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Transitioning from command-and-control measures to market-based mechanisms for sustainable groundwater governance in hyper-arid regions

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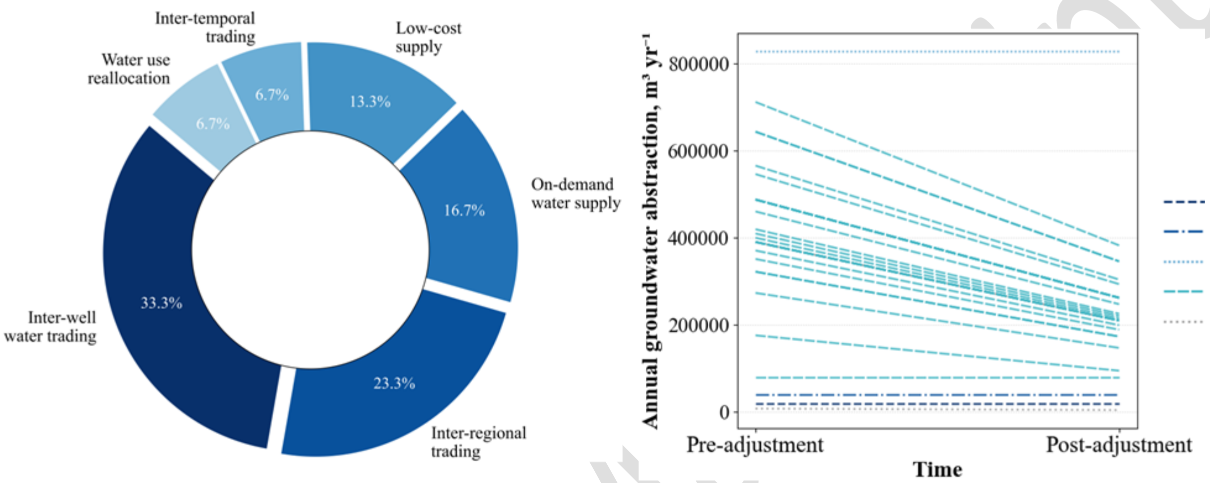
GRAPHICAL ABSTRACT



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ABSTRACT

Despite concerted efforts to stabilize groundwater levels in arid regions through engineering interventions, aquifer depletion remains a critical challenge, often exacerbated by a disconnect between rigid top-down policies and local socio-economic realities. This study presents a forensic hydro-institutional analysis of the restoration and balancing plan in the hyper-arid Boshruyeh Plain, Iran, to evaluate the efficacy of technical controls versus economic instruments. By integrating a 27-year hydro-physical time series (1995–2023) with a tripartite stakeholder analysis (farmers, executive experts, and academic elites), the research reveals a complex paradox. Hydrological results indicate that while the implementation of smart metering post-2014 successfully induced a structural break in abstraction trends and enforced regulatory compliance, it failed to arrest the chronic annual deficit of ~62 MCM. Socio-institutional analysis exposes a significant perception gap; while academic elites emphasize participatory governance, executive experts identify technical and cultural barriers as primary causes of policy failure. However, a strategic consensus was found regarding the potential of water markets. Contrasting with common assumptions of resistance, 89% of farmers expressed willingness to participate in a regulated market, driven primarily by the need for operational flexibility and drought risk management rather than profit maximization. The study concludes that sustainable aquifer restoration requires a paradigm shift from a purely police-patrol model to a cap-and-trade system, utilizing existing metering infrastructure to facilitate inter-temporal water banking and cross-sectoral reallocation.

1. Introduction

Despite concerted global efforts to stabilize groundwater levels, hydrological evidence increasingly indicates that the prevailing paradigm of engineering solutions and infrastructure-centric management has failed to arrest the declining trends of strategic aquifer reserves, particularly in arid and semi-arid regions (Akbarpour *et al.* 2024). This unidimensional approach, which predominantly relies on control mechanisms such as the installation of smart meters and the sealing of unauthorized wells, often overlooks the socio-economic complexities and the subsistence economy of stakeholders. Consequently, this has led to the phenomenon of policy failure in many critically depleted plains across Iran (Samani, 2021; Shamshirgaran *et al.* 2025).

Reducing the water crisis to a purely technical issue has resulted in the neglect of motivational dimensions and voluntary stakeholder participation, creating a profound chasm between the governmental goals of aquifer restoration and field realities (Howell *et al.* 2023). By

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ignoring power structures and social intricacies at the micro-level, this top-down approach frequently leads to symbolic participation and the failure of developmental interventions in managing common-pool resources (Shen & Wang, 2023). Therefore, modern water governance literature emphasizes the necessity of transitioning from reactive and command-and-control management to a multi-faceted framework that integrates ecological, financial, and social dimensions as the pillars of sustainability (Han *et al.* 2024).

In such a paradigm, the utilization of economic regulatory tools, specifically water markets, plays a pivotal role (Tosan *et al.* 2026a). These markets function not only as a mechanism for optimal allocation based on the relative value of usage but also as a catalyst for behavioral change among stakeholders, linking hydrological sustainability with social equity and economic efficiency (Ortiz-Partida *et al.* 2023; Ortiz-Partida *et al.* 2026).

A review of global experiences reveals that traditional approaches to groundwater management have encountered numerous dead ends. (Howell *et al.* 2023; Tosan *et al.* 2026b), in their study on stakeholder engagement in Azerbaijan, concluded that despite governmental modernization efforts, a deep gap persists in stakeholder perception; institutional biases within the government hinder a genuine understanding of participation challenges, thereby exacerbating the divide between policy and practice. This necessity to rethink governance structures is also highlighted by (Shunglu *et al.* 2022), who criticized socio-technical approaches and found that ignoring local power structures reduces management programs to mere formalities.

