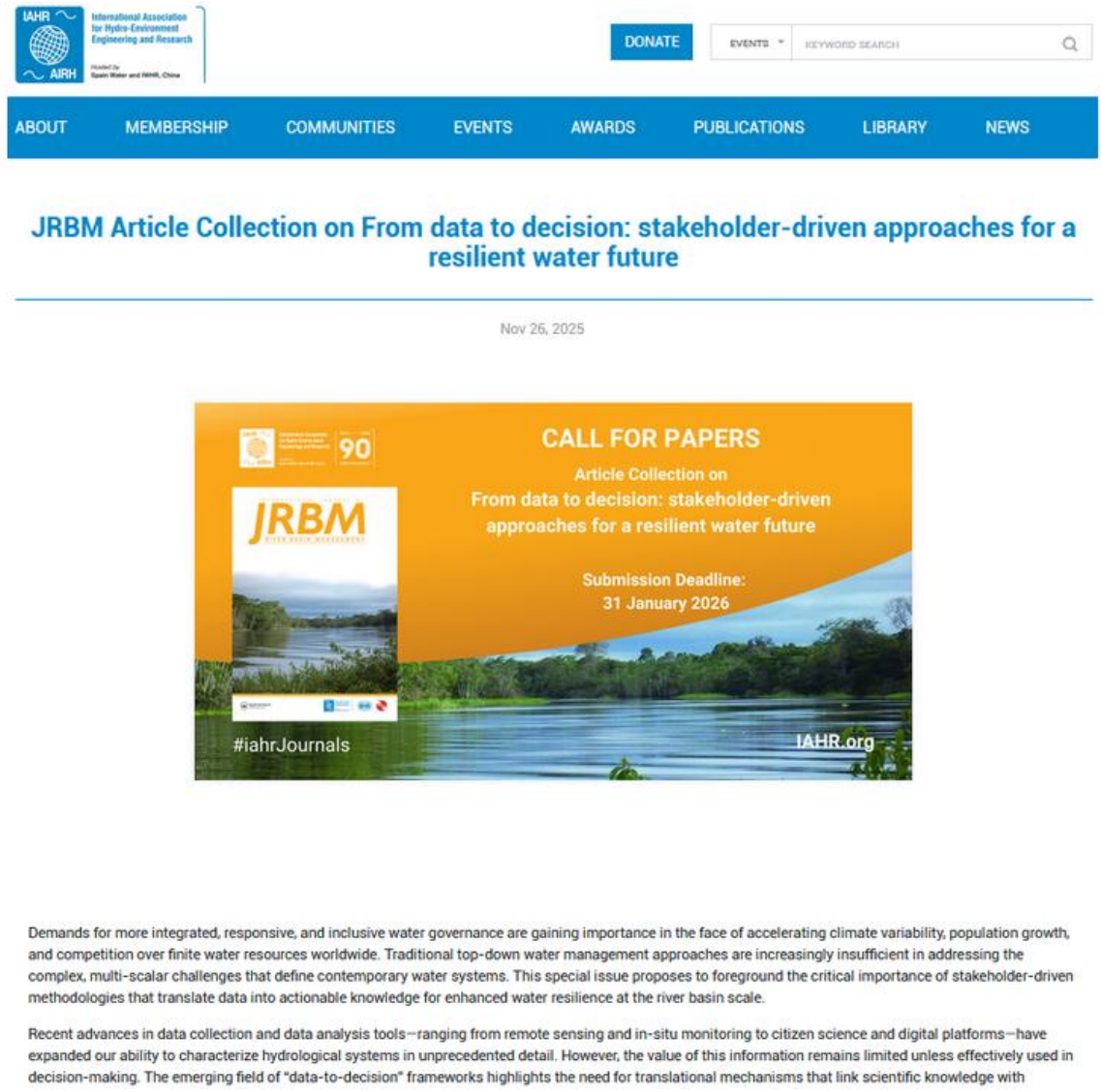

Figure 2. Journal's landing page for the special issue (https://www.iahr.org/index/detail/2133).

