The Effects of Climate Change and Drought on the Morphology, Qualitative Changes, and Regime of rivers and Wetlands

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ABSTRACT

Climate change, in conjunction with extended droughts, is dramatically altering the form and function of riverine and wetland ecosystems worldwide. These effects are manifested through the physical modification of river morphology, including channel incision, sedimentation, and bank erosion, and through the extreme alteration of the hydrological regimes that govern seasonal flow patterns and wetland inundation cycles. Heightened evaporation and precipitation decrease streamflow and groundwater recharge, leading to fragmented aquatic habitats, high salinity, and poor water quality. Contaminant buildup during low-flow and high-temperature water periods enhances potential for eutrophication, habitat destruction, and loss of biodiversity. Wetlands as a critical hydrological network buffer are especially vulnerable, relying as they do on continuous water inputs to sustain vegetation, enable wildlife, and provide ecosystem services such as flood control and water filtration. Such changes are not unidimensional and often vary by geography, climatic zone, and watershed characteristics. Use of remote sensing technology, coupled hydrological-sediment models, and adaptive ecosystem management strategies is becoming ever more essential to mitigate and monitor climate-induced stress. The following article synthesizes existing knowledge on the effects of drought and climate variability on river and wetland ecosystems through empirical case studies and state-of-the-art interdisciplinary models. It emphasizes proactive, evidence-based, and context-specific solutions that aim to preserve ecological integrity and resilience of these interconnected systems in the face of increasing climatic pressures.

Keywords: River morphology, Wetland degradation, Climate change impacts, Hydrological regime alteration, Drought resilience strategies

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1. *INTRODUCTION*

Rivers and wetlands form the lifeline of the global freshwater system, performing critical functions of hydrological cycle regulation, biodiversity maintenance, and water quality maintenance. These ecosystems are coming under heightened pressures due to the cumulative effects of climate change and prolonged drought conditions. Under rising global temperatures and shifting precipitation regimes, many rivers and wetlands are undergoing alterations in morphology, hydrological regimes, and chemical composition, leading to extreme cascading ecological and socio-economic consequences.

Drought, which was once thought to be an occasional climatic phenomenon, now manifests as an intrinsic result of anthropogenic climate change and mismanagement of water resources. In basins such as Iran's Zayanderud Basin, extensive over-exploitation of agricultural water use, coupled with recurring drought, has led to the complete dryness of downstream flow and collapse of wetland systems, including those of the Gavkhuni Wetland (Zaki et al., 2020). The same trends have been seen in Australia's Murray-Darling

Basin, where long dry spells and over-allocation of water have widely damaged once safeguarded wetlands under the Ramsar Convention (Overton & Doody, 2013). The morphological effects of drought encompass riverbed incision, channel constriction, and sediment aggradation. These changes simplify habitat and impair aquatic connectivity (Zhou et al., 2024). Hydrological regimes, as characterized by flow magnitude, duration, frequency, and timing, are being disrupted as baseflows diminish and floods become either less variable or more extreme. In the Coongie Lakes system of Australia, for instance, satellite monitoring reveals that ENSO-induced drought has caused spectacular declines in flood extent and vegetation cover with ramifications for ecosystem vulnerability to climatic extremes (Xie et al., 2016). Water quality is deteriorating in many drought-stricken rivers. Typically, in European Rhine and Meuse rivers, lowered summer flows as a result of drought have formed increased water temperatures, increased salinity, along with increased concentrations of pollutants, mainly medicines and heavy metals (Zwolsman & van Bokhoven, 2007); (Wolff & van Vliet, 2021). The same patterns are being seen in Oregon's Sprague River Basin, where future climate conditions are expected to significantly increase total phosphorus and sediment loads (Records et al., 2014). The biodiversity of both temperate and arid systems is threatened. In the UK, freshwater taxa like invertebrates and fish are suffering from increasingly common drying events, especially in rivers that were formerly perennial (Stubbington et al., 2024). In the Macquarie Marshes of Australia, climate modeling suggests that during drier future climates, the wetlands will be in degraded state for periods of up to 89% of time, rendering them hardly ecologically sustainable (Quijano et al., 2022). Aside from climatic aspects, socio-economic attributes—like land use change, expansion in urban areas, and heightened irrigation activities—intensify the sensitivity of river-wetland environments. Research incorporating meta-modeling techniques conducted in the UK advises that both climatic changes as well as socio-economic tendencies—such as rising urban abstraction of water—are capable of rendering wetlands inhospitable for local biodiversity in low flow circumstances (Harrison et al., 2008). Though there is heightened awareness, the majority of existing water governance arrangements remain reactive and poorly equipped to deal with long-term variability. To address this, scholars emphasize the need for adaptive, integrated strategies that combine hydrological modeling, ecosystem monitoring, and participatory decision-making. These strategies need to detect the feedback loops between climate, hydrology, ecology, and human systems and be capable of foreseeing thresholds beyond which ecosystems may not be able to recover.

