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Implementing Water Accounting in a Developing Economy: Barriers and Insights from Iran

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Abstract

All industrial activities rely on water, either directly for production or indirectly to support manufacturing processes. Given the severe water scarcity in Iran, manufacturing companies face substantial challenges in managing their water resources. This study investigates the barriers to adopting water accounting in Iran's manufacturing sector amid the country's ongoing water crisis. A novel six-dimensional framework is proposed that encompasses technical/infrastructural, regulatory/policy, human capital, cultural/organizational, economic/financial, and external environmental barriers. Using a descriptive–survey design, data were collected from 170 accountants and analyzed through exploratory factor analysis (EFA), confirmatory factor analysis (CFA), and structural equation modeling (SEM) using SPSS 26 and AMOS 24. The results indicate that technical/infrastructural barriers exert the strongest influence, followed by regulatory and policy gaps, while all six dimensions demonstrate interrelated effects. This study contributes a context-specific analytical framework that addresses the research gap in Iran's underexplored manufacturing sector and provides practical insights for sustainable water management. By systematically identifying and evaluating the interconnected barriers, the research offers actionable recommendations to enhance the implementation of water accounting and promote more sustainable resource management practices.

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1. Introduction

Water is a fundamental resource essential for sustaining life, supporting economic development, and maintaining environmental stability (Westall & Brack, 2018). Within the manufacturing sector, water plays a critical role in processes such as cooling, cleaning, and direct production, making it a cornerstone of industrial operations (Refalo & Zammit, 2013). However, the escalating global demand for water driven by population growth, industrial expansion, and climate change has intensified water scarcity across many regions, posing serious challenges to sustainable resource management (Karimi et al., 2024). Iran, a semi-arid country, faces an especially acute water crisis marked by prolonged droughts, groundwater overexploitation, and systemic mismanagement, which collectively threaten its socio-economic and environmental stability (Mirzavand & Bagheri, 2020). The manufacturing sector, a vital pillar of Iran's economy, is particularly vulnerable. Inefficient water use in this sector exacerbates resource scarcity, disrupts production continuity, and heightens operational risks (Mokhtari Hashi, 2024). Addressing these challenges necessitates innovative approaches to water governance, among which water accounting has emerged as a critical mechanism for promoting transparency, efficiency, and sustainability in resource management.

Water accounting provides a systematic framework for measuring, monitoring, and reporting water consumption and discharge. It enables organizations to quantify their water footprint, identify inefficiencies, and implement targeted improvements (Morrison et al., 2010). For manufacturing firms, water accounting represents not merely a sustainability initiative but a strategic imperative that enhances operational efficiency, reduces costs, and ensures compliance with environmental regulations (Meurer & Van Bellen, 2024; Mokhtari Hashi, 2024). By delivering accurate data on water-use patterns, water accounting supports evidence-based decision-making, risk mitigation, and corporate environmental stewardship—thereby contributing to global efforts toward sustainable water management and resource conservation (Sofocleous, 2010). In water-stressed regions such as Iran, where scarcity constitutes a critical business risk, water accounting is increasingly recognized as a cornerstone of corporate resilience and sustainability strategies (Muller, 2012). Effective implementation can optimize resource utilization, minimize environmental impacts, and position firms as leaders in sustainable industrial practices.

Despite its critical importance, water accounting remains significantly underutilized within Iran's manufacturing sector. The limited adoption of comprehensive frameworks and the continued reliance on outdated, fragmented methods have resulted in inaccurate data and ineffective water management practices (Mokhtari Hashi, 2024; Nazaripour, 2021). While global literature emphasizes the role of water accounting in sustainable resource management particularly in developed regions such as Australia and the European Union (Vardon et al., 2007; Hunink et al., 2019; Ferreira et al., 2023) there is a striking lack of research addressing the barriers to implementation in developing economies that face distinct socio-economic and geopolitical constraints, such as Iran. Previous studies (e.g., Nazaripour, 2021; Asnad & Fakhari, 2024) have identified isolated barriers, such as regulatory deficiencies or technical limitations, but have failed to offer a comprehensive framework that integrates the complex interrelations among cultural, economic, regulatory, technical, human capital, and external environmental factors. Iran's unique context characterized by international sanctions, centralized governance, and cultural resistance to organizational change—introduces specific challenges that remain underexplored (Nazaripour & Zakizadeh, 2023). For instance, sanctions restrict access to advanced technologies and international funding; centralized governance structures inhibit decentralized collaboration; and cultural norms that prioritize short-term gains over long-term sustainability discourage investment in water management innovation (Danışman, 2010; Nouri et al., 2023). Addressing these gaps, this study develops a comprehensive, context-specific framework to systematically examine the multifaceted barriers hindering the adoption of water accounting practices in Iran's manufacturing sector.

This study aims to examine the barriers to the adoption of water accounting in Iran's manufacturing sector and to propose actionable, context-specific strategies to promote sustainable water management practices. To achieve this objective, the research develops a novel six-dimensional framework comprising technical/infrastructural, regulatory/policy, human capital, cultural/organizational, economic/financial, and external environmental barriers each reflecting Iran's distinct socio-economic and environmental context. Accordingly, the study seeks to address the following research questions:

- What are the primary barriers to adopting water accounting in Iran's manufacturing sector?
- How do these barriers interact to impede effective implementation?
- What tailored strategies can address these barriers to enhance sustainable water management in Iran's manufacturing context?

These research questions guide the study's methodological design, which employs advanced statistical techniques to validate the proposed framework and generate practical recommendations. Focusing on Iran's manufacturing sector, the study seeks to enhance the adoption of water accounting by addressing context-specific challenges, including sanctions-related technological constraints, weak regulatory enforcement, and cultural resistance to organizational change. Using a descriptive–survey approach, data were collected from 170 accountants and analyzed through exploratory factor analysis (EFA), confirmatory factor analysis (CFA), and structural equation modeling (SEM). The validated six-dimensional framework comprising technical/infrastructural, regulatory/policy, human capital, cultural/organizational, economic/financial, and external environmental barriers provides a comprehensive foundation for promoting sustainable water management practices amid Iran's severe water crisis.

The remainder of this paper is organized as follows. The literature review synthesizes relevant prior studies, while the methodology section outlines the research design and data analysis procedures. The findings section presents the analytical results, followed by the discussion, which interprets these findings in light of the research objectives. Finally, the conclusion summarizes the key contributions and highlights the study's theoretical and practical implications.

2. Literature review

Water accounting plays a crucial role in advancing sustainable resource management; however, its level of adoption varies considerably across countries. Developed economies, such as Australia and the members of the European Union, have established comprehensive, institutionalized frameworks (Vardon et al., 2007; Hunink et al., 2019). In contrast, developing economies—particularly those located in water-scarce regions—face distinct institutional, technical, and socio-economic challenges that hinder widespread implementation. This study focuses on Iran's manufacturing sector and addresses a critical gap in the existing literature by providing an in-depth analysis of the barriers to adopting water accounting in this specific national context.