At a deeper level, emerging literature underscores the inextricable link between social and hydrological systems. Studies by (Prakash *et al.* 2025) demonstrate that in water-stressed regions, adaptive governance is achievable only through understanding the intersection of human behavior, cultural norms, and hydrological processes. Furthermore, (De Angeli *et al.* 2024) emphasize that drought assessment must transcend disciplinary boundaries and move towards the co-creation of knowledge with end-users.

In response to these challenges, a shift in allocation tools and the adoption of economic incentives has become imperative. (Han *et al.* 2024) concluded that focusing solely on efficiency without considering the multiple values of water jeopardizes sustainability. Regarding operational solutions, (Wheeler, 2021), through a comprehensive analysis of 20 countries, demonstrated that the success of water markets depends on the correct sequencing of reforms, including establishing extraction caps and precise water accounting. However, (Ortiz-Partida *et al.* 2023) warn that even the most advanced hydro-economic models cannot offer sustainable solutions for groundwater management if they ignore social justice components and stakeholder preferences.

Against this background, the primary objective of the present study is a multi-faceted analysis of the inhibitory challenges facing the implementation of the Aquifer Restoration and Balancing Plan in the Boshruyeh Plain, Iran, and to explicate the potential of a water market as an economic regulatory tool to mitigate conflicts among stakeholders. This research aims to identify the gap between mandatory government policies and the socio-economic realities of the region by integrating rigorous hydrological evidence (trends in aquifer level changes) with a systematic analysis of the perceptions of three distinct stakeholder groups: farmers, executive experts, and academic elites. By identifying the structural, legal, and behavioral barriers to restoration, this study evaluates the water market not only as a means to improve allocation efficiency but also as a flexible mechanism to resolve conflicts of interest and ensure the hydrological sustainability of the Boshruyeh Plain under critical conditions.

2. Materials and methods

2.1. Study area and hydro-climatic setting

The research was conducted in the Boshruyeh Plain, an arid region covering approximately 790,000 hectares in eastern Iran (South Khorasan Province), characterized by a hyper-arid climate according to the De Martonne classification (Fig. 1). The main alluvial aquifer, spanning 620 km², serves as the sole freshwater source for the region's agricultural-dependent economy (Rezvani Moghaddam *et al.* 2016). The main crops cultivated in this plain include pistachios (dominant orchard crop), cotton, barley, and wheat, all of which are salt-tolerant and well-adapted to the region's high groundwater salinity. The aquifer system is under severe hydraulic stress, with the piezometric head exhibiting a continuous decline ranging from 13 m in the southern discharge zones to over 100 m in the northern recharge areas (Tosan *et al.* 2024). To quantify the hydro-climatic stress, the general aquifer budget equation was utilized to characterize the baseline conditions. The groundwater volume change (∆S) over the hydrological year was conceptualized as:

$$\Delta S = \left(R_{rf} + R_{ir} + Q_{in}\right) - \left(E_{gw} + Q_{out} + Q_p\right) \quad (1)$$

where, R_{rf} and R_{ir} represent recharge from rainfall and irrigation return flows, Q_{in} and Q_{out} denote lateral subsurface inflow and outflow, E_{gw} is evapotranspiration from the water table, and Q_p signifies the total groundwater pumping (abstraction) (Voudouris, 2006; Nourani *et al.* 2025a). Empirical data from the Regional Water Company indicate a chronic deficit, where Q_p ~ 87 MCM (Million Cubic Meters) (predominantly agricultural), far exceeding the natural recharge rate, resulting in an annual deficit of ∆S ~ -62 MCM. This imbalance has elevated the electrical conductivity (EC) to over 6000 µS/cm in critical zones, rendering the plain a representative case study for analyzing water markets under extreme scarcity.

2.2. Hydro-physical data analysis

To evaluate the efficacy of the restoration and balancing plan, a long-term time-series analysis (1995–2023) was performed on groundwater level data derived from a network of observation wells. The unit hydrograph of the plain was reconstructed to calculate the cumulative volume deficit. The spatiotemporal variation of the groundwater table was analyzed using the Thiessen polygon method to assign representative areas to each piezometer (**Fig. 2**) (Masoumi *et al.* 2019; Nourani *et al.* 2025b). The weighted average water level (Havg) for the entire aquifer was calculated as:

$$H_{avg} = \frac{\sum_{i=1}^{n}(A_i \times h_i)}{A_{total}} \quad (2)$$

Where Ai is the area of the Thiessen polygon associated with piezometer i, hi is the observed water level, and Atotal is the total aquifer area. Furthermore, the discrepancy between allocated volume (Valloc) and actual abstraction (Vactual) was examined for 200 agricultural wells equipped with smart counters to assess regulatory compliance.

2.3. Socio-hydrological survey design

A mixed-method approach was employed to capture the human-water interactions. Three distinct stakeholder groups were targeted: (1) Farmers (End-users), (2) Executive Experts (Gov. agencies), and (3) Academic Elites.

2.3.1. Instrument development and validation

Data collection utilized semi-structured questionnaires tailored to each group's role in the water governance hierarchy. The instrument measured constructs such as policy effectiveness, Institutional trust, and willingness to participate in water markets using a 5-point Likert scale. Questionnaires were distributed using two modes based on the stakeholder group: (i) self-administered questionnaires for Experts & academics, who completed them independently; (ii) face-to-face semi-structured interviews for farmers to capture qualitative insights into informal water market mechanisms. The survey was conducted during two periods: October–December 2024 and 2025.To ensure the internal consistency of the constructs, Cronbach's Alpha coefficient (α) was calculated for each section of the questionnaire using the following equation (Taber, 2018):

$$\alpha = \frac{K}{K-1}\left(1 - \frac{\sum_{i=1}^{K}\sigma_{Y_i}^2}{\sigma_X^2}\right) \quad (3)$$

where, K is the number of items, $\sigma_{Y_i}^2$ is the variance of the i-th item, and σ_X^2 is the variance of the observed total test scores. An $\alpha \geq 0.7$ was considered the threshold for acceptable reliability.

