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Patent Intelligence for Water Security Governance: Mapping Technological Trajectories and Policy Options for Iran

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ABSTRACT

This article examines how patent intelligence can support screening-oriented water-security governance for Iran without treating patent data as sufficient evidence for final policy decisions. Method: The study conducts a first-level patent landscape analysis of 276,890 records retrieved from Lens.org on 20 April 2026 through a structured query covering titles, abstracts, and claims, combined with water-related CPC/IPC classification filters. The analysis examines temporal trends, legal status, document type, technology classifications, applicants, owners, jurisdictions, and citation patterns. Findings: The results show that patenting activity in the selected dataset is strongly concentrated in treatment, purification, wastewater reuse, membrane processes, monitoring systems, smart water networks, remote sensing, and climate-related water intelligence. They also indicate that these technologies are embedded in legally structured and institutionally concentrated global innovation systems. Conclusion: For Iran, patent intelligence can help identify candidate technology areas, ownership concentration, legal-status patterns, dependency-risk exposure, and future assessment needs. However, final policy prioritization requires complementary techno-economic, environmental, claim-level legal, institutional, and domestic capability assessments.

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1. Introduction

Water security is increasingly shaped not only by hydrological conditions, infrastructure capacity, and demand management, but also by technological capability. Climate variability, population growth, pollution, infrastructure aging, and competing water uses have intensified the need for technologies that can monitor, treat, reuse, allocate, and protect water resources. The United Nations World Water Development Report 2024 frames water as a foundation for prosperity, stability, and cooperation, while the IPCC Sixth Assessment Report shows that climate change is already increasing water-related risks through droughts, floods, water-quality deterioration, and pressure on water-dependent systems (UNESCO WWAP, 2024; IPCC, 2022). From this perspective, water security is no longer only a resource-management issue; it is also a technological, institutional, and governance challenge.

This shift is particularly important for countries facing structural water stress. Iran, located in an arid and semi-arid region, faces persistent pressures from uneven precipitation, high agricultural water withdrawal, groundwater depletion, declining recharge, and rising urban, industrial, and agricultural demand. FAO reports that agriculture accounts for the dominant share of Iran's water withdrawal, while recent studies show that groundwater depletion and declining groundwater recharge have become long-term threats to the country's water resilience (FAO, 2008; Ashraf, Nazemi, & AghaKouchak, 2021; Noori et al., 2023). These pressures cannot be addressed through supply-side infrastructure alone. They require a policy approach that links water governance with science, technology, innovation, and strategic intelligence.

In this context, technologies such as wastewater reuse, desalination, membrane processes, water purification, water-quality monitoring, groundwater observation, leak detection, remote sensing, smart water systems, digital twins, and drought/flood intelligence can form part of the technological base of future water security. However, their relevance for any specific country cannot be inferred from patent activity alone. These technologies differ in maturity, cost structure, environmental suitability, infrastructure requirements, intellectual-property intensity, and local adaptability. Patent information can therefore help identify where global technological activity is concentrated, but it should be combined with techno-economic, environmental, legal, and institutional assessment before being translated into national policy priorities (EPO, 2024; OECD, 2009).

A central governance challenge is that countries under water stress may approach water technologies mainly as purchasable equipment rather than as capabilities that require learning, maintenance, adaptation, regulation, and long-term institutional coordination. Such an approach can increase exposure to supplier concentration, licensing barriers, fragmented procurement, constrained maintenance capacity, and limited opportunities for domestic learning. Patent intelligence can contribute to strategic awareness by showing where inventive activity is concentrated, which actors and jurisdictions are visible, and which areas may require closer technical, legal, or institutional assessment. In this article, anticipatory governance is not used to imply that patent analysis alone constitutes a foresight exercise. Rather, retrospective patent intelligence is treated as one input into anticipatory governance and mission-oriented innovation policy (Guston, 2014; Mazzucato, 2018; Schot & Steinmueller, 2018).

Patent intelligence provides one practical way to support preliminary strategic understanding. Patent documents contain technical, legal, geographical, institutional, and temporal information about inventive activity. When analyzed systematically, they can reveal expanding technological areas, major applicants and owners, geographical patterns of protection, legal-status structures, citation linkages, and possible areas of technological concentration. However, patent data cannot by themselves determine technological quality, economic feasibility, environmental suitability, legal freedom to operate, or deployment readiness. The OECD Patent Statistics Manual emphasizes that patent data can support the measurement of science and technology activities if their limitations and biases are recognized (OECD, 2009). WIPO similarly presents patent landscape analysis as a method for mapping technological fields, identifying actors, and supporting strategic decision-making (WIPO, 2015). In water-related technologies, the European Patent Office has shown that patent information can illuminate trends in water provision, pollution control, and protection from water-related hazards (EPO, 2024).

For Iran, the key issue is not merely identifying which water technologies exist globally. The more cautious and policy-relevant question is how global patent patterns can help screen candidate technology areas for further assessment. Desalination, wastewater reuse, smart monitoring, leak detection, groundwater observation, membrane systems, and digital decision-support platforms differ in maturity, cost structure, intellectual-property intensity, local adaptability, environmental implications, and relevance to Iran's water challenges. Therefore, patent intelligence should not be treated as a final prioritization tool. Its value is to identify areas where additional techno-economic, environmental, legal, institutional, and domestic capability assessments are needed before policy decisions are made.

Although Iran's water-policy debates have extensively addressed scarcity, water transfer, agricultural consumption, pricing, groundwater depletion, and institutional coordination, the technological and intellectual-property dimensions of water security require more systematic integration into policy analysis. These conventional policy themes remain necessary, but they do not fully capture the technological foundations of future water resilience. Even successful reforms in water allocation may produce limited strategic resilience unless they are accompanied by capability development in treatment technologies, monitoring systems, membrane materials, digital control platforms, sensor networks, data governance, and adaptive water-intelligence systems. This article therefore argues that Iran's water policy can be strengthened by connecting water governance more explicitly with science, technology, innovation, and patent intelligence.

