DYNAMICS OF EXPECTATIONS, (DIS)SATISFACTION, AND PARTICIPATION IN CHANGING STATES OF WATER GOVERNANCE SYSTEMS

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Study aim

A system is a set of interconnected elements organized to achieve a specific purpose. It comprises components such as elements (or participants), their interrelationships, a function or purpose, boundaries, and inputs and outputs. In the context of water governance, the system consists of participants who govern water within their jurisdictions, each pursuing specific purposes tied to desired outcomes. These objectives ultimately shape participants' expectations, and interactions within the system in relation to water demand and supply.

The purpose of this work is to assess how the state of the water (demand-supply) governance system changes based on participants' expectations about water supply, which influence their interactions—particularly in terms of the number of participants and interaction patterns. This dynamic is captured and analyzed using a theoretical metric: the Hamiltonian system cost.

Methodology : CONCEPTUAL SCHEME OF THE FRAMEWORK

1. EXPLORE

Backchannel promoters
Political, Economic, Ideological, etc.

Anthropogenic factors
Spatial/Jurisdictional Boundaries
Governance Protocols/Regulatory Directives

Biophysical factors
The Basin Boundary/Water Availability & Accessibility

2. IDENTIFY

Objectives
Mechanisms
System Framework Development
Policy Shaping
Developing Expectations

3. DISTINGUISH

Institutional Interaction Rules

Water Allocation Policy

4. DRIVE/MODEL

Compromising parameter
Non-adaptive/unfit governance systems; Elevated demand and supply levels

Enhancing parameter
Adaptive governance systems; Rationalized demand and supply levels

Demand-Supply Interactions

Structural reforms	Hydrovolume fluctuations
Interaction structure change Vertical alternations Horizontal variations	Change in water demand and supply amounts

5. MEASURE

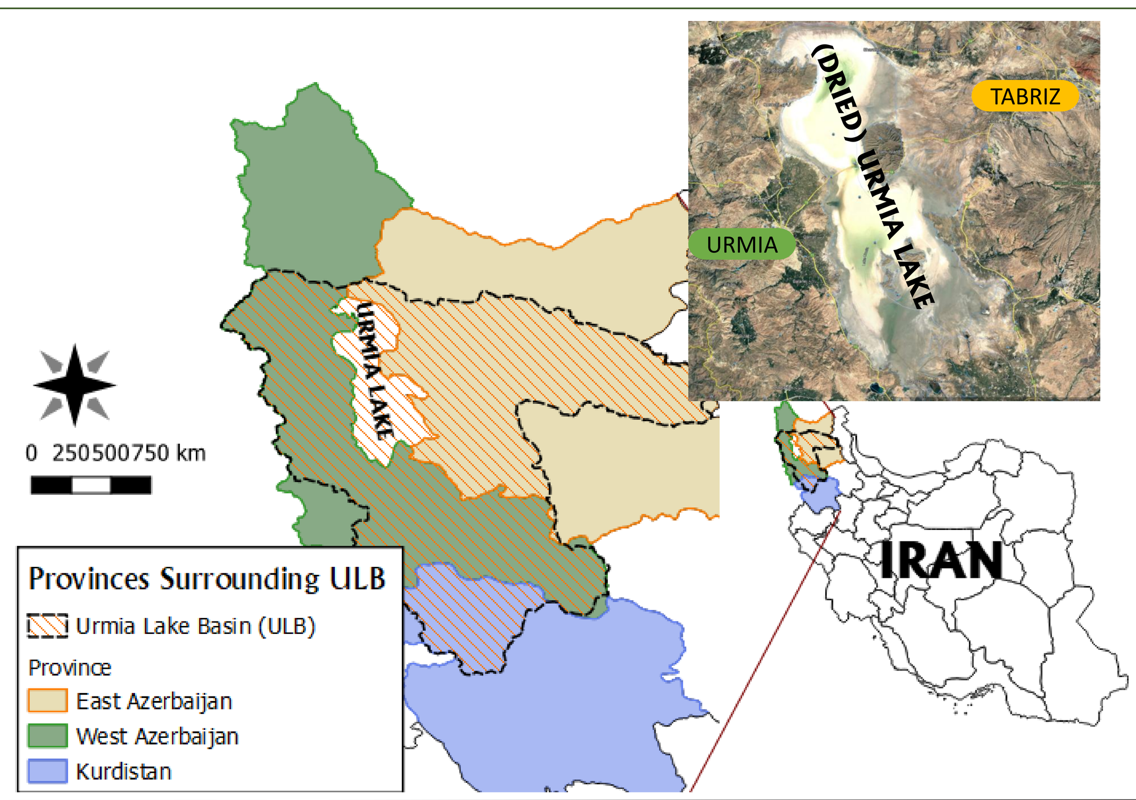
Outcomes
System & Individual level (costs) [1]

The **Hamiltonian** cost represents the aggregate of kinetic and potential components that influence the dynamic behavior of the governance system [1].
The **formulation** of the Hamiltonian cost function needs to be adapted to the specific characteristics of the context.