This article synthesizes and reviews current research on interlinkages between drought, climate change, and the health of river and wetland ecosystems. It concentrates on morphological changes, water quality, and hydrologic regimes but also considers novel approaches to ecosystem monitoring, modeling, and adaptive management in different geographic settings.

2. *METHODOLOGY*

This research embraced a combined, multi-layered methodology approach to assessing the impacts of climate change and drought on the physical character of rivers and wetlands, hydrological regime, and qualitative changes. The approach combines a systematic review of the literature, geospatial analysis, model evaluation, and case study synthesis in order to achieve scientific rigor, contextual relevance, and thematic comprehensiveness. The model was organized into five major stages: literature screening, data extraction, coding and classification, evaluation of modeling and geospatial tools, and integration of case studies.

A systematic search process was conducted through databases like Scopus, Web of Science, and Google Scholar, including literature from 2000 to 2024. The search included combinations of the following keywords: climate change, river morphology, drought, wetland degradation, hydrological regime changes, sediment transport, ecosystem services, water quality, resilience, and adaptation. Inclusion criteria required studies to: Be empirical or modeled evidence-based regarding climate and drought effects on river or wetland systems, Address physical (e.g., channel morphology, flow regimes), chemical (e.g., salinity, eutrophication), or biological (e.g., vegetation, biodiversity) components, Employ tools such as drought indices (e.g., SPEI, RDI), hydrological models (e.g., SWAT, HEC-HMS), or remote sensing observations (e.g., MODIS, Landsat), Not be lacking a sound methodological approach and sufficient temporal or spatial extent. Not included in those studies were studies that only focused on marine ecosystems, were not peer-reviewed, or were editorials or opinion pieces.

Each of the selected studies was coded and analyzed using qualitative data analysis software (NVivo). The studies were divided into thematic categories: Morphological impacts (e.g., erosion, sedimentation, *channel morphology changes), Hydrological regime alteration (e.g., reduction in baseflow, flood duration changes), Water quality impairment (e.g., nutrient concentrations, salinity), Ecological response and resilience (e.g., habitat destruction, species alteration), and Adaptive management and monitoring approaches. This enabled synthesis across interdisciplinary outcomes, wherein not just ecological trends but also human-environment feedback processes were incorporated.*

To analyze predictive and mechanistic data, the research reviewed the application of the following models and indices: Hydrological Models: SWAT (applied in climate impact analysis in Oregon's Sprague River (Records et al., 2014), NAM (Qi et al., 2020), and Soil & Water Assessment Tool (Mirosław-Świątek et al., 2020), Drought Indices: Standardized Precipitation Evapotranspiration Index (SPEI), Reconnaissance Drought Index (RDI), and effective RDI were evaluated in Iranian wetland studies (Mirakbari & Ebrahimi-Khusfi, 2021), Remote Sensing Tools: MODIS, Landsat, NDVI time-series, and Synthetic Aperture Radar (SAR) were evaluated for land cover change, vegetation stress, and water surface extent analysis. The aforementioned techniques were widely employed in research on the Yellow River Basin (Zhang et al., 2024) and Helmand-Hamoun system (Maleki et al., 2019).