2.3.2. Sampling strategy

Given the specialized nature of the inquiry, a purposive non-probability sampling method was adopted for the expert and academic groups. A total of 79 questionnaires were distributed, yielding 51 valid responses (64.5% response rate). For the farming community, 30 in-depth semi-structured interviews were conducted to capture qualitative insights into the informal water market mechanisms. The interviewed farmers had agricultural experience ranging from less than 5 years to more than 15 years, operated irrigated holdings up to approximately 10 hectares, and received water allocation of 8 to 24 hours per irrigation cycle.

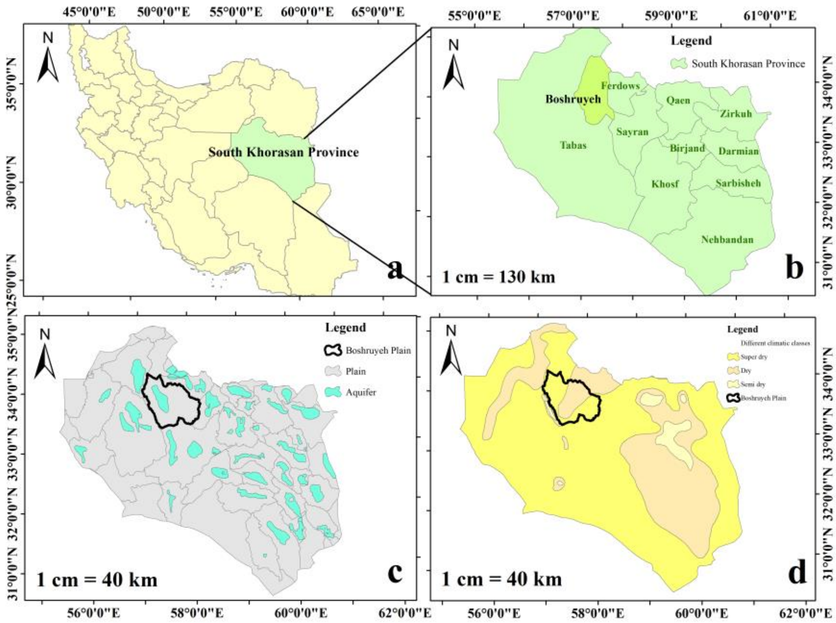


Fig. 1. Geographical setting: (a, b) Location of Boshruyeh Plain in Iran and South Khorasan Province; (c) Aquifer boundaries; and (d) De Martonne hydro-climatic classification.

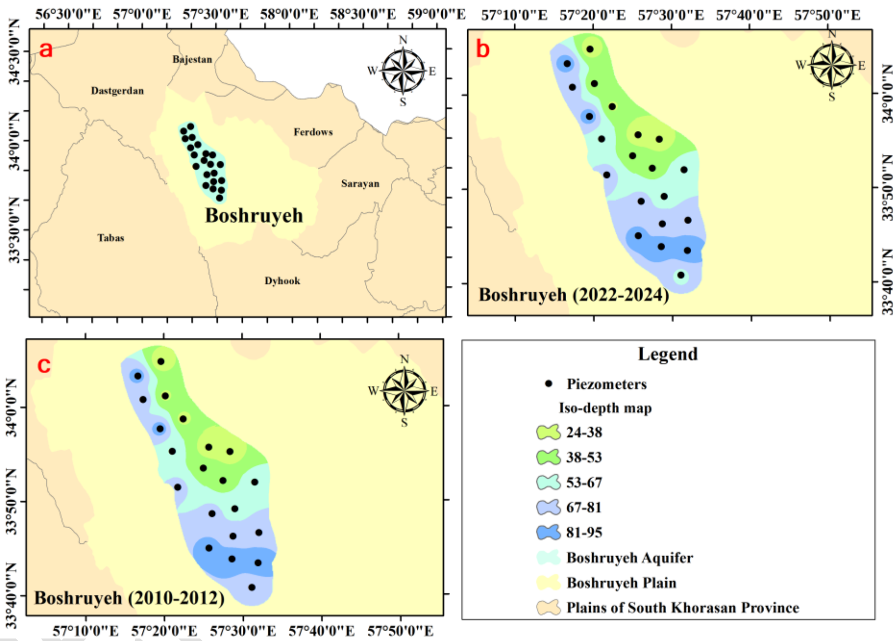


Fig. 2. Spatiotemporal groundwater depth analysis: (a) Study area location; (b) Iso-depth map for the 2022–2024 period; and (c) Iso-depth map for the 2010–2012 period.

Table 1. Survey instrument structure and constructs across stakeholder groups.

Questionnaire section	Target group	Key constructs measured	Item type
Demographics	All groups	Age; Education; Experience; Land ownership	Multiple choice
Policy effectiveness	Experts & academics	Success of restoration plan; Policing efficiency; Aquifer recovery	5-point Likert
Market readiness	Farmers	Willingness to trade; Shadow price perception; Risk aversion	5-point Likert
Institutional trust	All groups	Trust in water authority; Perception of justice; Conflict resolution	5-point Likert

2.4. Statistical analysis framework

Data normality was assessed using the Shapiro-Wilk test. The test produced p-values below 0.05 for all Likert-scale constructs (typically ranging from <0.001 to 0.03), indicating a significant departure from normality. Since the Likert-scale data violated the normality assumption, non-parametric tests were employed .To compare the perceptions across the three independent groups (Farmers vs. Experts vs. Academics), the Kruskal-Wallis H test was utilized, determined by (Okoye & Hosseini, 2024):

$$H = \frac{12}{N(N+1)} \sum_{j=1}^{k} \frac{R_j^2}{n_j} - 3(N+1) \tag{4}$$

Where N is the total number of observations, R_j is the sum of ranks for the j-th group, and nj is the sample size of the j-th group. Furthermore, the association between categorical variables (e.g., factors contributing to project failure) was analyzed using the Pearson Chi-Square test (χ^2):

$$\chi^2 = \sum \frac{(O_i - E_i)^2}{E_i} \tag{5}$$

where, O_i is the observed frequency and E_i is the expected frequency (Turhan, 2020). All statistical analyses were performed using SPSS (v.27), and data visualization was executed using Python (Matplotlib/Seaborn libraries) to ensure high-resolution graphical outputs.