Case study

Urmia Lake—the world's second-largest hypersaline lake before it started drying up—is an endorheic lake, a UNESCO-protected biosphere and a recognized wetland under the Ramsar Convention

The study area (spatial scale level): **Urmia Lake Basin** (ULB);
The basin is surrounded by the three Iranian provinces:
East Azerbaijan: yellow,
West Azerbaijan: Green, and
Kurdistan: blue



Scenarios

Participants - INTERACTION

Rules of interaction for water supply and demand are aligned with political-administrative objectives

(i) the local entities can almost never interact with each other

(ii) In each province, every local entity can interact with its respective headquarters — the central administrative offices located in the provincial capitals

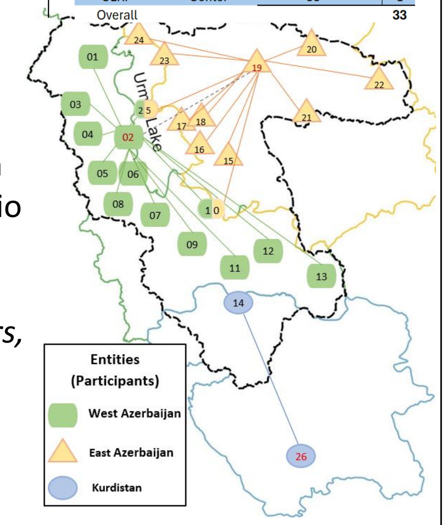
The **interaction scenarios** related to governance structures:

1. The basin is shared between the two provinces of West and East Azerbaijan, and the only entity from Kurdistan Province within the ULB was reasonably assumed to interact with the team from West Azerbaijan Province
2. The basin is shared among the three provinces of West Azerbaijan, East Azerbaijan, and Kurdistan (real case)
3. The Urmia Lake Restoration Program (ULRP), serving as an overarching authority, is incorporated into the first scenario
4. The ULRP is incorporated into the second scenario

Institutionally, the ULRP was situated above the headquarters, and

(iii) based on the administrative hierarchy, only the headquarters—and not the local utilities—were allowed to interact directly with the ULRP' representatives [2]

		Participant	Total
Local entities	West Azerbaijan	1-9, 10w, 11-13, 25w	14
Local entities	East Azerbaijan	10e, 15-24, 25e	12
Local entities	Kurdistan	14	1
Headquarters	West Azerbaijan	2*	1
Headquarters	East Azerbaijan	19*	1
Headquarters	Kurdistan	26*	1
ULRP	West Azerbaijan	31**	1
ULRP	East Azerbaijan	32**	1
ULRP	Center	33**	1
Overall			33



Expectation - PARTICIPATION

Drawing on data from the Ministry of Energy (MOE, 2014) [3], and considering supply levels relative to demand in the drinking water sector across distinct zones of the basin, four **supply expectation scenarios** were established;

The participant is satisfied and willing to engage in system interactions upon receiving at least:

1. 65% of their demand.
2. 80% of their demand.
3. 90% of their demand.
4. 95% of their demand.

In any given scenario, if a participant (local entity) does not receive their expected supply amount, they become dissatisfied and withdraw from the system.

Mathematical model – Hamiltonian Cost Function

The Hamiltonian of a water demand-supply governance system can be formulated based on the system's total force, comprising:

- kinetic presence—arising from the dynamic interactions (J) characterized by the rates of water demand and supply;
- and latent potential—stemming from external forces (h) defined by the system's interaction rule (Equations 1-3) [1].

We assume that the interacting system of participants (entities, $i = 1, \ldots, N$) can be generally Hamiltonized, with uniformly distributed binary random spins (e.g. $(\sigma = (-1,1))$) governed by predefined interaction rules, as**.**

$$H_N(\sigma) = -\frac{J}{2N}\sum_{i,j=1}^{N}\sigma_i\sigma_j - h\sum_{i=1}^{N}\sigma_i \quad (1)$$

The interested mean-field approximation by Curie-Weiss can be summarized as follows:

$$H_N(\sigma) = -N\left(\frac{1}{2}\sum_{i,j=1}^{N}\alpha_i\alpha_j J_{ij} m_i m_j + \sum_{i=1}^{N}\alpha_i h_i m_i\right) \quad (2)$$

The magnetization of the binary configuration—representing the average group trait in a social community—is defined by $\boldsymbol{m_N}(\boldsymbol{\sigma}) = \frac{1}{N}\sum_{i=1}^{N}\boldsymbol{\sigma_i}$, and it is meaningfully related to the proportional size of the corresponding subset, denoted as $\boldsymbol{\alpha_k} = \frac{N_k}{N}$ ($\boldsymbol{k}$ is the number of sets).