Against this background, the central problem addressed in this article is the need to strengthen the integration between water-security policy and technology-intelligence mechanisms in Iran. The article asks how patent intelligence can support preliminary strategic screening for anticipatory governance of water-security technologies. It does not treat patent data as a complete measure of innovation, technological performance, market success, environmental suitability, legal freedom to operate, or domestic deployment feasibility. Rather, it uses patent information as a strategic signal for identifying technological concentration, dominant actors, jurisdictional patterns, legal-status structures, and areas that may require further dependency, legal, technical, or capability assessment. The broader aim is to show how global patent trends can inform, but not determine, Iran's science, technology, and innovation policy in the water-security domain.

Accordingly, the study is guided by three research questions. First, what are the dominant technological trajectories in the global patent landscape of selected water-security technologies? Second, which legal-status patterns, applicants, owners, jurisdictions, and citation structures shape potential access, dependency-risk exposure, and learning opportunities in these technologies? Third, how can patent-landscape signals be translated into a cautious, screening-oriented policy framework for Iran's science, technology, and innovation system in the field of water-security governance?

To answer these questions, the present study uses patent landscape analysis to examine the global landscape of selected water-security technologies and develop screening-oriented implications for Iran's science, technology, and innovation system. The study draws on patent data retrieved from Lens.org through a structured search strategy covering desalination, water reuse, wastewater treatment, water purification, water-quality monitoring, groundwater monitoring, leak detection, pipeline monitoring, smart water systems, digital twins, remote sensing, flood monitoring, and drought monitoring. The resulting patent landscape is analyzed in terms of temporal growth, technological concentration, legal status, document type, major applicants and owners, jurisdictional distribution, classification patterns, and citation linkages. These indicators are interpreted as first-level signals rather than as sufficient evidence for final technology prioritization, legal freedom-to-operate conclusions, or deployment decisions.

The contribution of this article is threefold. First, it connects patent landscape analysis with anticipatory governance by positioning retrospective patent intelligence as an input to, rather than a substitute for, foresight and policy assessment. Second, it reframes water-security technologies as part of science, technology, and innovation policy while recognizing that patent signals must be complemented by techno-economic, environmental, legal, institutional, and domestic capability assessments. Third, it provides an Iran-oriented screening framework that shows how technological concentration, ownership structures, legal-status patterns, and jurisdictional distribution can help identify candidate areas for further policy analysis, strategic technology monitoring, public procurement review, and domestic capability-building. Figure 1 summarizes the analytical framework of the study, moving from patent intelligence to anticipatory governance of water-security technologies.

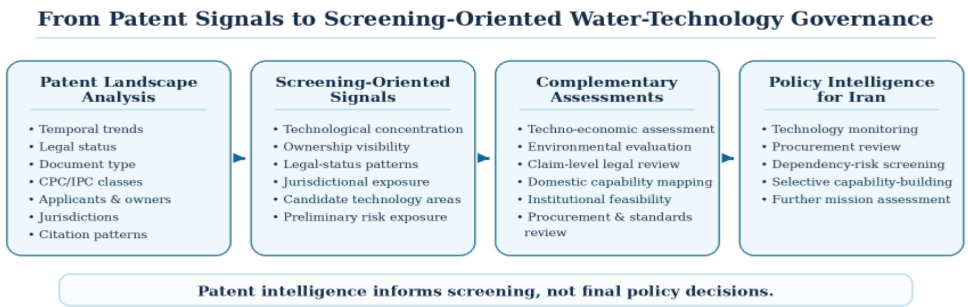

Fig. 1. Analytical framework of the study: from patent signals to screening-oriented water-technology governance for Iran.

2. Theoretical Background

2.1. Water security as a technology-governance problem

Water security is commonly understood as the capacity of a society to ensure sustainable access to adequate quantities and acceptable quality of water, while protecting populations, ecosystems, and economies from water-related risks. This definition moves the analysis beyond physical scarcity and includes governance, risk, infrastructure, and adaptive capacity (Grey & Sadoff, 2007; UN-Water, 2013). Cook and Bakker (2012) show that water security is not a single technical concept but an emerging paradigm shaped by social, ecological, economic, and institutional priorities. For countries facing chronic stress, the technological dimension is central: reuse, desalination, monitoring, leakage control, and climate-intelligence systems increasingly mediate the relationship between water demand and water availability.

2.2. Technology security in water-security governance

In this article, technology security does not refer narrowly to cybersecurity or to the protection of digital systems alone. It refers to the capacity of a country to access, understand, maintain, adapt, regulate, and selectively develop critical technologies that support water resilience. In the water-security domain, this includes technologies related to treatment, reuse, desalination, monitoring, leakage detection, groundwater observation, digital water systems, and climate-related water intelligence.

Technology security is therefore treated as a governance concept rather than a purely technical concept. It concerns the ability of public agencies, utilities, firms, research institutions, and regulatory bodies to manage dependency-risk exposure, intellectual-property constraints, supplier concentration, maintenance requirements, data-related vulnerabilities, and standards embedded in water technologies. From this perspective, the strategic question is not whether a technology exists globally, but whether it can be accessed, evaluated, adapted, governed, and integrated into domestic water-security priorities under acceptable legal, economic, environmental, and institutional conditions.