Five key regions were chosen for in-depth examination to underpin findings across varying ecological zones: Yellow River Basin, China, demonstrating the fragmentation of landscape, water use efficiency, and declines in ecosystem productivity (Zhang et al., 2024); Murray-Darling Basin, Australia, demonstrating long-term Ramsar wetland degradation through over-allocation and climate change-induced drought (Overton & Doody, 2013); Sprague River, USA, simulating future water quality under different scenarios of wetland loss using downscaling of climate models (Records et al., 2014); Hamoun Wetlands, Iran, demonstrating the integrated effects of unsustainable land use patterns and drought on wetland degradation (Maleki et al., 2019); and UK River Ecosystems, examining drying trends across temperate biomes and associated biodiversity losses from drought (Stubbington et al., 2024). These sites were assessed for hydrological sensitivity, environmental vulnerability, and governance institutions.

In the interest of objectivity, data were screened and coded for themes by two authors independently. Disagreements in inclusion and interpretation were addressed through cross-validation and discussion. Reviewing was undertaken with methodological transparency, empirical replicability, and geographic representation in mind.

Further, experiments with differing methodologies experimental, observational, and modeling were triangulated to support robust conclusions over spatial and temporal scales. Pluralistic method allowed for combining different datasets and analytical perspectives.

3. *DISCUSSION*

This review emphasizes the widespread and linked effects of climate change and drought on riverine and wetland ecosystems. The effects span physical, hydrological, chemical, ecological, and socio-economic domains, showing the complexity and vulnerability of these natural systems to increasing environmental stress.

An important consequence of long-term drought is the alteration of river morphology. Diminished streamflow reduces the potential for sediment transport, resulting in channel narrowing, deposition, and incision of the riverbed. Such alterations detrimentally affect habitat heterogeneity and reduce the structural complexity of aquatic habitats. Yellow River Basin long-term aridity has caused the river network to fragment and streamline, interrupting ecological connectivity and landscape function (Zhang et al., 2024). The morphological impacts are seen in other areas of drought as well, where channel instability and erosion are becoming increasingly intensified and periodic (Parasiewicz et al., 2019). At the same time, hydrological regimes are affected through decreased baseflows, decreased flood durations, and recharge cycle delays. These changes destabilize natural seasonal processes that regulate wetland flooding, aquatic migration, and vegetation succession. In the Polish Biebrza wetlands, for example, changes in flood timing and duration will change vegetation structure and nutrient processing with potential implications for changing rates of peat accumulation and long-term habitat reorganization (Mirosław-Świątek et al., 2020). In temperate countries such as the United Kingdom, the change from perennial to rivers that periodically experience dry periods is linked to a loss of biodiversity and concerns about some ecological systems nearing tipping points from which recovery is improbable (Stubbington et al., 2024). Secondly, droughts severely impair water quality. Low water levels combined with elevated temperatures cause the concentration of pollutants, decreased oxygenation, and greater risks of eutrophication and salinization. Rising temperature and decreasing precipitation in Iranian *wetlands are triggering increasing salinity, menacing aquatic productivity and species survival (Mirakbari & Ebrahimi-Khusfi, 2021). Modeling of the United States' Sprague River Basin suggests that future climatic conditions will intensify nutrient and sediment loading, especially when compounded with wetland loss (Records et al., 2014). Such qualitative changes lead to habitat loss and undermine the ability of wetlands to sustain essential ecosystem services such as water filtration, carbon sequestration, and nutrient cycling. Ecological effects of such changes are inextricably linked with socio-economic repercussions. Deteriorated rivers and wetlands shrink wildlife habitats, decrease the availability of freshwater resources, and disrupt fisheries-, agriculture-, and tourism-based livelihoods. In the Murray-Darling Basin of Australia, over-allocation and drought have led to degradation of Ramsar-listed wetlands, reduced species richness, and triggered competition for available water resources (Overton & Doody, 2013). In the Helmand Basin of Iran as well, desiccation of the Hamoun wetlands due to upstream water diversion and climate change-induced drought has triggered large-scale land abandonment, population displacement, and economic decline in the region (Maleki et al., 2019). These images show how easily hydrological and ecological degradation would translate into human exposure and political instability.*