2. Methodology

2.1. Scope definition

An editorial team was appointed to coordinate the preparation of the special issue, liaise with the journal office, and, subsequently, support the journal selection and submission process. The editorial team developed a preliminary scope and thematic framework for the special issue and presented it to all members of the consortium for comments and approval.

The thematic focus of the special issue was defined following discussions among project partners regarding the most appropriate framework for showcasing the scientific outcomes of STARS4Water. Three alternative approaches were considered initially. The first focused on technical and methodological advances, including next-generation modelling approaches such as process-based, data-driven, and hybrid models for water systems analysis. The second emphasized management and governance aspects, including the policy implications of project results and the application of concepts such as safe operating spaces for sustainable water resources management. The third centered on stakeholder engagement, co-creation processes, and stakeholder-driven research approaches for addressing complex water challenges. Following these discussions, the selected scope was designed to accommodate contributions across these interconnected dimensions, reflecting the multidisciplinary nature of STARS4Water and its objective of integrating scientific innovation and stakeholder participation in water resources research.

The scope of the special issue was intentionally designed with two goals in mind. Firstly, to accommodate a broad range of contributions, including manuscripts produced within the project and complementary contributions from external researchers working on related topics. This approach aimed to enhance the scientific relevance, interdisciplinarity, and visibility of the special issue beyond the immediate project consortium. Secondly, the scope of the special issue was designed to fit within the "aims and scope" description of broad range of academic journals, to optimize the task of contacting journal editors.

The final version of the special issue description that was used to contact journal editorial offices reads as follows:

"Demands for more integrated, responsive, and inclusive water governance are gaining importance in the face of accelerating climate variability, population growth, and competition over finite water resources worldwide. Traditional top-down water management approaches are increasingly insufficient in addressing the complex, multi-scalar challenges that define contemporary water systems. This special issue proposes to foreground the critical importance of stakeholder-driven methodologies that translate data into actionable knowledge for enhanced water resilience at the river basin scale.

Recent advances in data collection and data analysis tools—ranging from remote sensing and in-situ monitoring to citizen science and digital platforms—have expanded our ability to characterize hydrological systems in unprecedented detail. However, the value of this information remains limited unless effectively used in decision-making. The emerging field of "data-to-decision" frameworks highlights the need for translational mechanisms that link scientific knowledge with stakeholder priorities, values, and institutional capacities. Bridging this gap requires co-produced knowledge, modelling approaches that take stakeholders into consideration directly, and iterative engagement

processes that promote mutual learning and trust among researchers, policymakers, water managers, and local communities.

This special issue seeks to explore how stakeholder-driven approaches can be systematically integrated into decision-making processes to build adaptive capacity and social-ecological resilience. Contributions consider different spatial and temporal scales to critically assess methodological innovations, policy instruments, decision-support tools, and institutional arrangements that facilitate the translation of complex water data into decisions that are both scientifically robust and socially legitimate. Case studies from diverse hydrological, geographic, and socio-political contexts are especially encouraged, as these provide critical insights into the operationalization of stakeholder-engaged data to decision frameworks.

Given the increasing emphasis on transdisciplinary research, the imperative to democratize water governance, and the growing availability of high-resolution data, the moment is ripe for a concerted scholarly examination of how data can be transformed into decisions through inclusive and stakeholder-responsive processes across different spatial and temporal scales. In this context, a fundamental goal of this special issue is to offer an interdisciplinary platform for advancing theory, practice, and policy around participatory water management in the face of uncertainty."

