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Interplay of climate change, policy, and human behavior in lake basins: identifying key factors and future climate hotspots (case study: Urmia lake basin, Iran)

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Highlights

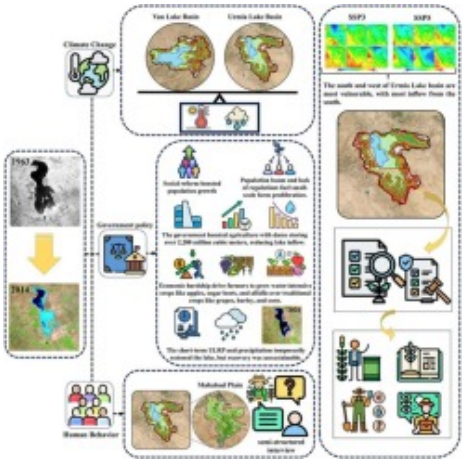
- **Climate change and policy interplay**: The study explores how climate change, policies, and human behavior interact to influence lake basin ecosystems.
- **Case study of Urmia Lake Basin**: The analysis identifies critical socio-environmental factors contributing to the lake's environmental degradation.
- **Key factors affecting basin sustainability**: Climate variability, agricultural practices, and ineffective water management emerge as major contributors to ecosystem stress.
- **Future climate hotspots**: The study identifies regions in the Urmia Lake Basin most vulnerable to future climate risks.

- **Policy recommendations**: Provides actionable strategies for sustainable water resource management, emphasizing integrated policy and behavioral changes.

Abstract

Climate change, government policy and human behavior pose unprecedented challenges to the sustainability of lakes worldwide, necessitating a nuanced understanding of their ecosystem impacts. This study focuses on Lake Urmia as a case study, unraveling the complex interplay between climate change, management strategies, and local farmer behaviors in shaping the lake's fate. Through comparative analysis with Van Lake in Turkey, we identify anthropogenic drought as a key driver of Lake Urmia's shrinkage, underscoring the need for proactive policy interventions. First, climate change in the region is measured using high-resolution climate data derived from five Earth System Models (ESMs) from the Coupled Model Intercomparison Project Phase 6 (CMIP6) analyzing c20 dimensions (5 indicators x 4 seasons) for each grid cell to identify Climate Change Hotspots (CCHs) and assess their potential impact on the Urmia and Van Lake basins. Second, semi-structured interviews and thematic analysis reveals the economic priorities of farmers in the Mahabad plains region, representing farmers in the basin, and highlighting a critical gap in water conservation attitudes. Our findings advocate for government intervention in promoting crops with low water needs and incentivizing sustainable water management practices. Additionally, we identify climate change hotspots in the Urmia Lake basin, providing vital insights for policymakers to prioritize mitigation measures. We propose targeted information campaigns and workshops to foster environmental responsibility among farmers, particularly in vulnerable regions. Ultimately, this study advocates for a comprehensive approach to sustainable water management, offering valuable lessons for preserving fragile ecosystems like Lake Urmia in the face of climate change

Graphical abstract



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Introduction

Lake Urmia in Iran, once the largest hypersaline lake in the Middle East, exceeding 5,000 km^2 in surface area, has experienced a dramatic decline over the past two decades, shrinking by 60 %. While historical estimates showed an 8-meter drop in water level since 1995 (Shadkam, 2017), recent observations indicate that the lake has now reached critically low depths, exacerbating the environmental crisis. This crisis mirrors a global pattern of shrinking water bodies, posing significant challenges to the sustainability of aquatic ecosystems (Karimi & Pareeth, 2019). Unraveling the primary factors behind Lake Urmia's deterioration is critical not only for its restoration but also for informing conservation efforts for threatened water bodies worldwide.