This definition also clarifies the role of patent intelligence in the article. Patent data do not determine technology security by themselves. Rather, they provide first-level signals about technological concentration, ownership structures, legal-status patterns, jurisdictional distribution, and knowledge linkages. These signals can help identify where further technical, economic, environmental, legal, and domestic capability assessments are needed before policy decisions are made.

2.3. Patent intelligence and technology foresight

Patent intelligence refers to the systematic analysis of patent information for strategic decision-making. Patent documents are legal-technical artefacts: they describe claimed inventions, identify applicants and owners, assign technology classifications, and show where protection is sought. The patent literature warns against naive counting but also recognizes patents as valuable indicators of technological trajectories, competitive positions, and knowledge flows (Ernst, 2003; OECD, 2009; WIPO, 2015). Patent landscape analysis is especially useful when a policy community must identify leading actors, crowded fields, emerging niches, and areas where expired or discontinued patents may support learning (Abbas et al., 2014; van Rijn & Timmis, 2023).

2.4. Anticipatory governance and mission-oriented innovation policy

Anticipatory governance emphasizes the need to identify emerging risks and opportunities before they become locked into infrastructure, regulation, markets, or dependency pathways (Guston, 2014; Tõnurist & Hanson, 2020). In water technology, this means connecting early signals from patents, standards, procurement, and field deployment. Mission-oriented innovation policy provides the policy logic for this connection: instead of dispersing public support across isolated projects, government can define strategic missions, align ministries and agencies, use procurement to create demand, and support experimentation across firms, universities, and public utilities (Mazzucato, 2018; Robinson & Mazzucato, 2019).

3. Literature Review

Previous studies relevant to this article can be grouped into three streams: patent-based studies on water-related technologies, methodological studies on patent intelligence as a policy tool, and water-security studies on Iran. The first stream shows that patent analysis has already been used to map technological activity in the water sector. The European Patent Office (2024), for example, provides a broad patent-based analysis of water-related technologies, covering water provision, pollution control, and protection from water-related hazards. WIPO's patent landscape report on desalination technologies also demonstrates how patent data can reveal technology fields, applicants, family structures, and links between desalination and alternative energy systems (WIPO, 2011). More focused studies have examined industrial wastewater treatment and membrane-based wastewater treatment through patent analysis and text mining, identifying technological trends, major applicants, and knowledge clusters in these subfields (Mao et al., 2022; Cerveira et al., 2022). These studies confirm the value of patent analysis for mapping water-related innovation, but they are mostly global, descriptive, or technology-specific.

A second stream treats patent information as a strategic intelligence tool for policy and decision-making. The OECD Patent Statistics Manual emphasizes that patent data can support the measurement of science and technology activities, provided that their limitations are recognized (OECD, 2009). WIPO's guidelines for patent landscape reports similarly present patent analysis as a structured method for mapping technological fields, identifying actors, and supporting strategic decisions (WIPO, 2015). Van Rijn and Timmis (2023) further argue that patent landscape analysis can help identify technology trends, research gaps, regulatory issues, and opportunities for better allocation of research and innovation funding. This literature is important for the present study because it moves patent analysis beyond counting inventions and positions it as part of a broader strategic intelligence system.

A third stream concerns Iran's water-security and water-governance challenges. Ashraf, Nazemi, and AghaKouchak (2021) show that groundwater depletion in Iran is strongly shaped by anthropogenic drought and unsustainable water use, while Noori et al. (2023) document a decline in groundwater recharge. Governance-oriented studies also show that Iran's water crisis is not only hydrological but institutional. Nabavi (2018) explains the failure of groundwater regulation in controlling over-abstraction. Nouri, Homaee, Pereira, and Bybordi (2023) identify governance gaps as a central factor in Iran's agricultural water-management dilemma. Ghafari et al. (2024) also show that water governance in Iran involves complex multi-level coordination challenges. These studies are valuable, but they rarely examine the technological and intellectual-property dimensions of future water security.

Taken together, the literature reveals a clear gap. Existing patent studies in the water sector mainly map global or sector-specific technological trends. Existing studies on Iran's water security mainly focus on hydrological, agricultural, institutional, or regulatory problems. What remains underdeveloped is the link between global patent trends in water-security technologies and Iran's science, technology, and innovation policy. This article addresses that gap by using patent data from Lens.org to examine selected technologies related to water security—such as desalination, wastewater reuse, water purification, water-quality monitoring, groundwater monitoring, leak detection, smart water systems, digital twins, remote sensing, flood monitoring, and drought monitoring—and by interpreting these patterns as signals for anticipatory governance, domestic capability-building, and technology-policy prioritization in Iran.

Table 1.
Selected studies related to patent intelligence, water-security technologies, and Iran's water governance.

Study	Main Focus	Contribution	Remaining Gap
European Patent Office (2024)	Water-related technologies	Maps patenting trends in water provision, pollution control, and protection from water-related hazards	Global scope; limited policy interpretation for Iran
WIPO (2011)	Desalination technologies	Identifies patent families, applicants, and technology fields in desalination	Technology-specific; weak link to national STI policy
Mao et al. (2022)	Industrial wastewater treatment	Uses patent analysis and text mining to identify trends and clusters	Sector-specific; limited governance interpretation
Cerveira et al. (2022)	Membrane wastewater treatment	Shows patent trends in membrane-based treatment technologies	Narrow technological focus
van Rijn & Timmis (2023)	Patent landscape analysis	Frames patent analysis as a tool for policy and research funding	Not specific to water security or Iran
Ashraf et al. (2021); Noori et al. (2023)	Iran's groundwater stress	Demonstrate depletion and recharge decline in Iran's groundwater systems	Hydrological focus; limited technology-policy linkage
Nabavi (2018); Nouri et al. (2023); Ghafari et al. (2024)	Iran's water governance	Identify regulatory, agricultural, and coordination weaknesses	Limited attention to patents, technology capability, and IP risks

4. Methods

This study uses a first-level patent landscape analysis with a screening-oriented policy interpretation. The purpose is not to test a causal hypothesis or to determine final technology priorities for Iran, but to map technological trajectories, ownership structures, legal-status patterns, jurisdictional distribution, and strategic signals relevant to water-security governance. Patent landscape analysis is appropriate for this purpose because patent documents provide structured technical, legal, institutional, geographical, and temporal information about inventive activity. In this article, patent data are treated as preliminary indicators of technological direction, knowledge concentration, ownership patterns, and areas requiring further assessment. They are not treated as direct measures of technological quality, market success, economic feasibility, environmental suitability, legal freedom to operate, or field deployment readiness.