2.2. Journal selection

A structured journal selection process was undertaken by the editorial team for the publication of the project manuscripts compiled in this deliverable. First, a broad list of journals within the water research field was identified through a screening process based on thematic relevance and scientific visibility (Table 1). Subsequently, the consortium jointly evaluated the candidate journals through a series of discussions considering several criteria, including whether the journal accepted external proposals for special issues, the journal scope and its alignment with the project objectives, the expected review and publication timelines, past experiences of project members, the availability of open-access publication, publication costs, and the potential audience.

Based on this assessment, a shortlist of five candidate journals was established. The shortlisted options were then further discussed among the project members, considering the collective priorities of the consortium and the suitability of each journal for hosting a compendium of manuscripts produced within the project. The final selection was made collaboratively by the project partners, resulting in the choice of the International Journal of River Basin Management as the target journal for the manuscript collection.

Based on this assessment, a shortlist of five candidate journals was established. The shortlisted options were then further discussed among the project members, considering the collective priorities of the consortium and the suitability of each journal for hosting a compendium of manuscripts produced within the project. The final selection was made collaboratively by the project partners, resulting in the choice of the International Journal of River Basin Management as the target journal for the manuscript collection.

Table 1. Results of journal scoping. Accurate as of May 2025, when the decision to approach the journals was made.

	JOURNAL	CATEGORY	RANKING (JIF)	MODEL	APC (€)
1	Environmental Modelling & Software	Computer Science, Interdisc.	33 / 170	Hybrid	3 100 €
2	Applied Water Science	Water Resources	10 / 128	Open access	2 090 €
3	Journal of Hydrology: Regional Studies	Water Resources	17 / 128	Open access	$2350 (2100€)
4	Journal of Hydrology X	Water Resources	37 / 128	Open access	$2300 (2050€)
5	Water Research X	Engineering, Environmental	5 / 128	Open access	2 800 €
6	Frontiers of Environmental Science & Engineering	Engineering, Environmental	20 / 81	Open access	2 890 €
7	Environmental Sciences Europe	Environmental Sciences	59 / 358	Hybrid	2 790 €
8	Nature Sustainability	Environmental Studies	2 / 182	Open access	10 690 €
9	Water Resources Management	Water Resources	28 / 128	Hybrid	2 890 €
10	Frontiers in Water	Water Resources	51 / 128	Open access	CHF1175 (1250€)
11	AQUA - Water Infrastructure, Ecosystems and Society	Engineering, Civil	83 / 182	Open access	2 550 €
12	Journal of Water and Climate Change	Water Resources	49 / 128	Open access	2 550 €
13	Journal of Hydroinformatics	Engineering, Civil	77 / 182	Open access	2 550 €
14	International Journal of River Basin Management	Water Resources	60 / 128	Hybrid	3 505 €
15	Hydrology	Water Resources	37 / 128	Open Access	1 927 €
16	Journal of Water Resources Planning and Management	Water Resources	40 / 128	Hybrid	2 205 €
17	Water	Water Resources	40 / 128	Open Access	2 783 €
18	Sustainability	Environmental Studies	66 / 182	Open Access	CHF2400 (2550€)
19	Hydrological Sciences Journal	Water Resources	45 / 128	Hybrid	3 505 €
20	Hydrological Processes	Water Resources	45 / 128	Hybrid	4 380 €
21	Environmental Earth Sciences	Water Resources	45 / 128	Hybrid	2 590 €
22	Hydrology Research	Water Resources	51 / 128	Open Access	2 590 €
23	International Journal of Water Resources Development	Water Resources	76 / 128	Hybrid	4 215 €
24	Sustainable Water Resources Management	Water Resources	72 / 128	Hybrid	2 590 €
25	Advances in Geosciences	Likely unindexed	Likely unindexed		

2.3. Special issue topics and guest editors

This special issue welcomed contributions from a wide variety of perspectives, including:

- Data-driven and process-driven models in river basin management, potentially including interactions between both approaches.
- Methodologies for engaging stakeholders in the co-design of basin-scale water monitoring systems, models, and management strategies.
- Development and application of tools (e.g., dashboards, scenario planning) that support stakeholder involvement in water management.
- Case studies on innovations that enable collaborative water governance and resilient management.
- Exploring hybrid approaches that bring together scientific and traditional knowledge systems in water decision-making.
- Methods for conveying probabilistic and scenario-based water data to policymakers and community stakeholders.
- Definition and application of indicators for resilient water management.
- Assessment of future water availability and risks across different spatial and temporal scales in the context of climate variability and evolving conditions.
- Development of safe operating space frameworks for water management.