To be able to respond to these challenges effectively, the application of adaptive management coupled with real-time observation is critical. Techniques involving MODIS-based remote sensing, NDVI time series analysis, and hydrological models like SWAT and NAM are becoming more commonly utilized to monitor vegetation stress, water surface area, and drought risk. Drought indices like SPEI and RDI provide forecast information that enables early action and resource planning. Research studies also corroborate the application of wetland reconnection projects, environmental flow management regimes, and controlled aquifer recharge as efficient approaches for building resilience in river and wetland ecosystems (Qi et al., 2020). Technology is not a sole solution. Increasing uncertainty associated with climatic effects demands a fundamental shift in ecosystem management from fixed conservation goals to adaptive and dynamic planning. Governance must incorporate resilience by adopting holistic models that reconcile ecological imperatives with human needs. Models like the Social-Ecological-Technical Systems (SETS) model offer state-of-the-art avenues for connecting scientific knowledge with adaptive policymaking and enhancing the resilience of both ecological and human systems to climatic uncertainty.

In conclusion, drought and climate change are reshaping the structural characteristics, flow regimes, and ecological health of river and wetland systems worldwide. Their impacts are intrinsically linked to social issues, which necessitate integrative, evidence-supported, and coordinated management strategies to secure freshwater ecosystems' future.

4. *Conclusion*

Climate change and rising droughts are exposing river and wetland ecosystems to profound and multiplex stressors. Evidence presented in this paper shows that impacts extend far beyond simple water loss they reshape river morphology, modify natural stream flows, degrade water quality, and diminish biodiversity and ecosystem function. Physical alterations such as cutting of the riverbed and channel narrowing reduce habitat complexity, but hydrological cycles that are disrupted reduce seasonal connectivity and result in wetland functional degradation. These physical and hydrological stresses are further accompanied by qualitative degradation of water quality such as increased salinity, nutrient deposition, and reduced oxygen levels.

The effects of such changes overflow into the human environment. They cascade through human systems, affecting agricultural productivity, water for drinking, and socio-economic stability particularly in those regions where societies are strongly dependent on freshwater ecosystems. China, Iran, Australia, Poland, and the UK are among the examples that river and wetland system deterioration is both an outcome and cause of broader environmental and governance challenges.

In view of these research findings, freshwater resource management needs to implement flexible, integrated, and anticipatory approaches as a matter of urgency. Integrating new technologies like remote sensing and hydrological modeling must be accompanied by participatory governance, restoration ecology, and policy re-engineering for the attainment of resilience. Ecosystem management plans must shift from a frozen, static past approach with established historic baselines to dynamic rather than models open to uncertainty, feedback loops, and long-term change.

Protecting rivers and wetlands from the increasing risks of climate change is not only an environmental imperative; rather, it is a primary step towards realizing ecological balance, economic prosperity, and social welfare in an increasingly dynamic globalized setting.

Future research should prioritize identifying ecological thresholds beyond which river and wetland systems may not recover, particularly under compounding pressures from drought and climate change. Quantifying these tipping points across different hydrological and ecological contexts will help guide early intervention strategies. At the same time, there is a growing need to integrate socio-hydrological models that capture the dynamic interplay between human behavior, water governance, and ecosystem responses. This would allow for more accurate predictions of how communities and water systems co-adapt under stress.

Long-term, high-resolution monitoring of river morphology using advanced remote sensing and in-situ surveys should be expanded to detect subtle yet critical changes in channel structure and sediment dynamics. In parallel, empirical assessments of adaptive water management practices—such as environmental flow releases, floodplain reconnection, and wetland restoration—are needed to evaluate their real-world effectiveness across diverse climatic and socio-economic settings.