The empirical data were retrieved from Lens.org on 20 April 2026. Lens.org was selected because it integrates patent records from multiple patent offices and provides analytical fields related to patent documents, patent families, applicants, owners, legal status, jurisdictions, technology classifications, citation patterns, and temporal trends. The final dataset contained 276,890 patent records, 232,340 simple patent families, 227,575 extended patent families, 112,281 cited patents, 136,348 citing patents, and 698,724 patent citations. The unit of analysis in the descriptive results is the patent record, unless otherwise stated. Patent-family indicators are reported separately to show the scale of related inventive activity beyond individual patent documents. The dataset is therefore used to describe the structure of global patent activity in selected water-security technologies, not to evaluate the technical performance or deployment feasibility of individual technologies.

The search strategy combined keyword-based retrieval with patent-classification filters. Keywords were searched in patent titles, abstracts, and claims. The keyword set covered selected water-security technologies, including desalination, water reuse, wastewater reuse, water recycling, water purification, water treatment, wastewater treatment, water-quality monitoring, groundwater monitoring, leak detection, pipeline monitoring, smart water systems, digital twins, remote sensing, flood monitoring, and drought monitoring. These keywords were selected because they represent major technological domains related to water provision, treatment, reuse, monitoring, infrastructure resilience, data-driven water management, and climate-related water intelligence.

To reduce the risk of relying only on keyword retrieval, the search also used relevant Cooperative Patent Classification and International Patent Classification filters. The main classification filters included CPC and IPC codes related to C02F and E03B, as well as the CPC code Y02A20. C02F was used because it covers treatment of water, wastewater, sewage, or sludge. E03B was included because it captures installations and methods related to water supply. Y02A20 was included because it covers technologies related to climate-change adaptation in water conservation, water availability, and water management. The combination of semantic keywords and classification filters was intended to balance breadth and relevance: the keywords captured policy-relevant and emerging terminology, while the classification filters anchored the dataset in established water-related technological domains. Because these filters are strongly connected to water treatment, water supply, and climate-adaptation categories, the empirical results should be interpreted as treatment- and water-technology-oriented rather than as a complete representation of all governance, digital, or intelligence dimensions of water security.

The full Lens.org search query is reported in Appendix 1 to support transparency and reproducibility. The search was intentionally designed to capture a cross-cutting field of selected water-security technologies rather than a single narrow technology such as membrane desalination or municipal wastewater treatment. However, this breadth also means that the dataset may include adjacent technologies that are only indirectly related to water security and may underrepresent some digital, governance, or intelligence-oriented technologies that are not strongly captured by the selected classification filters. For this reason, the findings are interpreted at the landscape level and are not used to make claim-level legal judgments, freedom-to-operate conclusions, or deployment recommendations for individual patents or technologies.

The analysis proceeded in five descriptive steps. First, the overall size and temporal distribution of patent activity were examined to identify long-term growth patterns in selected water-security technologies. Second, legal-status and document-type distributions were analyzed to distinguish between active, pending, expired, inactive, and discontinued records, as well as between applications, granted patents, and other document types. Third, CPC and IPC classifications were analyzed to identify the dominant technological areas within the dataset. Fourth, applicant, owner, and jurisdictional patterns were examined to identify the institutional and geographical structure of inventive activity and possible concentration of technological control. Fifth, citation indicators were reviewed to identify broad knowledge linkages and potential knowledge anchors within the landscape. These steps were designed to provide a first-level mapping of patent signals; they do not constitute patent-quality assessment, claim interpretation, technology-network analysis, or legal due diligence.

The analytical indicators used in the study include annual patent-document counts, simple and extended patent families, legal status, document type, CPC classifications, IPC classifications, applicants, owners, jurisdictions, cited patents, citing patents, and patent citations. These indicators were selected because they provide first-level signals about technological activity, legal-status structure, institutional concentration, geographical protection, and knowledge linkages. They do not, by themselves, establish patent value, technological superiority, commercial success, environmental performance, or legal freedom to operate. The results are therefore interpreted through the lens of anticipatory governance, technology security, and mission-oriented innovation policy as preliminary policy intelligence rather than as a sufficient basis for final policy decisions. Technology security is used as an interpretive concept in this study, not as a directly measured variable; the patent indicators are treated as signals that can point to areas where further capability, legal, technical, environmental, and institutional assessment is required.

The policy interpretation follows a structured and cautious logic. Patent patterns are used to identify candidate areas that may be relevant to Iran's water-security challenges, domestic capability-building, supplier concentration, intellectual-property exposure, and future mission-oriented policy assessment. This interpretive step does not imply that patent data alone can determine national priorities, technology missions, procurement decisions, localization strategies, or legal-risk conclusions. Rather, patent intelligence is used as one layer of preliminary strategic evidence that should be combined with hydrological data, techno-economic analysis, environmental evaluation, claim-level legal assessment where required, industrial capability mapping, expert judgment, market analysis, public-procurement needs, and institutional assessment.