The Guest Editors were picked from the Stars4Water team, and included:

- Pedro Martínez-Santos (Editor), Universidad Complutense de Madrid, Spain.
- Albretch Weerts, Deltares, The Netherlands.
- Harm Duel, Deltares, The Netherlands.
- Helmut Habersack, Institute of Hydraulic Engineering and River Research, Austria.
- Michiel Blind, Deltares, The Netherlands.
- Leandro Ávila, Research Centre Jülich, Germany.
- Maggie Kossida, SEVEN-Engineering Consultants, Greece.
- Virginie Keller, UK Centre for Ecology & Hydrology, United Kingdom.
- Julie Collignan, INRAE, France.

2.4. Manuscript submission and review process

All manuscripts included in this deliverable were submitted in accordance with the standard procedures and requirements of the selected academic journal and its Special Issue. Authors prepared their manuscripts following the journal's guidelines regarding formatting, ethical standards, data reporting, and scientific quality.

Initially, a deadline for submission was set for December 31, 2025, to increase the chances that all manuscripts would be published by the end of the project. This deadline was subsequently extended until January 31 and April 10, 2026.

Submissions were made through the journal's online manuscript management system. Following submission, each manuscript underwent an initial editorial screening to assess its suitability for the scope of the special issue and its compliance with the journal's requirements.

To facilitate the review process, members of the STARS4Water project served as Associate Editors for the Special Issue. In this role, they were responsible for managing the peer-review process, including the selection and coordination of reviewers from the journal's established reviewer pool. Reviewers were independent researchers who were not affiliated with the STARS4Water project in any way, thus ensuring an objective and impartial evaluation of the manuscripts.

Each manuscript was assessed through the journal's standard peer-review procedure. Based on reviewers' comments and recommendations, authors were requested to revise their manuscripts as necessary and respond to the review feedback. Associate Editors oversaw the review and revision process and provided recommendations regarding the manuscripts' suitability for publication.

The final editorial decision on all manuscripts rested exclusively with the Editor-in-Chief of the journal, who considered the reviewers' evaluations, the Guest Editors' recommendations, and the journal's publication standards when determining acceptance, revision, or rejection.

3. Compendium of special issue manuscripts

The abstracts compiled in this deliverable correspond to STARS4Water manuscripts submitted to the Special Issue and represent scientific contributions developed within the framework of the STARS4Water project and its associated research activities. Table 2 presents the article titles and topics, whereas the following pages present the manuscript titles, authors, abstracts, and links to all preprints.

Table 2. List of manuscripts submitted to the special issue and uploaded to the project's Zenodo site.