Additionally, the effect of exogenous factors on interactions can be quantified as the abstract of external forces

$$h_i = tanh^{-1}(m_i) - \sum_{j=1}^{N}\alpha_j(J_{ij})m_j \quad (3)$$

Results

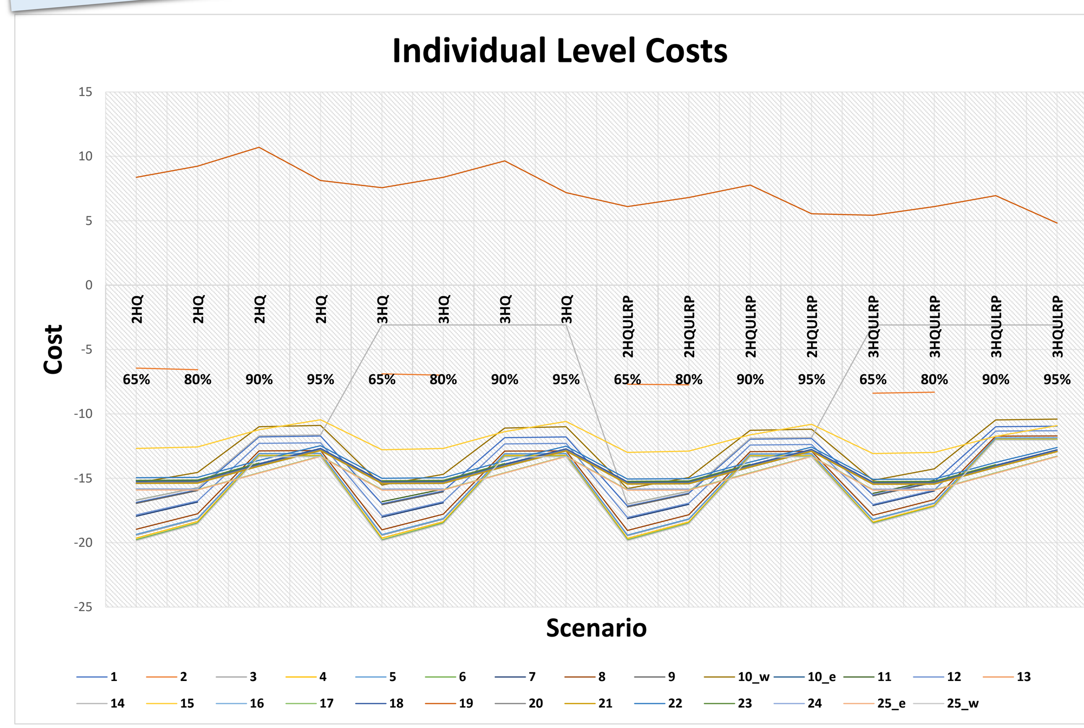


Figure 1: Costs incurred by local entities across three provinces within the ULB under various scenarios, with costs differentiated by color. 'HQ' denotes headquarters; 'HQULRP' refers to ULRP-based scenarios