3. Results and discussion

3.1. Hydro-physical dynamics and the limits of technical interventions

The analysis of the representative unit hydrograph for the Boshruyeh aquifer over a 27-year hydrological period (1995–2023) reveals a persistent monotonic decline in piezometric heads. The aquifer has experienced a cumulative drawdown of 14.94 m (average annual decline of 0.55 m), resulting in a cumulative reservoir deficit of 21.07 MCM. This chronic imbalance is primarily driven by the absolute dominance of agricultural abstraction, which accounts for 94% of the total withdrawal. However, a distinct structural break in the time series is observable post-2014. This shift coincides with the rigorous implementation of the restoration and balancing plan, particularly the accelerated installation of smart metering infrastructure (Fig. 3). Government reports indicate that the smart metering infrastructure has been financed and installed under the national aquifer restoration plan, with the upfront costs not directly passed on to farmers. While the piezometric decline has not been fully arrested; indicating a lingering disequilibrium between the negligible natural recharge (26.5 MCM) and massive discharge (88.5 MCM); the significant deceleration in the drawdown rate suggests that physical interventions have successfully imposed a degree of hydro-physical discipline on the system.

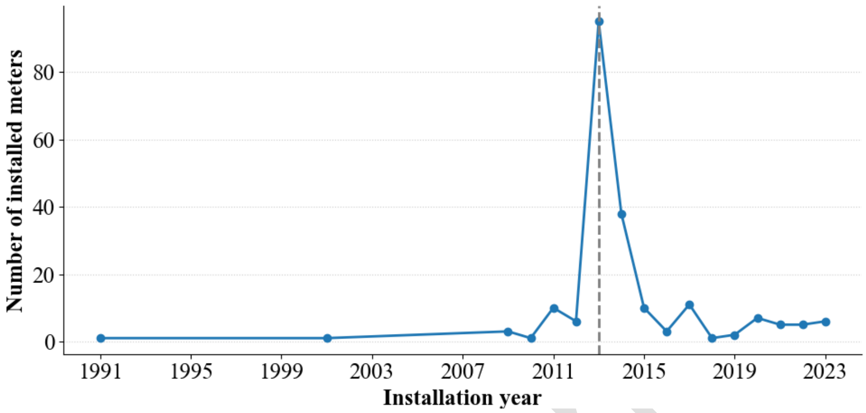


Fig. 3. The process of installing meters for exploited wells in the Boshruyeh Plain

Further evidence of this regulatory efficacy is observed in the narrowing gap between the allocated volume and actual abstraction. In the 2023-2024 hydrological year, the actual recorded abstraction from 200 representative agricultural wells (73.14 MCM) closely mirrored the allocated cap (71.22 MCM). The boxplot analysis of annual abstraction (Fig. 4) corroborates this trend, showing a marked reduction in the interquartile range (IQR) and outliers post-2014. Furthermore, comparative analysis (Fig. 5) confirms that command-and-control measures, such as volumetric monitoring, have been effective in curbing the exponential growth of anthropogenic stress.

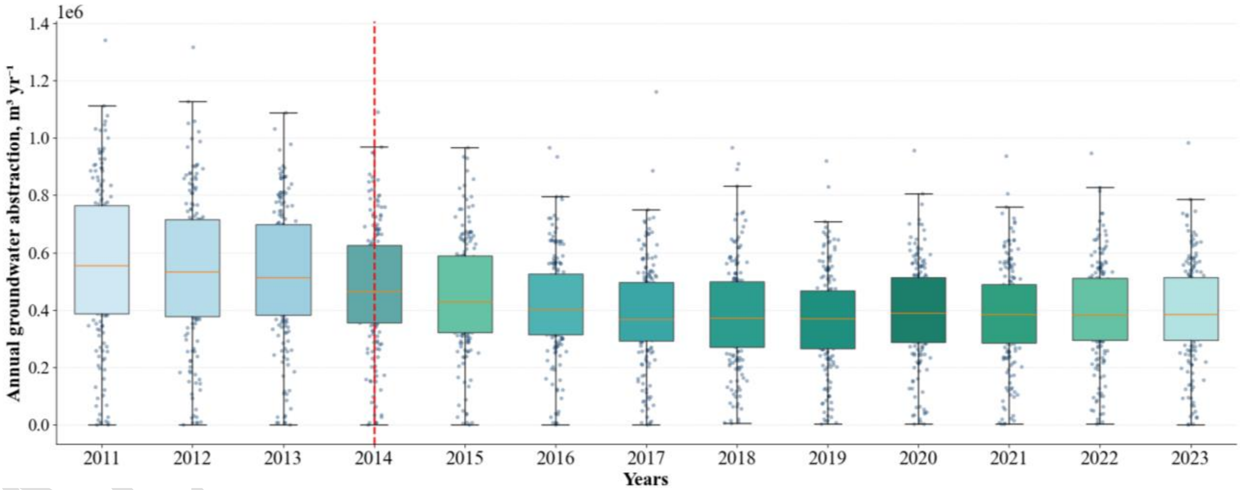


Fig. 4. Boxplot analysis of annual groundwater abstraction distribution (2011–2023), demonstrating the reduction in outliers and homogenization of withdrawal rates.