Authors	Basin	Title	Topic
Avila et al	Drammen	A deep-learning surrogate based model to predict daily snow water equivalent in Southern Norway	Data-driven models
Baron et al	East Anglia, Seine, Duero	Subseasonal to Seasonal Forecasting of Reservoir Storage Using a Machine Learning Model in Western Europe	Data-driven models, reservoirs
Collignan et al	Seine	The added value of considering evapotranspiration fluxes in the calibration of a semi-distributed hydrological model	Process-based models
Engeland et al	Drammen	Climate change impacts on hydrology and electricity production – a case study from Drammen river basin in Norway	Process-based models, hydropower, reservoirs
García-Menéndez et al	Duero	A method for assessing short-to mid-term groundwater availability: application to the Duero River Basin	Safe operating space, water scarcity and droughts
Gómez-Escalonilla et al	Duero, East Anglia	Spatial prediction of groundwater nitrate through machine learning and stakeholder cocreation: The Chalk Aquifer case in East Anglia	Data-driven models, water quality, groundwater
Hegdahl et al	Drammen	Water availability, energy production, and ecological flows defining the 'safe operating space' for the Drammen basin	Safe operating space, environmental flows, hydropower
Kenne et al	Global	Exploring Inductive Transfer Approaches for Machine Learning Based Rainfall-Runoff Modelling	Data-driven models
Purnasamari et al	Rhine	Assessing Navigation and Ecological Flow Risks of the Rhine River under Climate Change Scenarios	Environmental flows, navigation
Rodríguez del Rosario et al	Duero	Data-driven spatial modelling of groundwater nitrate contamination: a multi-year analysis in the Duero basin	Data-driven models, water quality, groundwater

A deep-learning surrogate based model to predict daily snow water equivalent in Southern Norway

Leandro Avila[1,2], Kolbjørn Engeland[3], Trine Jahr Hegdahl[3], Stefan Kollet[1,2]

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[2]Centre for High-Performance Scientific Computing in Terrestrial Systems, Geoverbund ABC/J, 52428 Jülich, Germany

[3]Norwegian Water Resources and Energy Directorate (NVE), Middelthuns Gate 29, 0368 Oslo, Norway

Abstract

Accurate estimation of Snow Water Equivalent (SWE) is crucial for water resource management and hydropower operations in snow-dominated regions. This study presents a surrogate model based on a ConvLSTM architecture to predict daily SWE at a high spatial resolution (1 km × 1 km) in the Drammen River Basin, Southern Norway. Designed to emulate the SeNorge snow model, the proposed framework uses meteorological inputs, such as precipitation and temperature from the SeNorge observational dataset, along with topographic features. To mitigate error propagation in the prediction process, the model was trained using an autoregressive scheme with scheduled sampling, allowing the model to incrementally shift from using true SWE target values to its own prior estimates as subsequent inputs. The surrogate model was also evaluated using input data from a global reanalysis dataset, such as ERA-5, to measure its potential for generalization and transfer, as well as to allow us to identify overfitting issues. Results demonstrate that the surrogate model effectively captures spatial and seasonal SWE dynamics in the study area, showing strong agreement between the ConvLSTM simulations forced with both the SeNorge and ERA5 datasets. This work highlights the potential of data-driven deep learning approaches for developing robust tools to support hydrological forecasting and water resource management.

Keywords: Snow Water Equivalent (SWE), ConvLSTM, Forecasting, Hydrological Modeling, Deep Learning, Water Resources, Management

Link: https://zenodo.org/records/18387273
DOI: doi.org/10.5281/zenodo.18387273

Subseasonal to Seasonal Forecasting of Reservoir Storage Using a Machine Learning Model in Western Europe

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[1]UK Centre for Ecology & Hydrology, Wallingford, UK

[2]Wallingford HydroSolutions, Wallingford, UK

Abstract

A multi-reservoir machine learning model has been built for seasonal to subseasonal reservoir storage forecasts on a monthly timestep, including a range of reservoirs from the UK, France and Spain. The model demonstrates strong predictive skill across all the reservoirs, with a median R2 of 0.73 for 1 month ahead and 0.65 for 3 months ahead predictions in the model testing period, outperforming a benchmark model in almost all cases. The model shows potential for generalisation, with good predictive skill for one reservoir not included in the training data, but poor predictive skill for another 'unseen' reservoir, due to the weak seasonal signal in the observed storage. Monthly and seasonal ensemble forecasts were produced for a subset of the reservoirs. The model shows good forecast skill for those reservoirs, with a median Continuous Ranked Probability Skill Score of 0.45 and 0.42 for 1 month ahead and seasonal forecasts, respectively. Overall, the model is shown to be suitable for operational monthly reservoir storage forecasts over the UK, and for reservoirs in Spain and France where a clear seasonal signal exists. There is potential for expanding this model to new regions, including areas with low volumes of accessible historical data.