Understanding the complex interplay between climate change, policy decisions, and human behavior is essential for developing effective restoration strategies for Lake Urmia and similar ecosystems. Unsustainable human behavior, driven by perceptions rather than realities, is a recognized driver of environmental degradation (Vlek et al., 2007). Analyzing these perceptions, particularly regarding water value and consumption, is key to advancing conservation efforts. Frameworks like Social Ecological Systems (SES) (Ostrom, 2009) and socio-hydrology (Sivapalan et al., 2011) offer valuable tools for examining these interactions, but they often fall short of capturing the full complexity of water management issues, particularly in regions like the Urmia Lake Basin (ULB).

While behavioral models such as the Theory of Planned Behavior (TPB) have been widely applied in environmental contexts (Ajzen, 1991, Castillo et al., 2021), their direct application in regions like the Urmia Lake Basin (ULB) may not fully capture the complexity of decision-making. Farmers' choices in this region are influenced not only by individual attitudes and perceptions (as TPB suggests), but also by collective norms, institutional ambiguity, and limited access to resources—factors that often fall outside the scope of TPB's structured constructs (e.g., perceived behavioral control). Similarly,

Social-Ecological Systems (SES) framework offers a useful conceptual lens for examining governance, resource use, and feedback loops (Ostrom, 2009), yet its application remains largely theoretical in the ULB due to fragmented authority and lack of cross-scale coordination (Madani, 2014). Therefore, while TPB and SES shed light on behavioral dimensions, their integration with system-level modeling remains limited.

Bridging this gap requires combining insights from social sciences with quantitative, resilience-based analyses of water systems. Several recent studies have attempted this by evaluating lake restoration under climate and human pressures through multi-criteria frameworks, simulation-based modeling (e.g., SWAT-MODSIM), and stakeholder-driven optimization. Techniques such as the Evidential Reasoning (ER) approach and hierarchical game-theoretic modeling have been used to handle uncertainties in both environmental dynamics and institutional behavior (Behboudian et al., 2023, Behboudian et al., 2024, Motlaghzadeh et al., 2023, Pourmoghim et al., 2022). These studies highlight the value of integrated approaches that align technical modeling with socio-political realities. However, in addition to macro-level optimization, it remains essential to understand how micro-level behavioral factors—such as farmers' perceptions, risk tolerance, and economic conditions—shape real-world water use in fragile basins like Urmia(Lalani et al., 2016, Mahdavi, 2021, Yazdanpanah et al., 2014).

The challenges faced by Lake Urmia are not unique. Similar issues afflict terminal lakes worldwide, such as Lake Chad and the Aral Sea, underscoring the global reach of human impacts on aquatic ecosystems. This study focuses on agricultural practices, which account for nearly 90% of water consumption in the Urmia Lake Basin (Farahmand et al., 2025, Pouladi et al., 2019, Schulz et al., 2020). Farmers' decisions directly affect water use, making it imperative to understand their actions and attitudes towards conservation (Jalilvand et al., 2019, Jalilvand et al., 2021, Jalilvand et al., 2023). By examining the complex interplay between human behavior and water resources through a socio-hydrological lens, this study seeks to develop a comprehensive framework for future policies addressing the challenges posed by climate change and human activities in the Urmia Lake Basin.

This study makes a novel contribution by integrating CMIP6-based climate scenario projections with granular, farm-level behavioral data—a combination rarely seen in studies of terminal lake basins. This dual-scale approach bridges long-term, global-scale climate modeling with short-term, on-the-ground decision-making by water users. Such integration is particularly rare and valuable in regions like Iran, where institutional fragmentation, limited behavioral datasets, and the challenges of water governance under international sanctions make data-driven planning difficult. By synthesizing climate trajectories with human behavioral patterns, our framework provides a more grounded understanding of how fragile socio-ecological systems—such as the Urmia Lake Basin—can adapt under combined environmental and policy pressures. This research also considers the case of Van Lake in Turkey, located in close proximity to Lake Urmia, as a critical point of comparison. By analyzing the similarities and differences between these two basins, this study will provide insights into the broader implications of human behavior and policy decisions on water

management in similar regions. Ultimately, the findings of this study aim to inform the development of more effective, context-specific strategies for the sustainable management of lake basins, with particular emphasis on mitigating the impacts of climate change and promoting environmental stewardship among local communities.