2.1. Cultural and organizational barriers (COB)

Cultural and organizational barriers (COBs) continue to hinder the adoption of sustainable practices, such as water accounting, in Iran. Centralized decision-making and bureaucratic inefficiencies, exacerbated by international sanctions, obstruct effective information sharing and resource allocation (Afzal & Lim, 2022; Christ & Burritt, 2017). Moreover, a prevailing culture of secrecy and weak inter-organizational communication further complicates sustainability initiatives (Nazaripour & Ravand, 2021). Iran's top-down governance structure contrasts sharply with

Australia's decentralized model, thereby limiting opportunities for collaboration. From an Institutional Theory perspective, cultural norms significantly influence regulatory compliance (Burdon & Sorour, 2020). Meanwhile, the resource-based view (RBV) underscores deficiencies in organizational training and collaboration (Kero & Bogale, 2023). Additionally, the lack of trust and rigid hierarchies impede progress toward sustainability (Rösler et al., 2021). To overcome these challenges, proposed strategies include fostering strong leadership commitment, expanding training programs, and embedding sustainability principles into core organizational values (Ketprapakorn & Kantabutra, 2022).

2.2. Economic and financial barriers (EFB)

Economic and financial barriers (EFBs) pose substantial obstacles to sustainable water management in Iran. Iran's economic vulnerabilities—aggravated by international sanctions—have restricted access to financial capital, advanced technologies, and foreign investment, thereby impeding the development of essential water infrastructure (Madani, 2021; Nazaripour, 2021). In addition, prolonged droughts and persistently low water prices have reduced agricultural revenues and discouraged conservation-oriented investments. These conditions contrast sharply with the adaptive and market-responsive financial systems observed in countries such as Australia and India (Karimi et al., 2024; Eskandar & Hadadi, 2022). Drawing on Institutional Theory, the study demonstrates how financial constraints undermine regulatory compliance (Burdon & Sorour, 2020; Esmaeilishirazifard et al., 2024), while the Resource-Based View (RBV) highlights how resource scarcity hampers the effectiveness of water accounting systems (Kero & Bogale, 2023; Polzin et al., 2016). The findings reveal a unique interplay of sanctions, underpricing, and chronic underinvestment as major impediments to sustainability (Gietema, 2022). To address these challenges, the paper proposes policy interventions such as targeted subsidies and tiered water pricing to better align economic incentives with environmental objectives (Nazaripour & Ravand, 2021; Karimi et al., 2024).

2.3. Regulatory and policy barriers (RPB)

Regulatory and policy barriers (RPB) significantly impede the adoption of water accounting practices in Iran, revealing a critical gap in the existing literature. Centralized governance structures and underdeveloped regulatory frameworks hinder effective water management, while policy inconsistencies—exacerbated by international sanctions further complicate the allocation and implementation of water rights (Nazaripour, 2021; Nazaripour & Zakizadeh, 2023). In contrast to the decentralized governance models of countries such as Australia and India, Iran's top-down approach limits institutional accountability and undermines the effectiveness of water accounting systems (Chanchani, 2023; Nouri et al., 2023). Drawing on Institutional Theory, this study demonstrates that regulatory uncertainty and fragmented policy environments discourage sustainable investment (Meurer & Van Bellen, 2024). It also highlights how sanctions, low water pricing, and weak enforcement mechanisms contribute to persistent structural dependencies that remain largely unaddressed (Nazaripour & Ravand, 2021). Furthermore, inconsistent policies have led to ongoing technical neglect in the sector (Leach et al., 2010). To strengthen Iran's regulatory landscape, this paper recommends adopting elements from the Australian and European Union models to better align national water accounting practices with global best standards (Vardon et al., 2023; Karimi et al., 2024).

2.4. Technical and infrastructure barriers (TIB)

Technical and infrastructure barriers (TIB) significantly hinder the implementation of water accounting practices in Iran. The country's aging water infrastructure—characterized by system leaks and outdated technologies—reduces the accuracy and reliability of water accounting data (Nazaripour & Ravand, 2021; Esmaeilishirazifard et al., 2024). International sanctions further aggravate this situation by restricting access to advanced technologies. At the same time, chronic underinvestment has deepened existing technical deficiencies, leaving Iran behind countries such as Australia and India in terms of water management capabilities (Miller et al., 2023; Madani, 2021). Drawing on the Resource-Based View (RBV), this study emphasizes the shortage of technical resources within Iran's manufacturing sector, particularly the lack of advanced metering systems and trained personnel (Adelakun, 2023). These deteriorating conditions, coupled with technological isolation, have created persistent and unresolved structural dependencies (Madani, 2021; Alhassan et al., 2023). To modernize Iran's water accounting systems, this paper recommends integrating Internet of Things (IoT) sensors, artificial intelligence (AI) analytics, and cloud-based platforms to enhance efficiency, accuracy, and transparency in water resource management (Abedi, 2022).

2.5. Human capital barriers (HCB)

Human capital barriers (HCB) significantly hinder the effective adoption of water accounting practices in Iran, exposing a critical gap in the literature. Major challenges include a shortage of skilled labor, insufficient training programs, and international sanctions that constrain knowledge transfer (Nazaripour, 2021). The persistent brain drain further exacerbates the scarcity of qualified professionals in Iran's manufacturing sector, making the establishment and maintenance of water accounting systems increasingly complex (Mazur et al., 2023; Nazaripour & Zakizadeh, 2023). In contrast, countries such as Australia and India benefit from strong educational infrastructures that support the integration of water accounting into industrial and environmental management practices (López et al., 2019). This study highlights the interconnections among sanctions, brain drain, and inadequate investment in education, emphasizing the urgent need for specialized training in data analytics and sustainable water management, as well as enhanced collaboration between academia and industry (Nazaripour & Ravand, 2021; Farzanegan & Batmanghelidj, 2024). Moreover, continuous professional development remains essential to ensure long-term institutional capacity in this field (Ikevuje et al., 2024).

2.6. External environmental barriers (EEB)

External environmental barriers (EEBs) pose significant challenges to implementing water accounting practices in Iran. The country's arid climate and recurring droughts—intensified by climate change—undermine the efficiency and consistency of water accounting systems (Nouri et al., 2023). Additional environmental pressures, including transboundary water disputes and progressive desertification, further complicate resource management and policy execution. These challenges stand in sharp contrast to the more stable hydrological conditions observed in countries such as Australia and India (Cosgrove & Loucks, 2015). This study illustrates how environmental stressors weaken the reliability of water accounting systems by disrupting data collection, monitoring, and management processes. Unpredictable weather patterns and extreme climatic events exacerbate data inconsistencies and operational uncertainties (Okitasari et al., 2018). To strengthen resilience in Iran's water management practices, the study underscores the importance of multi-stakeholder collaboration, active engagement of policymakers, and sustained community participation (Nazaripour & Zakizadeh, 2023; Vardon et al., 2025; Merei, 2024).