Nevertheless, the persistence of an annual deficit of approximately 62 MCM despite strict policing underscores the inherent limitations of a purely engineering-centric approach. As noted by (Zeydalinejad *et al.* 2023) in similar arid contexts, technical solutions can mitigate the symptoms (drawdown rate) but often fail to cure the underlying malady if the socio-economic drivers of water demand remain unaddressed. This observation aligns with the hydro-climatic outlook presented by (El Kenawy, 2024), suggesting that without integrating stakeholder motivations and economic incentives, physical controls act merely as a temporary brake rather than a sustainable solution. Consequently, understanding the disparity between this forced discipline and the stakeholders' actual willingness to cooperate becomes a prerequisite for long-term sustainability, as explored in the subsequent section.

3.2. Socio-institutional analysis: Divergence in stakeholder perceptions

3.2.1. The policy-practice gap in governance effectiveness

The comparative analysis of stakeholder perceptions reveals a structural dissonance between the theoretical logic of the academic elites and the operational reality experienced by executive experts. As detailed in Table 2 and Fig. 6, academic respondents consistently rated the necessity and effectiveness of the restoration and balancing plan higher than their executive counterparts. Specifically, regarding the efficacy of smart monitoring (telemetry), a statistically significant disparity ($p < 0.001$) was observed, with academics expressing high confidence (4.45 ± 0.63) compared to the more skeptical view of executive experts (3.72 ± 0.88) (Table 3). This divergence aligns with findings by (Calderwood *et al.* 2020), suggesting that while the scientific community emphasizes the potential of real-time data for aquifer sustainability, field practitioners are likely more attuned to the logistical challenges of maintenance, vandalism, and data transmission failures in remote arid regions.

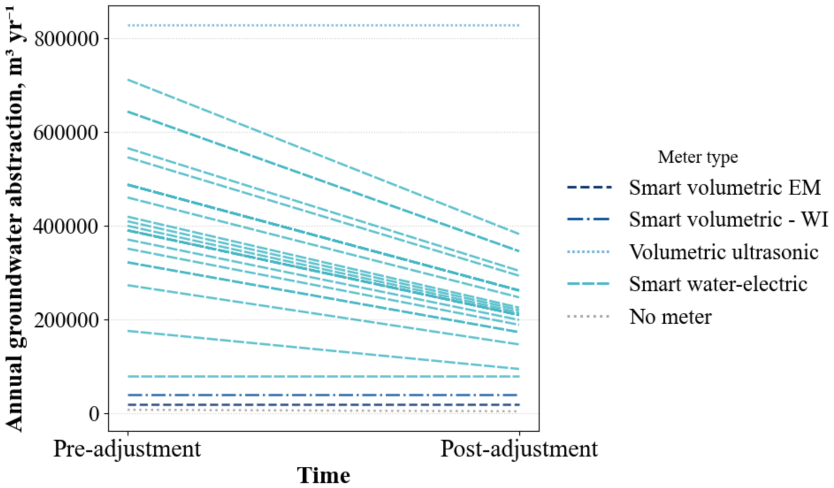


Fig. 5. Comparative discharge patterns between metered and non-metered wells, highlighting the regulatory impact of smart metering on abstraction control.

Table 2. Comparative assessment of the restoration plan effectiveness (Mean ± SD).

Variable / construct	Academic elites	Variable / construct	Academic elites
Necessity of plan implementation	4.70 ± 0.65	4.42 ± 0.65	High consensus
Overall effectiveness of Plan	3.50 ± 0.68	3.27 ± 0.89	Moderate gap
Impact on illegal withdrawals	4.32 ± 1.09	4.11 ± 0.95	High consensus
Impact on water quality	3.90 ± 0.55	3.44 ± 0.77	Significant divergence

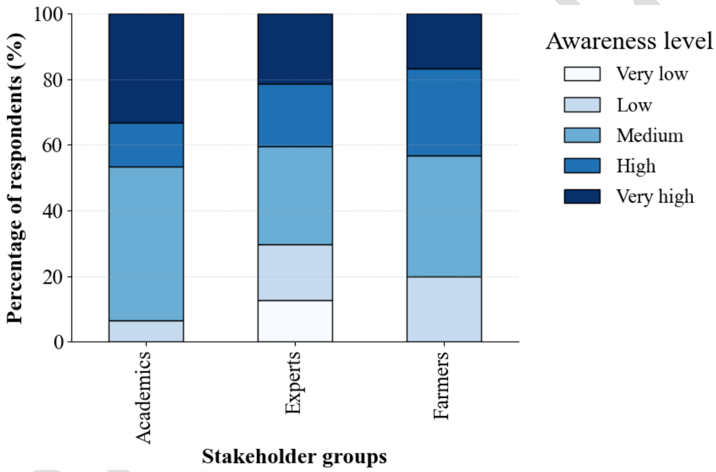


Fig. 6. Comparative analysis of stakeholder attitudes (Academic elites vs. Executive experts) toward the overall effectiveness of the restoration and balancing plan.

Table 3. Kruskal-Walli's test results for technical interventions perceptions.

Policy intervention	Experts (mean rank)	Academics (mean rank)	P-Value	Sig.
Smart monitoring (telemetry)	3.72 ± 0.88	4.45 ± 0.63	0.0007	✓
Reduction of well permits	3.45 ± 0.89	3.81 ± 0.62	0.0370	✓
Volumetric meter installation	4.02 ± 0.94	4.24 ± 0.79	0.3840	✗
Correction of operation licenses	2.93 ± 0.75	3.30 ± 0.82	0.1169	✗

Interestingly, while there is a significant difference in perception regarding well capping ($p = 0.037$)—with academics favoring stricter enforcement—no statistically significant difference was found regarding the installation of volumetric meters ($p \geq 0.05$). This convergence suggests that metering has transitioned from a contentious policy to an accepted institutional norm across both groups.