Future studies must also explore the interaction between climate change and other environmental stressors such as pollution, invasive species, and land-use change. Modeling should move beyond mean climatic trends to simulate the impact of extreme events, including megadroughts and flash floods, on ecosystem structure and function. In terms of biodiversity, there is a need for more comprehensive investigations that span multiple trophic levels, incorporating responses of microbial communities, vegetation, birds, and mammals in addition to aquatic fauna.

Research should also consider the evolving trade-offs among ecosystem services, particularly how drought reshapes the balance between ecological integrity and resource demands such as agriculture and water supply. Testing nature-based solutions, including wetland buffers and reforestation projects, at landscape scales will be essential for validating their hydrological and ecological benefits. Finally, incorporating Indigenous and local knowledge systems into scientific frameworks can enrich understanding of ecosystem resilience and support culturally informed conservation practices.

REFERENCES

[1] *Harrison, P. A., Berry, P. M., Henriques, C., & Holman, I. P. (2008). Impacts of socio-economic and climate change scenarios on wetlands: Linking water resource and biodiversity meta-models. Climatic Change, 90(1–2), 113–139.*

[2] *Maleki, S., Koupaei, S. S., Soffianian, A., Saatchi, S., Pourmanafi, S., & Rahdari, V. (2019). Human and climate effects on the Hamoun wetlands. Weather, Climate, and Society.*

[3] *Mirakbari, M., & Ebrahimi-Khusfi, Z. (2021). Evaluation of the climate change effects on the future drought characteristics of Iranian wetlands. Arabian Journal of Geosciences, 14.*

[4] *Mirosław-Świątek, D., Marcinkowski, P., Kochanek, K., & Wassen, M. (2020). The impact of climate change on flow conditions and wetland ecosystems in the Lower Biebrza River (Poland). PeerJ, 8, e9778.*

[5] *Overton, I., & Doody, T. (2013). The River Murray-Darling Basin: Ecosystem response to drought and climate change. Drought in Arid and Semi-Arid Regions, pp. 217–234.*

[6] *Parasiewicz, P., King, E., Webb, J., Piniewski, M., Comoglio, C., Wolter, C., Buijse, A. D., Bjerklie, D., Vezza, P., Melcher, A., & Suska, K. (2019). The role of floods and droughts on riverine ecosystems under a changing climate. Fisheries Management and Ecology.*

[7] *Qi, P., Xu, Y., & Wang, G. (2020). Quantifying the individual contributions of climate change, dam construction, and land use/land cover change to hydrological drought in a marshy river. Sustainability, 12(9), 3777.*

[8] *Quijano, J., Carlier, R., Rodríguez Rodríguez, J. R., Sandi, S., Saco, P., Wen, L., & Kuczera, G. (2022). And we thought the Millennium Drought was bad: Assessing climate variability and change impacts on an Australian dryland wetland using an ecohydrologic emulator. Water Research, 218, 118487.*

[9] *Records, R., Arabi, M., Fassnacht, S., Duffy, W., Ahmadi, M., & Hegewisch, K. (2014). Climate change and wetland loss impacts on a western river's water quality. Hydrology and Earth System*

Sciences, 18(11), 4509–4527.

[10] *Stubbington, R., England, J., Sarremejane, R., Watts, G., & Wood, P. J. (2024). The effects of drought on biodiversity in UK river ecosystems: Drying rivers in a wet country. WIREs Water.*

[11] *Wolff, E., & van Vliet, M. T. H. (2021). Impact of the 2018 drought on pharmaceutical concentrations and general water quality of the Rhine and Meuse rivers. Science of the Total Environment, 778, 146182.*

[12] *Zaki, N. A., Torabi Haghighi, A., Rossi, P., Tourian, M., Bakhshaee, A., & Kløve, B. (2020). Evaluating impacts of irrigation and drought on river, groundwater and a terminal wetland in the Zayanderud Basin, Iran. Water, 12(5), 1302.*

[13] *Zwolsman, J., & van Bokhoven, A. J. (2007). Impact of summer droughts on water quality of the Rhine River a preview of climate change? Water Science and Technology, 56(4), 45–55.*