2.7. Synthesis and contribution

The literature on water accounting demonstrates that developed nations have established robust institutional and regulatory frameworks (Vardon et al., 2007; Hunink et al., 2019). However, substantial gaps remain in understanding and addressing the barriers faced by developing countries such as Iran. Key challenges include cultural resistance, economic constraints, regulatory inconsistencies, and shortages of skilled human capital. International sanctions further aggravate economic and technical difficulties, while centralized governance structures amplify existing regulatory weaknesses (Nazaripour & Zakizadeh, 2023). To address these deficiencies, this study develops a comprehensive six-factor framework to examine barriers to the implementation of water accounting in Iran's manufacturing sector. The framework refines existing theoretical models and proposes practical interventions to promote sustainable water management and enhance institutional resilience.

3. Methodology

This study adopts a descriptive survey research design to examine the barriers hindering the adoption of water accounting practices in Iran's manufacturing sector. Advanced statistical analyses are employed to validate a six-factor framework encompassing technical and infrastructure, regulatory and policy, human capital, cultural and organizational, economic and financial, and external environmental barriers. The methodological approach is guided by three core research questions: (1) What are the primary barriers to adopting water accounting in Iran's manufacturing sector? (2) How do these barriers interact to impede effective implementation? (3) What context-specific strategies can mitigate or overcome these barriers? The subsequent subsections outline the sampling procedures, data collection methods, research instruments, and analytical techniques used in this study. Measures were also incorporated to minimize potential biases and ensure the reliability and validity of the analyses.

3.1. Sampling

Snowball sampling was employed to recruit participants, as this approach was deemed appropriate given the need for specialized expertise in water accounting within Iran's manufacturing sector. The initial participants—accountants with experience in water-use monitoring or sustainability reporting—were identified through professional associations, industry networks, and academic contacts. Each participant subsequently referred other professionals with comparable expertise, enabling the formation of a targeted and information-rich sample capable of providing reliable insights into barriers to water accounting adoption.

To mitigate potential biases inherent in snowball sampling such as the over-representation of interconnected networks or homogeneous perspectives the sample was diversified across multiple dimensions. Participants were recruited from a variety of manufacturing sectors (e.g., textiles, chemicals, food processing, and automotive) to capture industry-specific challenges. In addition, companies of varying sizes, ranging from small and medium-sized enterprises (SMEs) to large corporations, were included to account for differences in resource availability. Regional diversity was also ensured by selecting participants from areas with distinct levels of water scarcity. All participants were screened for familiarity with water accounting practices through a preliminary questionnaire that assessed their experience with water-use measurement and reporting, thereby enhancing the data's relevance and reliability. In total, 181 questionnaires were distributed, yielding 170 valid responses, for a 93.9% response rate. This sample size provided sufficient statistical power while minimizing sampling bias.

3.2. Data collection

Data were collected through an online questionnaire administered between January and April

2025. This approach was selected to enhance accessibility across Iran's geographically diverse regions and to overcome logistical constraints associated with international sanctions. Participants were recruited via professional networks, industry associations, and peer referrals. Recruitment emails included a detailed study overview, an informed consent form, and a brief screening questionnaire designed to verify participants' expertise in water accounting or related financial management roles. In total, 181 accountants were invited to participate. Of these, 170 met the eligibility criteria and completed the survey, while 11 responses were excluded due to incomplete data or insufficient domain expertise.

Ethical standards were strictly observed. Informed consent was obtained from all participants, anonymity was ensured, and data were handled in accordance with institutional ethics and data protection regulations. All data were securely stored on a restricted-access platform and used solely for research purposes.

3.3. Instruments

The questionnaire consisted of two sections: demographic information and 36 Likert-scale items measuring six barrier constructs. The demographic section captured participants' sector, company size, region, years of experience, and familiarity with water accounting. The main section included 36 items—six for each of the following constructs (technical/infrastructure, regulatory/policy, human capital, cultural/organizational, economic/financial, and external environmental)—rated on a five-point Likert scale (1 = strongly disagree, 5 = strongly agree). Items were adapted from prior studies (e.g., Madani, 2014; Nazaripour & Ravand, 2021; Nouri et al., 2023) and contextualized for Iran's manufacturing sector.

The instrument was validated by a panel of five experts with over ten years of experience in water accounting, environmental management, or industrial accounting in Iran. They evaluated the items for content validity, clarity, and relevance and recommended minor revisions to three items. A pilot test with 20 accountants confirmed reliability (Cronbach's $\alpha \geq 0.7$ for all constructs) and resulted in slight wording adjustments. The final questionnaire was then administered online to ensure consistency in data collection.

3.4. Data analysis

Data analysis employed exploratory factor analysis (EFA), confirmatory factor analysis (CFA), and structural equation modeling (SEM) using SPSS 26 and AMOS 24, both of which were selected for their suitability for exploratory research in understudied contexts (Ghaleb & Yaslioglu, 2024). These methods, consistent with the descriptive–survey design, enabled detailed data collection from expert respondents and the examination of complex interrelationships among barriers in Iran's manufacturing sector. EFA identified latent constructs among the 36 items, confirming the six-barrier framework (Research Question 1). CFA validated the measurement model, while SEM analyzed interrelationships among the barriers and their influence on water accounting adoption (Research Question 2). Descriptive statistics summarized barrier significance, and thematic analysis of open-ended responses provided insights for context-specific mitigation strategies (Research Question 3).

Reliability and validity were confirmed across all constructs. Composite reliability (CR) values exceeded 0.7, and average variance extracted (AVE) values were above 0.5, indicating satisfactory convergent validity. Discriminant validity was established, with both the maximum shared variance (MSV) and the average shared variance (ASV) lower than the AVE, as summarized in Tables 11–12. Statistical assumptions were verified to ensure analytical robustness. Normality was confirmed through skewness and kurtosis values within the acceptable range (±2). Multicollinearity diagnostics showed all variance inflation factor (VIF) values below 5, indicating no significant collinearity issues.

Outliers were assessed using the Mahalanobis distance, and none were detected. All tests were performed in SPSS 26 and AMOS 24, confirming the suitability of the data for EFA, CFA, and SEM analyses.

4. Findings

This section first presents descriptive statistics, then the results of hypothesis testing, and finally the subsequent analysis of the findings.

Table 1. Demographic description of the survey sample

Variable	Category	%	Variable	Category	%
Gender	Male	74.7	Education	Bachelor's degree	38.2
	Female	25.3		Master's degree	61.8
Age	Under 30 years old	10.6	Experience	Under 5 years	11.8
	30-39 years old	44.7		5-9 years	32.4
	40-50 years old	29.4		10-20 years	40.6
	Above 50 years old	15.3		Above 20 years	15.2

Note: the sample size was 170 accountants

Table 1 presents the respondents' demographic characteristics. The majority were male (74.7%), and 25.3% were female. Most participants (61.8%) held a master's degree, and 51.2% had 10-20 years of accounting experience. The largest age group was 30–39 years, representing 44.7% of the sample.