The study has several limitations. First, patent data over-represent codified, patentable, and commercially strategic inventions, while under-representing tacit know-how, informal engineering practices, trade secrets, and non-patented technologies. Second, the results depend on the search design; broad keywords increase coverage but may also introduce noise, while narrow queries may exclude relevant inventions. Third, the classification filters used in the study anchor the dataset strongly in treatment, water-supply, and climate-adaptation categories; therefore, the analysis may underrepresent some governance-oriented, digital-platform, or intelligence-oriented dimensions of water security. Fourth, patent counts and simple citation indicators do not measure technological effectiveness, patent quality, economic feasibility, environmental suitability, commercial success, deployment readiness, or social acceptance. Fifth, legal status and ownership information may change over time, so the findings should be interpreted as a snapshot of the dataset at the time of retrieval. Sixth, the study provides a landscape-level analysis and does not conduct claim-level interpretation, freedom-to-operate analysis, design-around assessment, techno-economic analysis, environmental assessment, or empirical mapping of Iran’s domestic technological capabilities. These limitations mean that the findings should be used for preliminary strategic orientation and screening-oriented policy intelligence, not as a substitute for technical evaluation, legal due diligence, investment appraisal, or final national technology prioritizationFurthermore, Fig. 1 illustrates a typical flow path for a manuscript from initiation to publication.

Table 2.
Summary of the methodological design.

Component	Description
Research design	First-level patent landscape analysis with screening-oriented policy interpretation.
Data source and retrieval date	Lens.org patent records, retrieved on 20 April 2026.
Search strategy	Keyword search in titles, abstracts, and claims, combined with CPC/IPC classification filters.
Technology scope	Selected water-security technologies, including desalination, reuse, treatment, monitoring, leak detection, smart water systems, digital twins, remote sensing, and drought/flood monitoring.
Main indicators	Temporal trends, legal status, document type, CPC/IPC classes, applicants, owners, jurisdictions, and citation patterns.
Interpretation logic	Patent patterns are interpreted as first-level signals for identifying candidate areas requiring further technical, legal, environmental, institutional, and domestic capability assessment.
Main limitation	The study does not conduct claim-level legal analysis, freedom-to-operate assessment, techno-economic assessment, environmental assessment, or empirical mapping of Iran’s domestic technological capabilities.

5. Results

This section presents the descriptive results of the patent landscape analysis. The results are organized around nine analytical dimensions: overall patent activity, legal status, document type, CPC classifications, IPC classifications, applicants, owners, jurisdictions, and citation patterns. The purpose of this section is to report the main empirical patterns observed in the dataset. Policy interpretation and implications for Iran are developed separately in the Discussion section.

5.1. Overall Pattern of Patent Activity

The Lens.org search retrieved a large patent dataset related to selected water-security technologies. The dataset includes 276,890 patent records, 232,340 simple patent families, 227,575 extended patent families, 112,281 cited patents, 136,348 citing patents, and 698,724 patent citations. This scale indicates that the selected technologies—covering desalination, wastewater treatment, water reuse, water purification, monitoring systems, leak detection, smart water systems, digital twins, remote sensing, flood monitoring, and drought monitoring—belong to a mature and highly active global field of inventive activity.

Patent data should not be interpreted as a direct measure of technological quality or deployment success. As emphasized in patent-analysis literature, patent records are better understood as structured signals of inventive activity, legal protection, knowledge accumulation, and strategic market orientation (OECD, 2009; WIPO, 2015). In this study, the value of the dataset lies not in counting patents alone, but in identifying where technological concentration, ownership, legal protection, and dependency risks may appear within the broader landscape of water-security technologies.

Figure 2 shows a long period of limited patent publication followed by a clear acceleration from the late 1990s and especially after the 2010s. The sharp rise in the 2010s and early 2020s suggests that water-security technologies have moved from a relatively specialized engineering domain into a major field of global technological activity. The visible decline in the most recent years should be interpreted cautiously because patent publication is affected by filing-publication delays and database updating cycles.

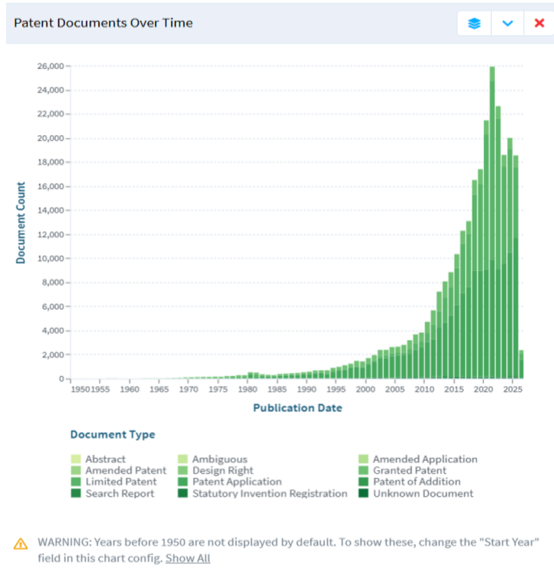

Fig. 2. Patent documents over time in selected water-security technologies.

5.2. Legal Status and the Structure of Technological Access

The legal-status distribution shows that active patents form the largest visible category, followed by discontinued, inactive, pending, and expired records. This structure matters because the patent landscape is not only a record of past inventive activity; it also indicates which parts of the technological field may remain under legal protection and which parts may have moved into inactive, discontinued, or expired status.

Figure 3 presents the legal-status distribution of patent documents in selected water-security technologies. The dominance of active and pending patents indicates that many technologies in this field remain under legal protection or are still moving through patent procedures. This is particularly relevant in technology areas such as membrane systems, desalination components, advanced filtration, water-quality sensors, smart monitoring platforms, and digital water infrastructure.