3.2.2. Attribution of failure and institutional distrust

Beyond the technical tools, the analysis of blame attribution using the Pearson Chi-Square test exposes a critical institutional fracture. Both groups identified the Ministry of Jihad Agriculture – the primary national department overseeing agricultural policy and production in Iran – as the primary entity responsible for the failure of conservation efforts ($\chi^2(3) = 8.008$, $p = 0.046$), citing nearly identical frequencies (Academics: 53.3%, Experts: 51.0%) (Fig. 7). This conflict is structural: the Ministry of Jihad Agriculture is legally mandated to maximize agricultural production and support farmers' livelihoods on one hand, while on the other hand it is responsible for implementing demand-side water conservation policies. This inherent paradox has led the Ministry to formally oppose the establishment of water markets, citing concerns over land-use change in agricultural areas. This consensus highlights a systemic conflict of interest in Iran's water governance (Jafari *et al.* 2024) where the agency responsible for maximizing crop production is simultaneously expected to regulate water demand—a paradox often cited as a root cause of policy failure.

However, the groups diverge significantly on the underlying causes of this failure ($\chi^2(5) = 23.899$, $p < 0.001$). As illustrated in Fig. 8, academics predominantly attribute failure to the lack of participatory management (30%), reflecting the theoretical emphasis on polycentric governance. In contrast, executive experts completely disregarded this factor, focusing instead on tangible obstacles such as cultural neglect (14.2%) and technical deficiencies (12.2%). This stark contrast mirrors the findings of (Shunglu *et al.* 2022), who argued that technocratic management often reduces participation to a buzzword, failing to recognize that local power dynamics and cultural barriers (as highlighted by the experts) are the actual impediments to success.

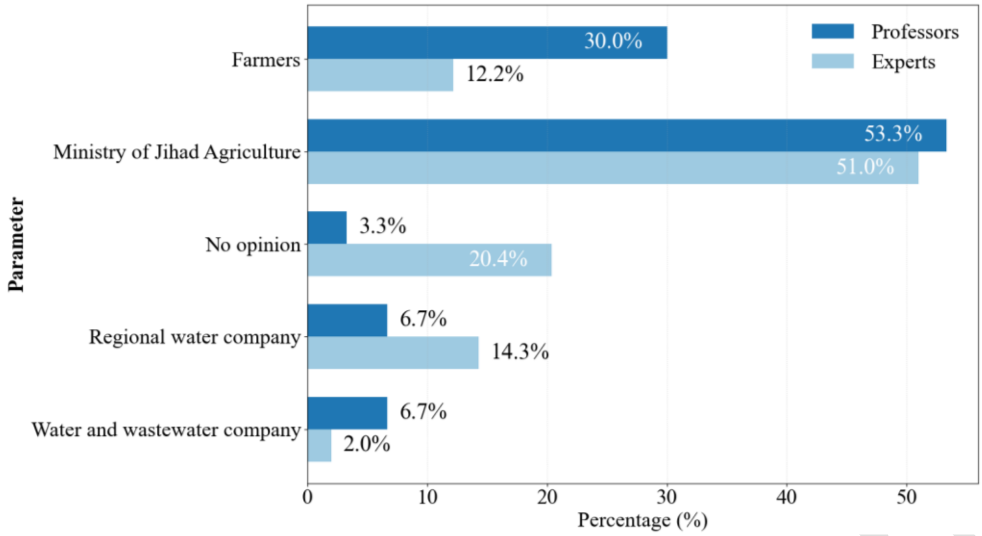


Fig. 7. Institutional blame attribution: comparative perceptions of academic elites and executive experts regarding the entities responsible for project failure.

Furthermore, although the Kruskal-Walli's test indicated no statistical significance in the Satisfaction with Information Dissemination (p = 0.204), the qualitative patterns suggest that communication breakdown remains a barrier. As noted by (Schattman *et al.* 2024), such non-significant statistical differences should not mask the practical reality that divergent priorities—academics focusing on long-term governance models versus experts focusing on immediate technical hurdles—create a silo effect that undermines the holistic implementation of the balancing plan.

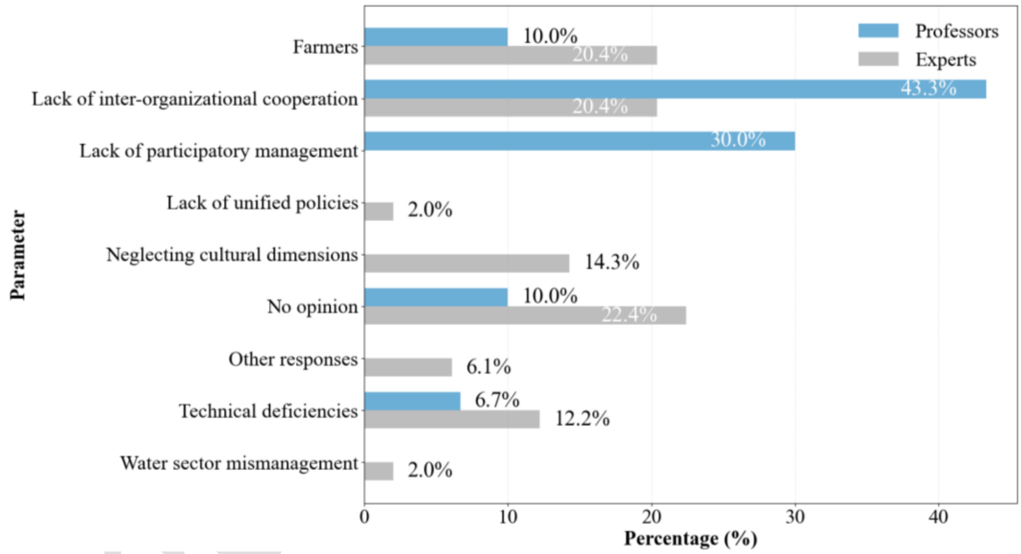


Fig. 8. Perceived causes of policy failure: divergence analysis between academic emphasis on lack of participation vs. expert emphasis on technical/cultural barriers.