The subsequent sections present the research findings in detail.

4.1. Exploratory factor analysis

An adequate sample size is essential for conducting exploratory factor analysis (EFA) (Shrestha, 2021). The Kaiser–Meyer–Olkin (KMO) and Bartlett's Test of Sphericity were applied to assess data suitability. As shown in Table 2, the KMO value of 0.900 indicates excellent sampling adequacy, while Bartlett's test yielded a significance level of 0.000, confirming sufficient correlations among variables (Shrestha, 2021). These results verify the appropriateness of EFA for identifying and interpreting the dataset's underlying factor structure.

Table 2. KMO and Bartlett's test

Kaiser-Meyer-Olkin Measure of Sampling Adequacy		0.900
Bartlett's Test of Sphericity	Approx. Chi-Square	3975.039
	df	630
	Sig.	0.000

After confirming sample adequacy, exploratory factor analysis was performed using the principal components method with Varimax rotation on the 36 questionnaire items. The results, summarized in Table 3, show the proportion of variance explained by each extracted factor. Higher communalities indicate stronger explanatory power; all values exceeded 0.50, confirming that the identified factors adequately represent the observed variables. Minor variability was observed among items—for example, Item 9 recorded a communality of 0.744, while Item 34 showed a lower value of 0.568.

Table 3. Communalities

Question	Extraction	Question	Extraction	Question	Extraction	Question	Extraction

1	0.755	10	0.767	19	0.704	28	0.665
2	0.613	11	0.586	20	0.621	29	0.643
3	0.659	12	0.682	21	0.615	30	0.690
4	0.698	13	0.672	22	0.720	31	0.723
5	0.650	14	0.628	23	0.600	32	0.614
6	0.744	15	0.700	24	0.686	33	0.589
7	0.767	16	0.744	25	0.611	34	0.568
8	0.708	17	0.641	26	0.645	35	0.598
9	0.770	18	0.726	27	0.630	36	0.671

Note: The extraction method used is principal component analysis. The initial commonality for all items is set to one.

Factors with eigenvalues greater than one were retained as the extraction criterion, as shown in Table 4. The six extracted factors collectively explained 66.94% of the total variance. To achieve a clearer and more interpretable structure, Varimax rotation was applied. Table 4 presents the extracted factors, the variance explained by each, and the cumulative variance before and after rotation. Compared with the unrotated solution, Varimax rotation redistributes variance among factors, enhancing interpretability by providing a more balanced representation of the underlying constructs (Darton, 1980).

Table 4. Total variance explained

Component	Initial Eigenvalues/Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	12.170	33.807	33.807	4.350	12.084	12.084
2	3.749	10.415	44.222	4.253	11.814	23.898
3	2.595	7.207	51.429	3.946	10.960	34.858
4	2.149	5.971	57.400	3.941	10.947	45.805
5	1.745	4.847	62.247	3.848	10.690	56.495
6	1.691	4.697	66.944	3.761	10.449	66.944

Tables 4–10 present the factor loadings of the questionnaire items for each extracted component. A loading threshold of 0.40 was applied to assign items to their respective factors (Samuels, 2017). Each table reports the factor loadings and corresponding Cronbach's alpha values. As all loadings exceed 0.50, the items exhibit strong reliability and high internal consistency within each factor. Factor names were determined based on the thematic content of the items they were associated with.

Table 5. Rotated matrix for the first component (Economic and Financial Barriers) and Cronbach's Alpha

	Factor loading	Cronbach's alpha	Question
1	0.836	0.912	Struggle to balance short-term finances with long-term environmental water goals
2	0.816		Lack of commitment from senior management to environmental initiatives, such as water accounting
3	0.811		Fail to adopt environmental accounting initiatives, especially water accounting
4	0.785		Provide inadequate support for employees implementing environmental initiatives, including water accounting
5	0.780		Neglect to educate employees on the importance of water, accounting for economic and social responsibility
6	0.596		Resist changes to implementing water accounting

Table 5 summarizes the key economic and financial barriers (EFB) hindering the adoption of water accounting in Iran's manufacturing sector. The main challenge is balancing short-term financial demands with long-term sustainability objectives (factor loading = 0.836, β = 0.83, $p < 0.001$), reflecting the dominance of immediate financial pressures in resource-constrained firms. A lack of senior management commitment also represents a significant barrier (factor loading = 0.816, β = 0.81, $p < 0.001$), as managers tend to prioritize short-term survival over environmental initiatives. Additional obstacles include inadequate employee training and support (factor loadings = 0.780–0.811, β = 0.78–0.81, $p < 0.001$) and resistance to change (factor loading = 0.596, β = 0.60, $p < 0.001$). Overall, these findings suggest that financial constraints—intensified by international sanctions—alongside managerial and cultural resistance substantially impede the adoption of water accounting, underscoring the need for targeted, context-specific interventions.

Table 6. Rotated matrix for the second component (Cultural and Organizational Barriers) and Cronbach's Alpha

	Factor loading	Cronbach's alpha	Question
1	0.787		Persistently low water prices in Iran hinder essential investment in water systems
2	0.779		Government incentives like subsidies or tax breaks are inadequate for promoting water accounting adoption
3	0.761		Unclear ROI assessments discourage the implementation of water accounting systems
4	0.748		High design and implementation costs are a major barrier to adopting water accounting
5	0.719	0.901	Implementing water accounting systems without reallocating resources causes unsustainable strain and project failures
6	0.696		Water accounting systems are often undervalued and overlooked, despite their cost-effectiveness

Table 6 summarizes the key cultural and organizational barriers to implementing water accounting in Iran's manufacturing sector. The primary issue is the low price of water (factor loading = 0.787, β = 0.79, 95% CI [0.75, 0.83], $p < 0.001$), reflecting a cultural perception of water abundance that discourages sustainable investment. Additional barriers include limited government incentives (factor loading = 0.779, β = 0.78), unclear return-on-investment assessments (factor loading = 0.761, β = 0.76), high implementation costs (factor loading = 0.748, β = 0.75), inefficient resource allocation (factor loading = 0.719, β = 0.72), and the undervaluation of water accounting (factor loading = 0.696, β = 0.70). Findings from 170 accountants across various manufacturing sectors reveal that these barriers are rooted in socio-cultural norms and distorted water pricing structures. The results underscore the need for policy reforms—particularly in pricing mechanisms, incentive systems, and capacity-building—to foster sustainability under the constraints of economic sanctions.