At the same time, the presence of discontinued, inactive, and expired records shows that the landscape also contains technical information that may no longer be protected in the same way as active patents. However, legal inactivity does not automatically imply technological relevance, commercial feasibility, or suitability for deployment. These distinctions require more focused technical and legal assessment at the subfield level.

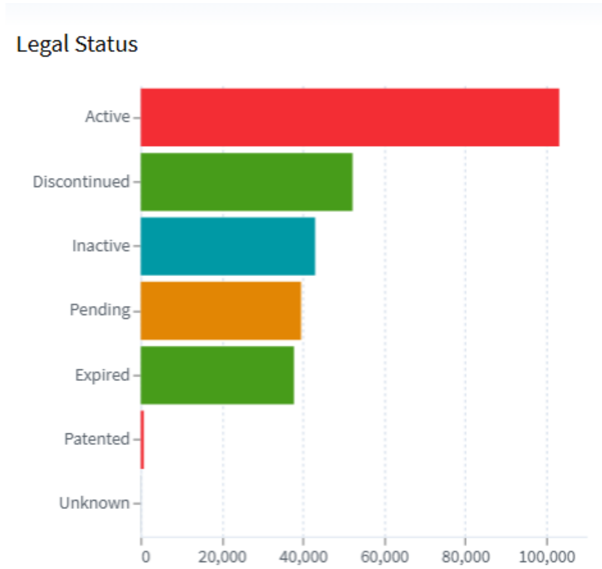

Fig. 3. Legal status distribution of patent documents in selected water-security technologies.

5.3. Document Type and Maturity of the Patent Landscape

The document-type distribution shows that patent applications and granted patents dominate the dataset, while other document types occupy much smaller shares. This pattern confirms that the field includes both early-stage legal claims and more mature granted rights.

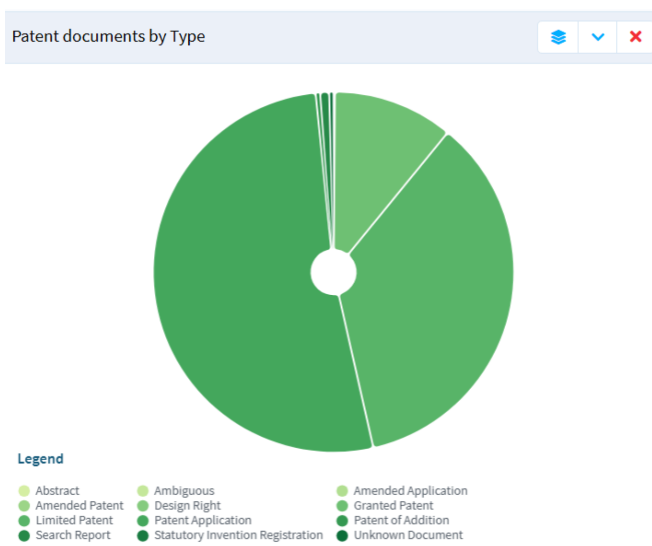

Fig. 4. Patent documents by type in selected water-security technologies.

This distinction is important for interpreting the maturity and legal structure of the patent landscape. Patent applications often indicate emerging technological interest, but they do not necessarily represent enforceable rights. Granted patents, by contrast, may indicate stronger legal control over specific technological solutions. Therefore, applications and granted patents should not be interpreted in the same way. Applications are more useful as early signals of inventive activity, while granted patents provide a clearer indication of protected technological assets.

The coexistence of applications and granted patents suggests that the field contains both emerging and more established areas of technological development. At the landscape level, this distribution shows that selected water-security technologies are not limited to exploratory research or early-stage invention. They also include a substantial body of legally recognized technological claims, indicating a relatively mature and strategically significant innovation field.

5.4. Technological Concentration Based on CPC Classifications

The CPC classification results show that patenting activity is strongly concentrated in treatment, purification, filtration, wastewater, membrane, and climate-related water technologies. The largest CPC category in the dataset is Y02W10/10 with 34,324 records, followed by C02F9/00 with 29,011 records and C02F1/001 with 25,194 records. Other important CPC categories include C02F1/441 with 14,876 records, Y02A20/131 with 13,794 records, C02F1/66 with 12,911 records, C02F1/283 with 12,203 records, and Y02A20/124 with 10,645 records.

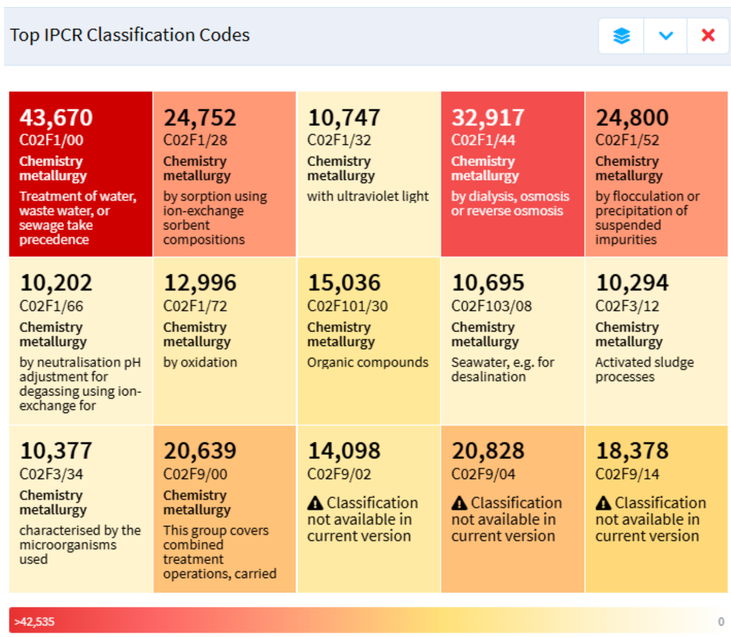

Fig. 5. Top CPC classification codes in selected water-security technologies.