Section snippets

Study area

The Urmia Lake Basin (ULB) and Van Lake Basin (VLB), both endorheic basins located less than 200 km apart in northwestern Iran and eastern Turkey (Fig. 1), exhibit notable differences despite their proximity. The ULB features a flatter topography, while the VLB's landscape is more diverse, with mountains and lowlands that likely influence precipitation and water flow dynamics (Nikraftar et al., 2021). Around 30 years ago, Urmia Lake had a shallow depth ranging from 2 to 16 m, averaging about …

Climate change Hot Spot

To assess potential climate change impacts on the Urmia Lake Basin, this study utilizes high-resolution climate data from the NASA Earth Exchange Global Daily Downscaled Projections (NEX-GDDP) dataset (Thrasher et al., 2022). NEX-GDDP offers a significant advantage over traditional General Circulation Models (GCMs) by employing a finer spatial resolution (0.25 degrees by 0.25 degrees) compared to the coarser grids used in many GCMs. This enhanced resolution allows for a more detailed …

Climate change impact on the past

To assess the historical impact of climate change on the Urmia Lake Basin, we employed five Earth System Models (ESMs) from the Coupled Model Intercomparison Project Phase 6 (CMIP6) archive: CanESM5, CESM2, MRI-ESM2-0, NorESM2-MM, and UKESM1-0-LL. These models simulated climate change across six historical periods (1960–1969, 1970–1979, 1980–1989, 1990–1999, 2000–2009) with a baseline of 1950–1959. Detailed results are presented in Fig. 4, with seasonal breakdowns available in the Appendix.

To …

Survey results

To understand farmer behavior and its influence on water resource management in the Urmia Lake Basin, we conducted a survey among 148 male farmers. This sample reflects the region's cultural

norms that limit female participation in the workforce. The respondents' age distribution is detailed in the Fig. 11, with an average age of 49.8 years. Notably, the largest group of respondents (nearly 61 %) falls within the 40–50-year-old age range. A summary of key structural insights from the interviews …

Future Hot Spot climate change in Urmia Lake Basin

Given the unique socio-economic conditions of the Urmia Lake basin, characterized by a surge in population growth and industrialization, it is crucial to select scenarios that align with these dynamics. This growth, common among developing nations, has often been prioritized over environmental sustainability, leading to significant challenges in water management, including resource scarcity and competition. The future trajectory of the region, underscored by government policies in Iran, appears …

Conclusion

In conclusion, this study has examined the complex interplay between climate change, management strategies, and local communities, using Lake Urmia as a case study. The methodological contribution of this study lies in its integrative design—linking CMIP6 climate scenario modeling with detailed behavioral data from 148 farmers in a water-stressed basin. While such approaches are emerging globally, they remain underutilized in regions like Iran, where behavioral data scarcity, fragmented …

CRediT authorship contribution statement

Mohammad Reza Mohammadi: Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Resources, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Razieh Taraghi Delgarm:** Writing – review & editing, Validation, Formal analysis, Data curation. **Hamid Farahmand:** Writing – review & editing, Investigation, Data curation. **Zahir Nikraftar:** Writing – review & editing, Formal analysis. **Sahar Badiezadeh:** Writing – review & editing, Investigation. …

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. …

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Climate scenarios used were from the NEX-GDDP-CMIP6 dataset, prepared by the Climate Analytics Group and NASA Ames Research Center using the NASA Earth Exchange and distributed by the NASA

Center for Climate Simulation (NCCS). …

Availability of data and material

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request. …

Code availability

Applicable. …

Authors' contributions

All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed …

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