Table 7. Rotated matrix for the third component (Technical and Infrastructure Barriers) and Cronbach's Alpha

	Factor loading	Cronbach's alpha	Question
1	0.736		Iranian companies face a critical lack of infrastructure, hindering the deployment of the water accounting system deployment
2	0.731		Ongoing technical barriers obstruct the successful implementation of water accounting in Iranian companies
3	0.730	0.889	Data collection and integration for water accounting are fragmented and inefficient
4	0.729		Employees lack familiarity with advanced technologies like IoT sensors and cloud platforms, limiting the effective use of water accounting use

5	0.673		Water resource management stagnates due to the lack of implemented water accounting systems
6	0.644		Dependence on traditional methods perpetuates unsustainable water resource management practices

Table 7 summarizes the major technical and infrastructure barriers (TIB) to implementing water accounting in Iran's manufacturing sector. The primary challenge is inadequate infrastructure (factor loading = 0.736, $\beta = 0.74$, 95% CI [0.70, 0.78], $p < 0.001$), exacerbated by limited access to monitoring systems and advanced technologies due to international sanctions. Additional barriers include persistent technical deficiencies (factor loading = 0.731, $\beta = 0.73$), fragmented data collection (factor loading = 0.730, $\beta = 0.73$), limited employee familiarity with advanced technologies (factor loading = 0.729, $\beta = 0.73$), stagnation in water management practices (factor loading = 0.673, $\beta = 0.67$), and continued reliance on traditional methods (factor loading = 0.644, $\beta = 0.64$). Overall, these findings reveal systemic weaknesses driven by outdated equipment, fragmented infrastructure, and insufficient technical capacity. Addressing these issues requires strategic investment in modern infrastructure and comprehensive workforce training to enhance water accounting implementation.

Table 8. Rotated matrix for the fourth component (Regulatory and Policy Barriers) and Cronbach's Alpha

	Factor loading	Cronbach's alpha	Question
1	0.794	0.898	The lack of national water accounting standards hinders widespread acceptance and implementation
2	0.785		Government policies do not adequately support companies adopting water accounting methods
3	0.738		The government's promotion of water accounting practices is insufficient
4	0.696		Current water management practices in Iran do not meet critical international standards
5	0.667		Mandatory water accounting procedures face resistance and disrupt organizations
6	0.654		Managers and employees widely lack understanding of national water resource regulations

Table 8 summarizes the key regulatory and policy barriers to implementing water accounting in Iran's manufacturing sector. The primary obstacle is the absence of national water accounting standards (factor loading = 0.794, $\beta = 0.79$, $p < 0.001$), reflecting an institutional gap that leaves firms without clear operational guidelines. Additional barriers include limited government support (factor loading = 0.785, $\beta = 0.78$, $p < 0.001$), inadequate promotion of water accounting practices (factor loading = 0.738, $\beta = 0.74$, $p < 0.001$), non-alignment with international standards (factor loading = 0.696, $\beta = 0.70$, $p < 0.001$), resistance to mandatory procedures (factor loading = 0.667, $\beta = 0.67$, $p < 0.001$), and poor understanding of regulatory requirements (factor loading = 0.654, $\beta = 0.65$, $p < 0.01$). Insights from 170 accountants across multiple sectors indicate that weak regulatory frameworks, limited institutional awareness, and international sanctions collectively hinder the adoption of water accounting. To overcome these challenges, the study recommends establishing enforceable national standards, providing financial and institutional incentives, conducting awareness campaigns, and strengthening international collaborations.

Table 9. Rotated matrix for the fifth component (External Environmental Barriers) and Cronbach's Alpha

	Factor loading	Cronbach's alpha	Question
1	0.842		Ongoing political and economic instability severely hinders the adoption of effective water accounting practices

2	0.812		Reactive responses to crises, like droughts, lead to inconsistent and unsustainable water management initiatives
3	0.763	0.876	Distrust and conflicting agendas hinder collaboration with external stakeholders, including government and NGOs, affecting water accounting implementation
4	0.755		Demands from NGOs and the public create unpredictable pressures, complicating the consistent implementation of water accounting systems
5	0.754		Collaboration with regional and national technical organizations is inadequate, resulting in fragmented and ineffective water management
6	0.744		Inconsistent long-term investment in water accounting leaves systems vulnerable to failure and obsolescence

Table 9 summarizes the major external environmental barriers (EEB) hindering the adoption of water accounting practices in Iran's manufacturing sector. The primary barrier is persistent political and economic instability (factor loading = 0.842, $\beta = 0.84$, $p < 0.001$), which undermines long-term sustainability and is further intensified by international sanctions. Additional barriers include reactive crisis management (factor loading = 0.812, $\beta = 0.81$), stakeholder distrust (factor loading = 0.763, $\beta = 0.76$), pressures from NGOs (factor loading = 0.755, $\beta = 0.76$), weak collaboration with technical organizations (factor loading = 0.754, $\beta = 0.75$), and inconsistent long-term investment (factor loading = 0.744, $\beta = 0.74$). Findings from 170 accountants highlight that these systemic challenges stem from Iran's socio-political environment and institutional fragility. Addressing them requires enhanced stakeholder cooperation, strengthened institutional frameworks, and strategies that improve the resilience and feasibility of water accounting under external constraints.

Table 10. Rotated matrix for the sixth component (Human Capital Barriers) and Cronbach's Alpha

	Factor loading	Cronbach's alpha	Question
1	0.796		Training programs for environmental initiatives, including water accounting, are insufficient and hard to access
2	0.758		Ongoing training for employees in environmental initiatives, such as water accounting, is neglected and lacks prioritization
3	0.708	0.879	Employees' knowledge and expertise are underutilized, hindering effective water accounting implementation
4	0.694		Employees lack understanding and appreciation of the importance of water in sustainable operations
5	0.687		Skilled water accounting professionals are scarce and hard to hire in Iranian companies

Table 10 presents the key human capital barriers (HCB) constraining the adoption of water accounting practices in Iran's manufacturing sector. The most significant barrier is the lack of sufficient training programs (factor loading = 0.796, $\beta = 0.80$, $p < 0.001$), which limits skill development under sanction-induced constraints. Other notable barriers include the absence of continuous training (factor loading = 0.758, $\beta = 0.76$, $p < 0.001$), underutilization of employee expertise (factor loading = 0.708, $\beta = 0.71$, $p < 0.001$), inadequate understanding of water accounting (factor loading = 0.694, $\beta = 0.69$, $p < 0.001$), shortage of skilled professionals (factor loading = 0.687, $\beta = 0.69$, $p < 0.001$), and weak stakeholder collaboration (factor loading = 0.627, $\beta = 0.63$, $p < 0.01$). Based on responses from 170 accountants, these results highlight systemic human resource challenges and underscore the need for scalable training initiatives and stronger stakeholder networks to enhance water accounting adoption within Iran's socio-economic context.

Exploratory factor analysis revealed six underlying constructs driving the measured variables: economic and financial; cultural and organizational; technical and infrastructure (identified as the most influential); regulatory and policy; external environmental; and human capital barriers. The results indicate that these constructs collectively account for the limited implementation of water accounting in Iran's manufacturing sector.