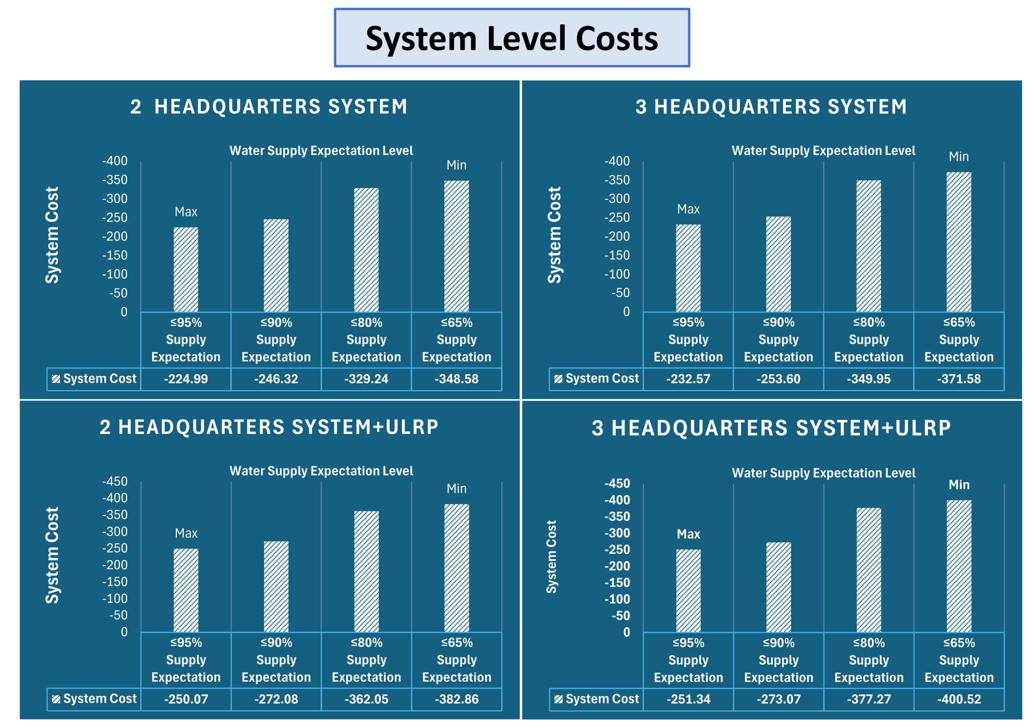


Figure 2: Total costs associated with the governance system across different scenarios.

Discussion

Individual-level Analysis

The capital of the Eastern Province (Entity 19) is not aligned with the water demand and supply patterns observed in other participants within the system, and its interactions exceed the system's capacity. This indicates that none of the examined governance models can adequately meet this entity's water supply needs with the currently available and allocated resources.

The capital of the Western group (Entity 2) tends to withdraw from the system when water supply expectations reach or exceed 90%. This trend highlights a structural decline within its regional subsystem. Interestingly, at lower supply expectation levels (65% and 80%), integrating the overarching system (ULRP) in the water governance system reduces the costs for these entities (19 & 2).

Other entities in both Eastern and Western groups generally display cost patterns directly related to their supply expectations. Lower expectations, accompanied by a larger number of participating entities, result in decreased individual costs. However, as entities in the Western group begin withdrawing from the system (starting at the 80% expectation level with Entity 13 and accelerating significantly at the 90% level, where four additional entities exit), the costs for the remaining entities sharply increase. After this point (90% to 95%), participant numbers stabilize, and costs remain relatively unchanged within the Western subsystem.

In the Eastern group, the withdrawal of entities is less severe, with only one participant exiting at the 90% level (Entity 23) and another at 95% (Entity 24). Notably, participant numbers at these higher expectation levels significantly influence competitive dynamics. At 90% expectation, the Western group reduces sharply to 11 entities, whereas the Eastern group remains relatively stable with 12 entities, resulting in higher average costs for the Western group. At the 95% expectation level, both groups stabilize at an equal number of entities (11), leading to similar interaction costs across both sets.

Regarding Entity 14—the sole participant from Kurdistan Province (Southern group)—it is evident that its costs rise significantly when the basin governance structure involves coordination across three separate provinces. Although geographically located within the basin, Entity 14 incurs additional administrative costs by coordinating with headquarters situated outside the basin boundaries. Conversely, when Entity 14 is administratively reassigned to the Western Province group, its costs notably decrease, especially when the ULRP framework is integrated into the governance model.

System-level Analysis

In the system-level analysis, it was observed that the system cost decreased when water supply expectations were lowered and participant satisfaction increased. However, the system cost exhibited a notable rising trend once water supply expectations exceeded 80%, causing dissatisfaction among five entities (four from the Western group and one from the Eastern group), each having at least a 90% supply expectation relative to their demand, leading them to withdraw from the system. Specifically, the two-headquarters system at the 95% supply expectation level, which had the minimum number of participants (22), demonstrated the highest overall system cost. Conversely, the three-headquarters system integrated with the ULRP institutions, encompassing 33 participants at the lowest supply expectation level (65%), exhibited the lowest system cost across all examined scenarios.

Conclusion and limitation:

- The overall system cost is strongly influenced by participants' expectations, their levels of (dis)satisfaction, and the extent of their participation.
- When political boundaries don't align with hydrological systems, local entities may face higher costs due to the need to coordinate with administrative centers located outside the basin.
- Institutional reforms that better align governance structures with natural systems, by fostering more effective participant interactions, can reduce overall system costs.
- A decline in participation—often driven by rising expectations and growing (dis)satisfaction—results in higher costs for the system and places a greater burden on the remaining participants.
- The proposed framework is adaptable and can be tailored to various contexts, provided case-specific conditions and provisions are considered.
- The current analysis was limited to a single-year snapshot due to data availability, providing only a static view of the system and the state of local entities under given scenarios.

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[3] MOE (Iran Ministry of Energy), Deputy of Water and Wastewater, Macro Planning Bureau, 2014. The National Water Master Plan Study: volumes 31–37, 5th Package- Analysis of Developmental Requirements Deployment in Urmia Lake Basin. Report Number: 2385070–2050-24142. (In Persian). Physical Copy Only