Keywords: machine learning; reservoirs; water resources; seasonal forecasting

Link: https://zenodo.org/records/18387500
DOI: 10.5281/zenodo.18387499

The added value of considering evapotranspiration fluxes in the calibration of a semi-distributed hydrological model

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Abstract

Trust in hydrological model projections is often challenged by the model's capacity to simulate streamflows under non-stationary conditions imposed by climate change. While many studies focus on uncertainties arising from climate scenarios or downscaling methods of climate projections, uncertainties linked to the hydrological model structure and calibration strategies remain comparatively overlooked. In this work, we investigate how model calibration choices influence the performance and robustness of a semi-distributed conceptual hydrological model under climate change. Beyond the traditional calibration based solely on discharge data, we introduce an additional constraint on evapotranspiration (ET) data to better represent the catchment's water balance under historic climate and enhance model transferability to simulate flows under future climate conditions. Our results show that the calibration strategy markedly affects future hydrological projections. The ET-constrained calibration strategy produces more spatially coherent fluxes and a more stable model response in non-stationary conditions. By better framing internal fluxes, this approach enhances the trustworthiness of hydrological projections under future climate scenarios, which is essential for water resources availability assessments and adaptive management.

Keywords: Hydrology, Semi-distributed model, Evapotranspiration, Calibration, Projection, Climate change

Link: https://zenodo.org/records/20157989
DOI: 10.5281/zenodo.20157988

Climate change impacts on hydrology and electricity production – a case study from Drammen river basin in Norway

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[2] Department of Geosciences, University of Oslo, Norway

ABSTRACT

Climate change impacts on hydrology and electricity production – a case study from Drammen river basin in Norway. In this paper we have assessed how climate change might impact hydrology and electricity production in the Drammen River basin. To assess climate change impacts, downscaled scenarios from several combinations of GCMs, RCMs and bias correction algorithms from both CMIP5 and CMIP6 were used by a gridded hydrologic model (HBV) to simulate runoff for a reference period and a future period. Thereafter the energy market model EOPS has been used to simulate electricity production, reservoir water levels, bypass and flood flows. In Drammen we see an increase in runoff, a reduction in the average seasonal variation in runoff and an increase in year-to-year variability. Most of the increase can be used for electricity production. There is an increase in flood risk during autumn and early winter and higher drought risk during summer. The increase in the year-to-year variability will impose new challenges for water resources management in the Drammen river basin.

Keywords: Climate change impacts; Hydropower; Water balance; CMIP5; CMIP6: HBV; EOPS

Link: https://zenodo.org/records/20157882
DOI: 10.5281/zenodo.20157881

A method for assessing short-to mid- term groundwater availability: application to the Duero River Basin

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Abstract

Groundwater reserves are increasingly threatened by excessive extraction and climate change, leading to both quantity depletion and quality degradation. These trends jeopardize groundwater-dependent economies and ecosystems, making the assessment of resource availability essential for sustainable management. Within the European project STARS4Water (Supporting Stakeholders for Adaptive, Resilient, and Sustainable Water Management), we developed a diagnostic system based on the Groundwater Resource Availability Index (GWAI), reference levels, and application guidelines. The results classify the quantitative status of groundwater into four categories: good status, good status under observation, poor status in recovery, and poor status in degradation. The diagnostic outcomes are readily interpretable by diverse stakeholders. The GWAI is designed for straightforward computation from standard monitoring datasets. Its calculation involves defining a 'calculation cycle' and determining the slope of groundwater-level time series within that period. The procedure is applied iteratively, starting from the earliest available data and shifting the calculation window forward by one year at each iteration. This approach provides both the temporal evolution of the index and its individual values. Calculations have been automated in a user-friendly spreadsheet. The system is conceived to be universally applicable and adaptable across a wide range of hydrological, climatic, and management contexts. Within the framework of the project, it has been applied to the Duero River Basin (Spain).