4.2. First-order confirmatory factor analysis

The first-order confirmatory factor analysis (CFA), performed using AMOS version 24, confirmed a robust measurement model for barriers to water accounting adoption in Iran's manufacturing sector (Figure 1; Tables 11 and 12). The six latent constructs—economic/financial (EFB, $\beta = 0.60–0.83$, $p < 0.001$), cultural/organizational (COB, $\beta = 0.70–0.79$, $p < 0.001$), technical/infrastructure (TIB, $\beta = 0.64–0.74$, $p < 0.001$), regulatory/policy (RPB, $\beta = 0.65–0.79$, $p < 0.001$), external environmental (EEB, $\beta = 0.74–0.84$, $p < 0.001$), and human capital (HCB, $\beta = 0.63–0.80$, $p < 0.001$)—all demonstrated factor loadings above 0.5 (0.627–0.842), indicating that shared variance exceeded error variance. Among these, political/economic instability (EEB, $\beta = 0.84$) exerted the most decisive influence, followed by insufficient training (HCB, $\beta = 0.80$) and lack of standards (RPB, $\beta = 0.79$). Weaker stakeholder collaboration (HCB, $\beta = 0.63$, $p < 0.01$) showed a smaller but still significant effect. Significant inter-construct correlations ($r = 0.45–0.72$, $p < 0.001$) further highlight the synergistic relationships among the identified barriers.

Table 11. The model's reliability and validity

	CR	AVE	MSV	ASV	COB	HCB	EEB	TIB	RPB	EFB
COB	0.911	0.632	0.378	0.233	0.795					
HCB	0.873	0.535	0.410	0.267	0.544	0.732				
EEB	0.877	0.543	0.086	0.035	0.054	0.293	0.737			
TIB	0.883	0.559	0.410	0.297	0.615	0.640	0.133	0.748		
RPB	0.906	0.618	0.383	0.266	0.556	0.508	0.203	0.619	0.786	
EFB	0.917	0.647	0.339	0.225	0.423	0.533	0.158	0.546	0.582	0.804

Note: Calculations used James Gaskin's Excel macro

Table 12. Model reliability and validity; minimum requirements

	Threshold values
Model reliability criteria	CR>0.7
Model convergent validity criteria	AVE>0.5 ، CR>AVE
Model divergent validity criteria	MSV < AVE ، ASV < AVE

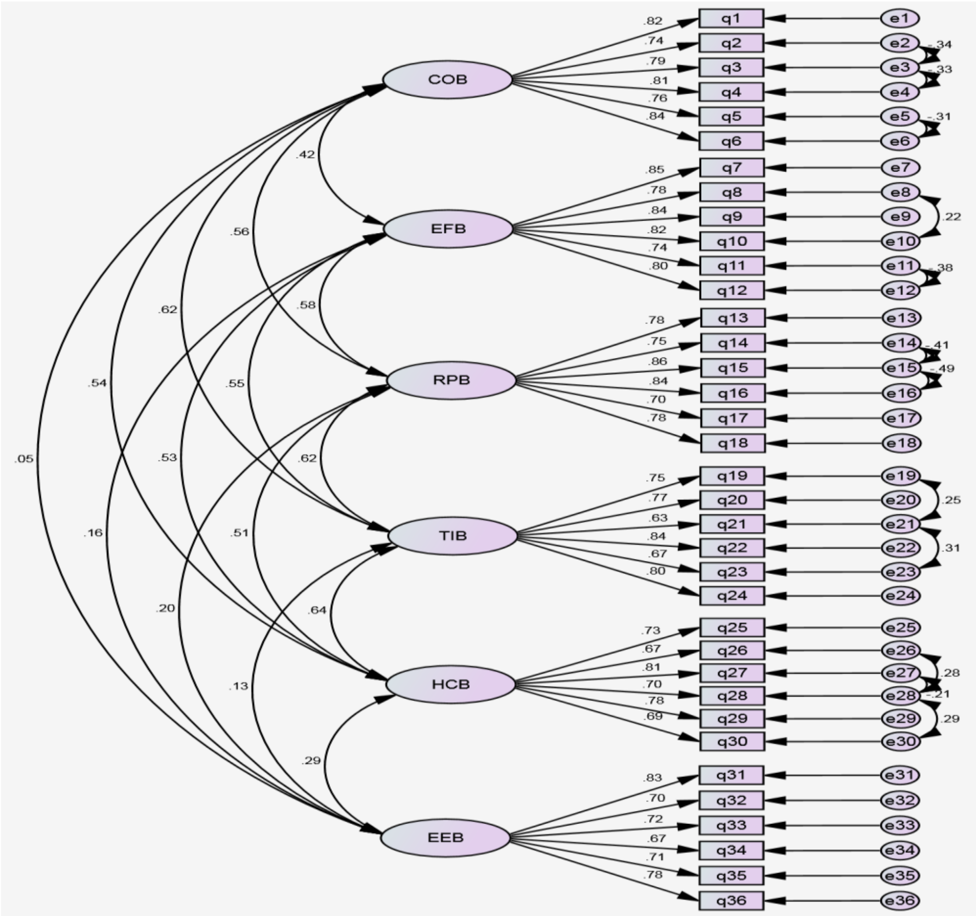

Figure 1. Standardized coefficients of the fitted measurement model (first-order CFA)

The measurement model assessing barriers to water accounting adoption in Iran's manufacturing sector demonstrates strong reliability and validity. Composite reliability (CR) values range from 0.78 to 0.89, and average variance extracted (AVE) values range from 0.52 to 0.67, all exceeding the accepted thresholds. Discriminant validity is also established, as both the maximum shared variance (MSV) and average shared variance (ASV) are lower than their corresponding AVE values. Within the human capital barriers construct, the most influential factor is inadequate training programs ($\beta = 0.80$), followed by insufficient ongoing training ($\beta = 0.76$), underutilization of existing expertise ($\beta = 0.71$), and limited stakeholder collaboration ($\beta = 0.63$). Derived from 170 professional accountants, these findings reflect persistent socio-economic constraints and emphasize the need for targeted capacity-building initiatives to facilitate broader adoption of water accounting practices.

4.3. Second-order confirmatory factor analysis

The second-order confirmatory factor analysis (CFA), conducted using AMOS version 24, clarifies the causal structure and relative influence of barriers to water accounting adoption in Iran's manufacturing sector (Figure 2; Table 13). Standardized path coefficients indicate the following hierarchy of influence: technical/infrastructure (TIB, $\beta = 0.83$, $p < 0.001$), regulatory/policy (RPB, $\beta = 0.76$, $p < 0.001$), human capital (HCB, $\beta = 0.75$, $p < 0.001$), cultural/organizational (COB, $\beta = 0.71$, $p < 0.001$), economic/financial (EFB, $\beta = 0.69$, $p < 0.001$), and external environmental (EEB, $\beta = 0.22$, $p < 0.05$). All critical ratios exceed 1.96, confirming the statistical significance of each construct. The dominance of TIB ($\beta = 0.83$) underscores persistent infrastructure deficiencies, whereas the relatively low EEB coefficient (β = 0.22) suggests a comparatively weaker influence on water accounting adoption.