This pattern shows that the technological core of the dataset is concentrated in concrete water-technology domains rather than in water governance as a general policy category. The dominant areas include wastewater treatment, multistage water treatment, filtration-based treatment, reverse osmosis, ultrafiltration, microfiltration, ion exchange, disinfection, desalination, and climate-adaptation-related water technologies.

The presence of Y02 categories is also significant. These classifications connect parts of the water-technology landscape to climate-change mitigation, adaptation, and environmental sustainability. This suggests that water-security technologies are increasingly positioned within the broader climate-technology and environmental-innovation agenda. The CPC distribution therefore indicates that the patent landscape is not only technically concentrated, but also linked to wider sustainability and adaptation-oriented technology classifications.

5.5. Technological Concentration Based on IPC Classifications

The IPC results confirm the general pattern observed in the CPC classifications. The largest IPC category is C02F1/00, with 43,670 records, covering treatment of water, wastewater, or sewage. This is followed by C02F1/44, with 32,917 records, related to dialysis, osmosis, or reverse osmosis; C02F1/52, with 24,800 records, related to flocculation or precipitation of suspended impurities; and C02F1/28, with 24,752 records, related to sorption using ion-exchange materials or sorbent compositions. Other major categories include C02F9/04 with 20,828 records, C02F9/00 with 20,639 records, and C02F9/14 with 18,378 records.

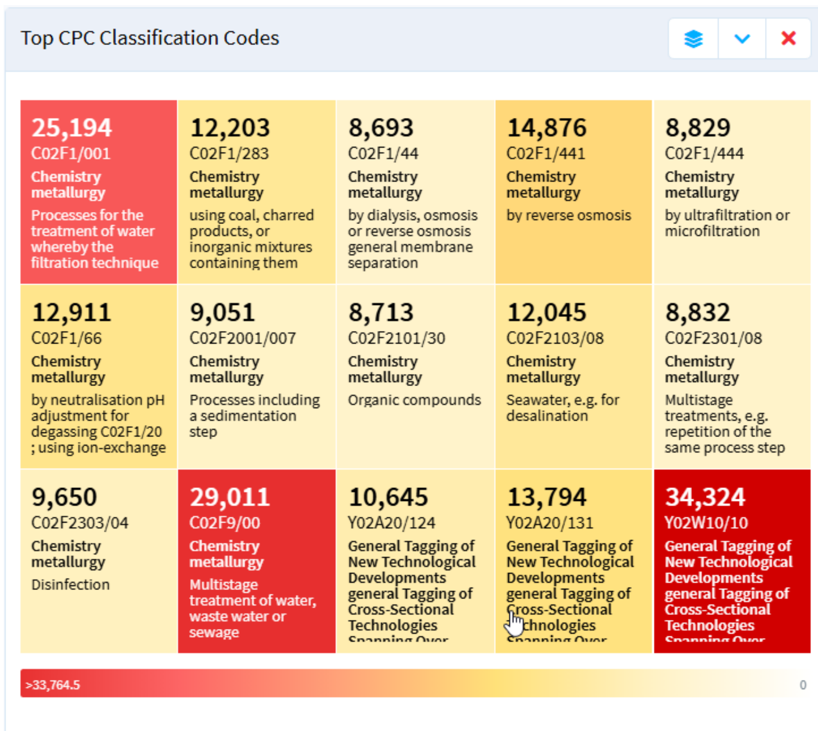

Fig. 6. Top IPC classification codes in selected water-security technologies.

The convergence between CPC and IPC results strengthens the internal consistency of the technological interpretation. Both classification systems point to the same broad conclusion: patenting activity in selected water-security technologies is heavily centered on treatment, purification, separation, reuse, and process integration.

The IPC distribution also indicates that the field is not dominated by a single technological pathway. Instead, it includes several related clusters: water and wastewater treatment, membrane-based processes, chemical treatment, precipitation and flocculation, sorption and ion-exchange materials, and integrated multistage treatment systems. This supports the interpretation that water-security innovation is developing through a portfolio of treatment and monitoring technologies rather than through one dominant technology alone.

5.6. Main Applicants and Institutional Structure of Innovation

The applicant distribution shows a mixed institutional landscape. Leading applicants include large industrial firms, specialized water-technology companies, Chinese and Japanese corporations, universities, and energy-related actors. The top visible applicants include Kurita Water Industries with 1,362 records, Midea Group with 1,173 records, Nanjing University of Technology with 780 records, a Foshan Shunde-based applicant with 780 records, China Petroleum/Sinopec with 768 records, Gree Electric Appliances with 711 records, Hitachi Ltd. with 663 records, General Electric with 635 records, Toshiba Corp. with 622 records, and Mitsubishi Heavy Industries with 604 records.