Keywords: groundwater level, groundwater quantitative index, groundwater status assessment, water resources management, Duero River Basin, STARS4Water European project

Link: https://zenodo.org/records/18386986
DOI: 10.5281/zenodo.18386985

Spatial prediction of groundwater nitrate through machine learning and stakeholder cocreation: The Chalk Aquifer case in East Anglia

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Abstract

Nitrate contamination in groundwater poses a threat to drinking water supplies in many regions of the world. Data-driven approaches can contribute to interpret existing nitrate datasets, thus shedding new insights on the magnitude of this problem and on mitigation strategies. This study documents the co-creation with stakeholders of a continuous nitrate contamination map for the Chalk aquifers of East Anglia, England. We compare supervised classification and regression approaches for four ensemble algorithms, namely, Random Forest, AdaBoost, Gradient Boosting, and ExtraTrees. Gradient Boosting outperformed the others, obtaining harmonic mean F1 scores of 0.96 in classification, and a 0.70 Pearson R2 correlation and a 15.3 mg/L root mean square error in regression. From a hydrogeological perspective, regression- and classification-based maps depict nitrate distribution adequately. The unconfined Chalk outcrops to the west of the study area and in some deep valleys in the central and northern sectors that are identified as the regions of greatest concern, whereas the areas where the Chalk aquifer is confined exhibit a lower probability of nitrate contamination. Both approaches suggest there are unsampled locations outside the official nitrate vulnerable zones that present similar markers to those that are known to be contaminated. Shapley analyses point at a control of geological variables and contamination sources as the main predictor for groundwater nitrate. Results lead to a two-fold conclusion: (1) improvements in data-driven approaches, including enhanced interpretability, are making data driven methods increasingly suitable for stakeholder uptake; and (2) while classification scores convey a greater sense of reliability than regression scores, map outcomes are noticeably similar. This points at the need to evaluate algorithm performance not only on the grounds of machine learning metrics, but also in terms of hydrogeological considerations.

Keywords: ensemble algorithms, nitrate contamination, regression, classification, groundwater

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Water availability, energy production, and ecological flows defining the 'safe operating space' for the Drammen basin

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Abstract

Climate change will affect the hydrological regime in the highly regulated Drammen River basin (Norway). In this study we use an integrated modelling chain combining downscaled climate projections (medium and high emissions), two hydrological models (HBV and LISFLOOD). A power market scheduling model (EOPS) was used to assess impacts on water availability, hydropower potential and realized production. Whereas the Ecological Risk due to Flow Alteration (ERFA) screening method was applied to assess ecologically relevant changes in flow regimes. The changes were analysed for 2041–2070 and 2071–2100 relative to 1991–2020. Projections indicate higher annual runoff and a marked shift towards higher winter flows, driven by reduced snow storage and more precipitation falling as rain. Increased inflow raises the hydropower potential, leading to an increase in production, but some production is lost because spillage and bypass losses grow. The losses are especially evident in wetter future, and power production further depends on electricity price assumptions. Hydrological responses differ across subbasins: high elevation, reservoir dominated headwaters benefit most om hydropower production, whereas smaller low elevation catchments show stronger low flow alteration and higher ecological risk. The results highlight how future 'safe operating space' in regulated basins emerges from interacting climatic change, operational constraints, ecological thresholds, and market driven operation, informing reservoir regulation and climate adaptation planning.