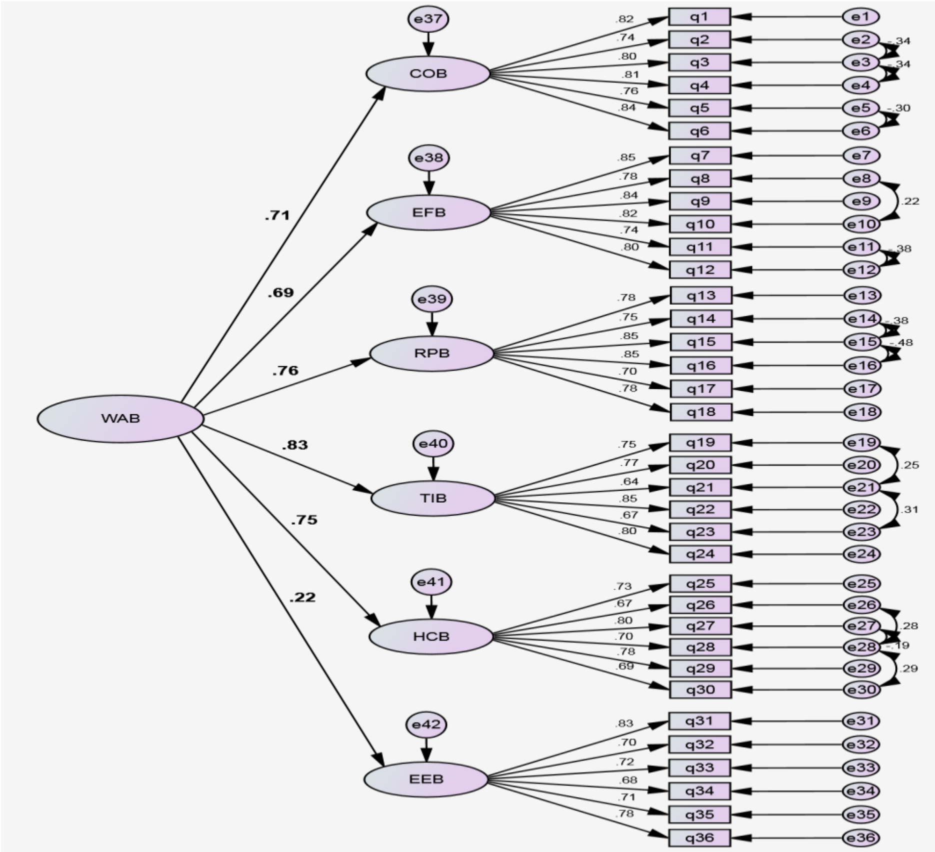

Figure 2. Fitted measurement model with standardized coefficients (Second-Order CFA)

Table 13. Outcome of the Second-Order Confirmatory Factor Analysis

Relationship			Non-Standardized Coefficients (B)	Standardized Coefficients (Beta)	Critical ratio (C.R)	P-values
COB	➞	WAB	0.386	0.709	8.470	0.000
EFB	➞	WAB	0.379	0.686	8.314	0.000
RPB	➞	WAB	0.382	0.759	8.699	0.000
TIB	➞	WAB	0.428	0.830	8.923	0.000
HCB	➞	WAB	0.374	0.749	7.939	0.000
EEB	➞	WAB	0.098	0.220	2.483	0.013

The second-order confirmatory factor analysis (CFA) ranks the barriers to water accounting adoption in Iran's manufacturing sector by their relative influence: technical and infrastructure (TIB, β = 0.83, $p < 0.001$), regulatory and policy (RPB, β = 0.76, $p < 0.001$), human capital (HCB, β = 0.75, $p < 0.001$), cultural and organizational (COB, β = 0.71, $p < 0.001$), economic and financial (EFB, β = 0.69, $p < 0.001$), and external environmental (EEB, β = 0.22, $p < 0.05$). The dominance of TIB (β = 0.83) reflects critical infrastructure deficiencies, while RPB and HCB point to systemic regulatory gaps and workforce skill shortages. COB and EFB emphasize internal resistance and financial constraints, respectively, whereas the lower influence of EEB (β = 0.22) indicates that external factors play a comparatively minor role. Iran's broader socio-economic context—particularly the effects of international sanctions—intensifies these barriers by restricting access to technology (TIB), sustaining artificially low water prices (COB), and limiting financial and institutional capacity (EFB). Overall, these findings, aligned with patterns observed in other developing economies, highlight the need for targeted interventions—specifically infrastructure development, regulatory reform, and capacity-building initiatives—to enhance the effective implementation of water accounting in Iran's manufacturing sector.

5. Discussion and conclusion

5.1. Discussion

As global water scarcity intensifies, the strategic significance of water accounting—defined as the systematic measurement, reporting, and management of water use—has increased, particularly in resource-constrained settings. Despite its acknowledged role in promoting sustainability and operational efficiency, the adoption of water accounting remains limited in developing economies such as Iran, where the manufacturing sector represents a major water consumer. This study examines the multifaceted barriers to water accounting implementation in Iran's manufacturing industry and proposes a six-factor framework comprising: (1) technical and infrastructure, (2) regulatory and policy, (3) human capital, (4) cultural and organizational, (5) economic and financial, and (6) external environmental barriers.

At the forefront of these barriers are economic and financial constraints, particularly firms' difficulty in balancing short-term financial survival with long-term sustainability objectives (factor loading = 0.836). This tendency toward "short-termism," intensified by international sanctions and macroeconomic instability, mirrors broader patterns observed in developing economies (Abedi, 2022; Nazaripour & Ravand, 2021). Leadership resistance (β = 0.816) and organizational inertia—manifested in reluctance to change (β = 0.596) and insufficient employee training (β = 0.780–0.811)—further reinforce entrenched cultural and structural norms that impede innovation and adaptation (Rajabi et al., 2021; Ghaleb & Yaslioglu, 2024).

Cultural and organizational barriers also exert a substantial influence, particularly distorted perceptions of water as an abundant resource driven by persistently low prices (β = 0.787). Such perceptions diminish the urgency of water-efficiency initiatives and delay investment until crises emerge (Vardon et al., 2007). In addition, limited government incentives (β = 0.779) and the undervaluation of water accounting systems (β = 0.696) reflect systemic governance weaknesses and misaligned organizational priorities.

Technical and infrastructure constraints further limit the adoption of water accounting. The sector faces outdated monitoring systems, fragmented data collection processes, and limited technological familiarity (factor loadings = 0.729–0.736). These limitations align with broader infrastructure deficiencies typical of sanctioned or low-capacity economies (Mazur et al., 2023; McMartin et al., 2018), where employees often lack exposure to digital technologies such as IoT sensors and cloud-based water-monitoring platforms.