3.3. Feasibility and strategic design of a regulated water market

3.3.1. The economic basis: resource heterogeneity as a prerequisite for trade

The fundamental prerequisite for any functional market is the existence of asymmetry in resource endowment. The scatter plot analysis of farmers' perceived water status (**Fig. 9**) confirms a significant heterogeneity across the Boshruyeh Plain. The data reveals two distinct clusters: a high-deficit/low-surplus group (potential buyers seeking to mitigate crop failure risk) and a high-surplus/low-deficit group (potential sellers capable of monetizing efficiency). This uneven distribution creates a natural arbitrage opportunity, where water trading could theoretically generate a pareto-optimal outcome. However, the dispersion of data points in the intermediate zones suggests that this market cannot function solely on a spot-price basis; it requires a flexible mechanism to handle temporal fluctuations in supply, echoing the findings of (Schmack *et al.* 2019) regarding the necessity of hybrid trading systems in constrained environments.

3.3.2. Social acceptance and institutional convergence

Contrary to the common narrative of resistance to pricing mechanisms, the survey results indicate a remarkably high social acceptance of water markets, with 89.18% of farmers expressing a positive attitude toward the establishment of a trading platform. Importantly, existing local cooperative networks – including the traditional "Akhtiare Barzegar" sharecropping system, joint well ownership with a representative for water negotiations, and seasonal water exchanges between orchard and field crop farmers – provide a social and operational foundation that could facilitate the implementation of a regulated water market by lowering transaction costs. This high willingness to participate suggests that stakeholders view the market not as a threat, but as a necessary adaptation tool to cope with hydrological uncertainty.

From an institutional perspective, the Kruskal-Walli's test results (Table 4) reveal a strategic alignment between the theoretical and executive layers of governance. No statistically significant difference (p = 0.547) was found between academic elites and executive experts regarding the feasibility of market implementation. This lack of divergence—often rare in environmental policy—indicates a form of institutional consensus, suggesting that the friction typically observed between policymakers (Academics) and implementers (Experts) is minimal regarding the principle of water trading. This consensus significantly lowers the political transaction costs for initiating the market mechanism, satisfying a key success factor identified by (Wheeler, 2021) in global water market reforms.

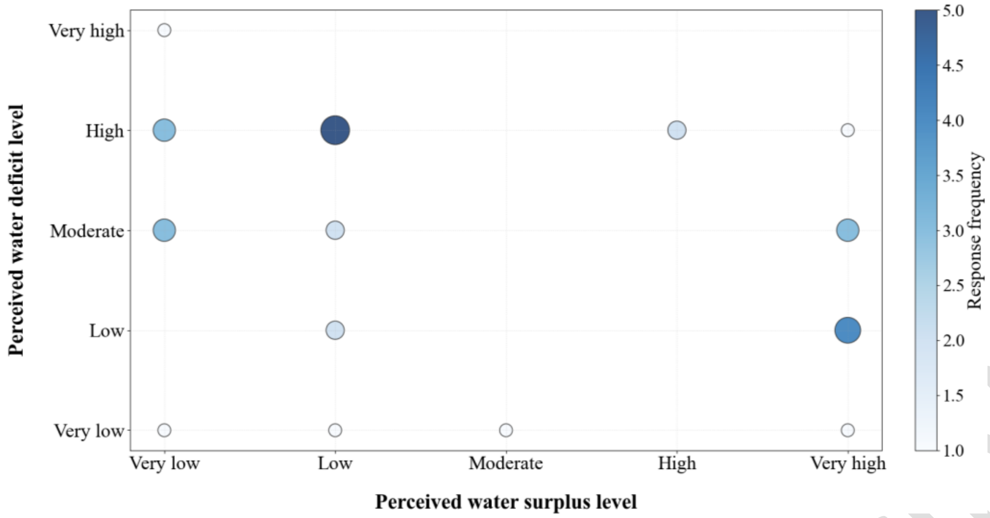


Fig. 9. Scatter plot of farmers' self-reported water status (surplus vs. deficit), identifying resource heterogeneity and market arbitrage opportunities.

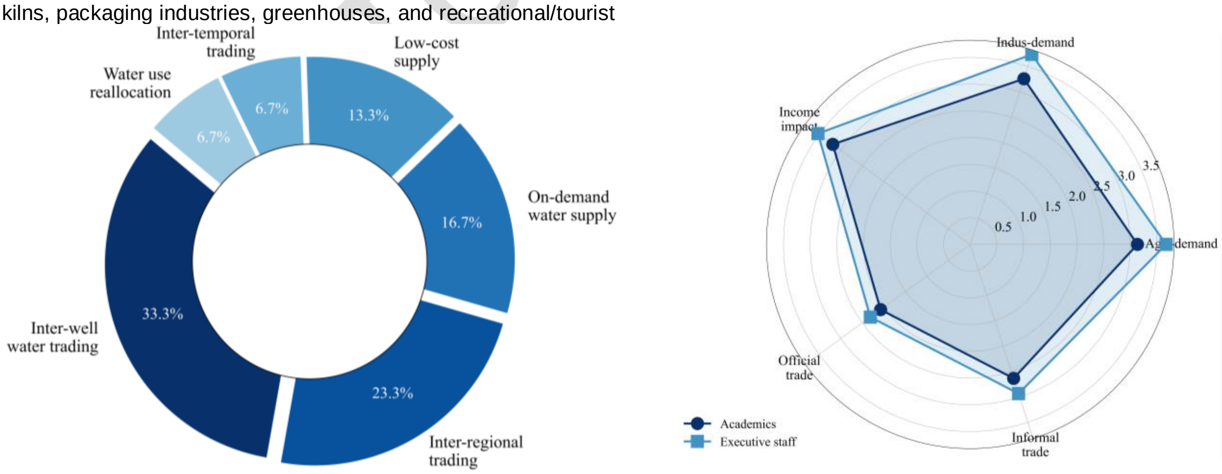
Table 4. Institutional convergence analysis regarding market feasibility.