Keywords: Climate change, Safe operating space, Water management, hydropower production, Flow regime alteration, Ecological impact

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Exploring Inductive Transfer Approaches for Machine Learning Based Rainfall-Runoff Modelling

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Abstract

Machine Learning is becoming an increasingly relevant approach to making accurate predictions in environmental science. Making the most of our data and knowledge is crucial for actionable rainfall–runoff prediction, which remains challenging in hydrological modelling. In this regard, techniques that enable the transfer of knowledge from one task to another have high potential to expand the scope of Deep Learning to new contexts, enabling generalisation of model by manipulating the data. We investigate three different forms of inductive transfer techniques on the basis of exemplary applications of rainfall–runoff modelling: data augmentation, task augmentation, and additional input. We apply these techniques in conjunction with Long Short-Term Memory networks (LSTMs) that incorporate static and dynamic inputs from 1981-2020. For training and evaluation we use on basins from Caravan, CAMELS-US, and Caravan-GRDC datasets around the globe. Our results suggest that inductive transfer approaches constitute an efficient and promising solution for hydrological simulations in low-data regimes.

Keywords: Machine Learning; data augmentation; time-series; environmental sciences

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Assessing Navigation and Ecological Flow Risks of the Rhine River under Climate Change Scenarios

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Abstract

Climate change is projected to intensify low-flow conditions across European river basins and threaten sustainable environmental flows and navigation. On the Rhine, one of Europe's most commercially significant waterways, declining summer discharge combined with increasing water demand impacts inland navigation and the maintenance of environmental flows. However, the relative sensitivity of each sector to changes in precipitation and temperature remains poorly understood. This study quantifies risk by comparing simulated river discharge with sector-specific operational thresholds along the main tributary of the Rhine using a large ensemble of CMIP6 climate simulations. Under mid-century scenarios, navigability at the Rhine bottleneck located at Kaub largely remains within the no-risk (<20 days below GIQ) or low-risk (20–30 days below GIQ) categories, suggesting that, on average, discharge is sufficient to sustain navigation through 2050. However, scenarios combining modest precipitation reductions with sustained warming result in a narrowed margin of safety that moves toward higher-risk thresholds. Precipitation emerges as the primary driver of navigation risk, while temperature has a secondary but nonnegligible influence. Similarly, environmental flow shows a comparable trajectory toward the end of the century with elevated risk emerging under the high-emissions scenario that reveals sectoral vulnerabilities not captured by annual water balance assessments alone. These findings indicate that sustainable environmental flows and navigability of the Rhine may increasingly be at risk under combined precipitation and temperature.

Keywords: Rhine, water resources management, inland navigation, environmental flow, low flow

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Data-driven spatial modelling of groundwater nitrate contamination: a multi-year analysis in the Duero basin

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Abstract

Groundwater contamination by nitrates is one of the main problems affecting water quality, with significant implications for drinking water supplies and groundwater-dependent ecosystems. This study analyses the Duero river basin (Spain), where aquifer nitrate concentrations have increased consistently over recent decades, driven by intensive agriculture and livestock farming. The objective is to predict the presence of elevated nitrate concentrations in groundwater using machine learning techniques, formulating the problem as a binary classification based on a threshold of 37.5 mg/L. Monitoring data combined with spatially derived environmental and anthropogenic predictors were used. Several tree-based algorithms were evaluated, with Random Forest selected for its robustness and predictive performance. Model reliability was ensured through repeated nested cross-validation and the use of metrics suitable for imbalanced datasets. A temporal analysis across hydrological years and a spatial validation were conducted by comparing predicted risk patterns with officially designated Nitrate Vulnerable Zones (NVZs), revealing a high degree of overlap and identifying potentially unrecognised areas. Model interpretability was assessed using SHAP values, which highlighted precipitation, diffuse agricultural pressures, distance to surface water bodies, NDVI, and soil properties as the most influential predictors. Overall, the results demonstrate the potential of machine learning approaches to improve the assessment, diagnosis, and management of nitrate pollution at the basin scale.

Keywords: Machine learning; Random Forest; Groundwater vulnerability; Nitrates; Contamination; Duero.

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