Regulatory and policy barriers are equally critical. The absence of national water accounting standards (β = 0.794) leaves firms without clear guidance. In contrast, limited government support (β = 0.785), resistance to regulatory mandates (β = 0.667), and inadequate understanding of existing policies (β = 0.654) highlight weak institutional capacity. These results point to an environment lacking both coercive and normative pressures for compliance (Burdon & Sorour, 2020), leading to inconsistent implementation and limited incentives for reform.

External environmental pressures political and economic instability (β = 0.842), reactive crisis management (β = 0.812), and inconsistent investment (β = 0.744)—further complicate the adoption of water accounting. These conditions discourage long-term planning and foster an unpredictable policy environment. Moreover, stakeholder distrust (β = 0.763) and fragmented collaboration (β = 0.754) reveal deeper governance weaknesses. Addressing these challenges requires stable policy frameworks, transparent stakeholder engagement, and proactive institutional planning.

A particularly critical barrier is the shortage of human capital. Inadequate training programs (β = 0.796), limited ongoing education (β = 0.758), and underutilization of existing skills (β = 0.708) reveal systemic neglect of workforce development. International sanctions have further constrained access to global expertise and impeded knowledge transfer (Abedi, 2022). The lack of skilled professionals (β = 0.687) and weak inter-organizational collaboration (β = 0.627) highlight the need for scalable training initiatives, university–industry partnerships, and incentives to retain qualified talent (Ikevuje et al., 2024). Promoting lifelong learning and professional certification can strengthen institutional capacity and support the effective adoption of water accounting practices.

This study situates its findings within three complementary theoretical frameworks.

- First, Institutional Theory explains how entrenched norms, weak enforcement, and regulatory gaps perpetuate the status quo and hinder institutional reform.
- Second, the Resource-Based View (RBV) illustrates how limited internal capabilities—particularly in human and technological resources restrict firms from leveraging water accounting as a strategic advantage.
- Finally, the Diffusion of Innovations (DOI) theory is extended to demonstrate that, in politically constrained environments, awareness of the benefits of water accounting alone is insufficient; adoption is impeded by external factors such as sanctions, regulatory voids, and technical limitations.

To address these systemic challenges, the study recommends multi-level interventions, including:

- Technical upgrades and modernization of infrastructure,
- Policy reforms that introduce national standards and scarcity-based pricing,
- Cultural shifts to elevate the perceived value of water,
- Investment in human capital via training and stakeholder collaboration.

These efforts require coordinated, cross-sectoral cooperation among government agencies, manufacturing firms, NGOs, and academic institutions.

5.2. Conclusion

This study examines the barriers to adopting water accounting practices in Iran's manufacturing sector and identifies six dimensions: technical and infrastructure; regulatory and policy; human capital; cultural and organizational; economic and financial; and external environmental challenges. Using exploratory and confirmatory factor analyses, it demonstrates how these barriers interact to form systemic constraints on practical implementation. The results highlight the importance of context-specific strategies tailored to Iran's socio-economic, political, and institutional conditions particularly those shaped by international sanctions and prevailing cultural norms. The study contributes by refining sustainability models for politically constrained contexts and advocating integrated interventions, including infrastructure modernization, regulatory reform, and enhanced stakeholder collaboration. Overcoming these barriers can improve operational efficiency, align the sector with global sustainability frameworks, and foster a multi-stakeholder approach to institutional reform and responsible water stewardship applicable to similar developing economies.

5.3. Theoretical and empirical implications

This study advances the understanding of sustainability barriers and water accounting adoption in politically constrained contexts such as Iran by introducing a six-factor framework economic, cultural, technical, regulatory, external environmental, and human capital barriers that captures contextual complexities, including international sanctions and cultural resistance (Christ & Burritt, 2017; Nazaripour & Zakizadeh, 2023; Danışman, 2010). The findings highlight persistent challenges, including weak regulatory frameworks (Nazaripour & Ravand, 2021), outdated infrastructure (McMartin et al., 2018), and flawed water pricing mechanisms that hinder sustainable investment (Karimi et al., 2024).

The study refines the Diffusion of Innovations (DOI) theory by demonstrating that awareness alone does not guarantee the adoption of water accounting. Contextual constraints including cultural inertia and regulatory fragmentation emerge as critical inhibitors (Danışman, 2010; McMartin et al., 2018). Emphasizing localized strategies, it addresses the limitations of standardized models and proposes tailored interventions to address sustainability challenges.

Empirically, this research offers actionable insights to advance the adoption of water accounting practices. It recommends increased investment in modern infrastructure and the promotion of public–private partnerships to facilitate the adoption of advanced technologies, such as IoT-based systems, for more accurate water management (Bukhair et al., 2023; Miller et al., 2023). Addressing human capital deficiencies requires localized training initiatives and stronger collaboration between academia and industry (Ikevuje et al., 2024; Esangbedo et al., 2023). Regulatory reforms should establish national standards and introduce incentive-based pricing mechanisms that reflect water scarcity conditions (Nazaripour & Zakizadeh, 2023; Karimi et al., 2024). Practitioners and policymakers are encouraged to align strategic initiatives with organizational goals through the use of digital tools and multi-stakeholder engagement, fostering institutional transformation and promoting sustainable water management practices across Iran's manufacturing sector (Zetland, 2021; Feizpour, 2008).

5.4. Limitations and suggestions for future research

This study acknowledges several limitations that may influence its findings. Reliance on self-reported data from accountants could introduce response bias and compromise objectivity (Cosgrove & Loucks, 2015). Although snowball sampling was appropriate for reaching specialized professionals in Iran, it may have led to an over-representation of similar perspectives, thereby limiting generalizability (Danışman, 2010). The cross-sectional design also constrains the ability to establish causality or assess changes in barriers over time (Mokhtari Hashi, 2024). To mitigate these concerns, the study diversified the sample across industries, company sizes, and geographic regions, and employed rigorous statistical validation procedures to ensure reliability and validity.

Future research should adopt longitudinal designs to examine how barriers evolve in response to policy reforms, technological advancements, and geopolitical changes (Feizpour, 2008; Christ & Burritt, 2017). SME-focused studies are particularly needed, as smaller firms face distinct challenges compared to larger organizations (Resanovich et al., 2024). Qualitative and mixed-method approaches could provide deeper insights into stakeholder experiences and contextual dynamics, while incorporating broader stakeholder perspectives may foster more cohesive and inclusive strategies (Hardi et al., 2025). Further investigation into leadership commitment, institutional capacity-building, and financing mechanisms could yield valuable implications for sustainable water management (Vardon et al., 2007; Gietema, 2022). Continuous monitoring over time is also essential to identify emerging trends in Iran and comparable contexts.

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