Institutional indicator	Academics (Mean Rank)	Experts (Mean Rank)	P-Value	Result
Feasibility of water market	3.73	3.58	0.547	Consensus
Adequacy of crisis Info	2.73	3.08	0.203	No Significant difference
Farmer willingness	-	-	-	89.18% Approval rate
Feasibility of water market	3.73	3.58	0.547	Consensus

3.3.3. Market architecture: moving beyond price to flexibility

A critical insight for the design of the market comes from analyzing the motivational drivers (Fig. 10a). The Donut chart analysis reveals that the primary driver for farmer participation is not Profit Maximization per se, but rather operational flexibility and inter-temporal trading (banking). Farmers prioritize the ability to save water credits for dry periods over immediate financial gain, indicating that the market should be designed primarily as a risk management tool rather than a speculative commodity exchange (Urquiza & Billi, 2020).

Furthermore, the radar chart (Fig. 10b) highlights a strong latent demand from the industrial sector. Based on Regional Water Company records, existing industrial consumers in the Boshruyeh plain include brick kilns, packaging industries, greenhouses, and recreational/tourist facilities. Additionally, if a water market is established, agricultural processing industries (e.g., pistachio terminals), livestock farming, and fish farming could also become potential buyers. This cross-sectoral demand potential elevates the proposed market from a simple agricultural exchange to a more complex inter-sectoral reallocation mechanism. As argued by (Garrick *et al.* 2022), incorporating high-value industrial buyers can provide the necessary liquidity and financial incentives for farmers to invest in water-saving technologies, thereby closing the loop between economic efficiency and hydrological sustainability. A future hydro-economic optimization model could build on these insights by explicitly incorporating seasonal crop price dynamics to determine the optimal allocation of water across agricultural and industrial uses under varying market conditions.



(a) (b)

Fig. 10. Market potential indicators (a) Farmers' motivational drivers for trading (emphasizing flexibility over profit), and (b) Radar chart depicting cross-sectoral demand potential.

4. Conclusions

This study provided a multidimensional assessment of the groundwater governance paradox in the hyper-arid Boshruyeh Plain, aiming to bridge the gap between rigid engineering interventions and the complex socio-economic realities of stakeholders. By integrating long-term hydro-physical time series with a tripartite stakeholder analysis, several critical conclusions emerge: First, the hydrological forensic analysis confirms that while the Restoration and Balancing Plan has successfully imposed a structural break in the abstraction trends post-2014—largely due to the rigorous implementation of smart metering—it has failed to arrest the chronic reservoir deficit. The persistence of an annual imbalance of roughly 62 MCM demonstrates that command-and-control mechanisms, in isolation, have reached their saturation point. They can enforce physical compliance but cannot induce the behavioral changes necessary for long-term recovery. Second, the socio-institutional investigation reveals a significant perception gap between the theoretical expectations of academic elites and the operational realities faced by executive experts. This dissonance, particularly regarding the causes of policy failure (lack of participation vs. technical barriers), underscores a fragmented governance structure. However, the overarching consensus across all groups—identifying the conflict of interest within the agricultural sector's management as a primary driver of failure—points to the urgent need for institutional reform. Third, and most significantly, this research debunks the myth of stakeholder resistance to economic instruments. The high social acceptance rate (approx. 89%) for a water market, coupled with the identification of risk management and operational flexibility as primary motivational drivers, indicates a ripe opportunity for a paradigm shift. The findings suggest that the existing informal exchanges are not acts of defiance but rational coping mechanisms against hydrological uncertainty. Based on these findings, it is recommended that water authorities in Boshruyeh (and similar arid regions) transition from a purely police-patrol model to a market-regulatory framework. This transition should involve:

1. Utilizing the successfully installed smart metering infrastructure not just for policing, but as the technological backbone for a regulated cap-and-trade system.
2. Structuring the market to allow for water banking and inter-temporal trading, addressing farmers' primary need for drought insurance rather than mere profit maximization.
3. Facilitating a controlled mechanism for industrial water purchase to inject financial liquidity into the agricultural sector, thereby funding the modernization of irrigation systems.

Future research should focus on developing a hydro-economic optimization model to determine the shadow price of water under this proposed market structure, explicitly integrating climate change projections (e.g., future rainfall trends, drought frequency scenarios), while ensuring that trading rules protect the aquifer's ecological base flow and maximize regional economic welfare.

Author Contributions

Ali Nasirian: Conceptualization, Methodology, Formal analysis, Investigation, Writing – original draft, Writing – review & editing, Visualization, Project administration.
Raziyeh Shamshirgaran: Conceptualization, Data curation, Validation, Investigation, Software, Writing – review & editing, Resources.
Moein Tosan: Investigation, Formal analysis, Software, Writing – review & editing, Data curation.

Conflict of Interest

The authors declare that they have no competing interests

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Data Availability Statement

The data that support the findings of this study are fully presented within this article and have not been previously published elsewhere.

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