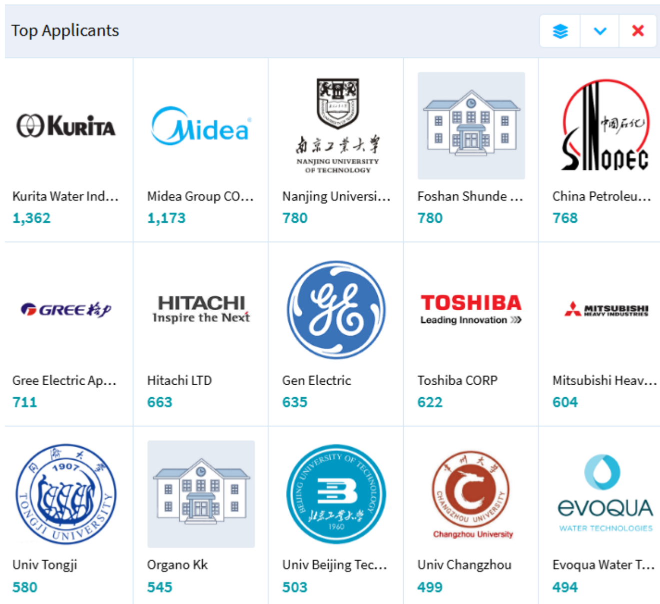

Fig. 7. Top applicants in selected water-security technologies.

This applicant structure shows that water-security technologies are not produced by a single type of institution. The field is shaped by large engineering firms, industrial conglomerates, specialized water companies, energy companies, universities, and technology-intensive manufacturing actors. This mixed structure is important because it indicates that water-security innovation is distributed across industrial, academic, and infrastructure-related organizations.

The presence of both firms and universities among leading applicants suggests that the field combines applied industrial invention with research-based technological development. The visibility of Chinese and Japanese actors also indicates that East Asian applicants play a significant role in the inventive activity captured by the dataset. Overall, the applicant distribution points to a diversified but institutionally concentrated innovation landscape.

5.7. Patent Ownership and Control Over Technological Assets

The owner distribution differs from the applicant distribution. This distinction matters because applicants show who filed patent documents, while owners may better reflect who currently controls the protected assets. The top visible owners include Evoqua Water Technologies with 326 records, Ecolab USA with 266 records, Siemens with 256 records, Veolia Water Solutions with 216 records, Siemens Water Technologies with 201 records, General Electric with 193 records, BI Technologies with 171 records, Mitsubishi Heavy Industries with 130 records, Saudi Arabian Oil Company with 106 records, and King Fahd University with 95 records.

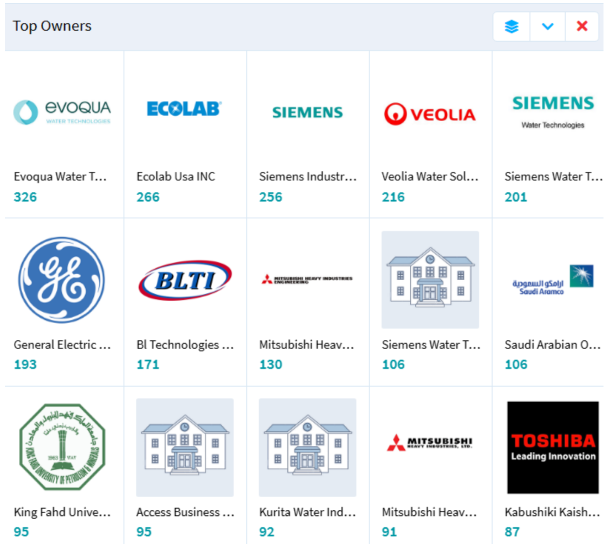

Fig. 8. Top patent owners in selected water-security technologies.

The owner data point to a more concentrated structure of technological control among specialized water-technology firms, multinational industrial actors, and selected research institutions. This differs from the broader applicant landscape, where universities, manufacturers, and industrial corporations appear together as filing actors. Ownership analysis is therefore necessary because the current control of patent assets may not be identical to the original filing structure.

The presence of specialized firms such as Evoqua, Ecolab, Siemens Water Technologies, and Veolia Water Solutions indicates that parts of the water-security technology landscape are controlled by actors with direct commercial positions in water treatment, infrastructure services, and industrial water systems. The ownership pattern also shows that water-security technologies are embedded in broader industrial portfolios, including energy, infrastructure, environmental services, and advanced manufacturing.

5.8. Jurisdictional Distribution and Strategic Geography of Protection

The jurisdictional distribution shows that patent activity is geographically uneven. China is the most visually prominent jurisdiction in the map, while the United States, Europe, Japan, South Korea, and other industrial regions also show visible activity.

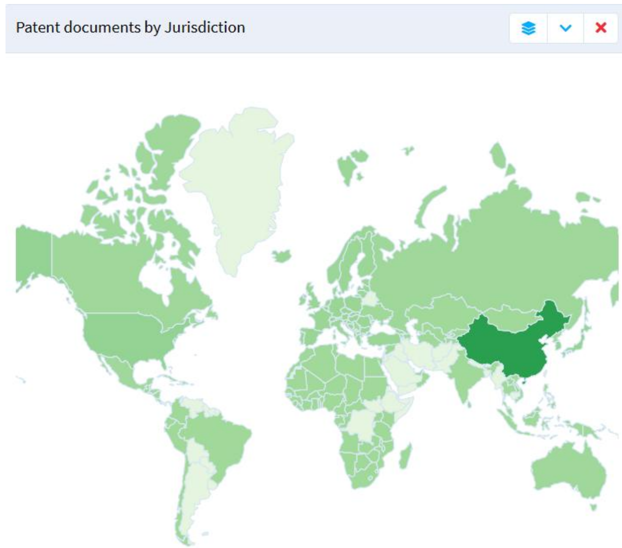

Fig. 9. Patent documents by jurisdiction in selected water-security technologies.

This pattern should not be interpreted as a direct map of water scarcity or water vulnerability. Patent jurisdiction reflects where applicants seek legal protection, where markets are strategically valuable, where innovation systems are active, and where enforcement is meaningful. Therefore, a jurisdiction may appear prominently because it represents a major innovation system, a large market, or a strategic protection environment, not necessarily because it faces the most severe water-security risks.

The geographical distribution of patent documents indicates that selected water-security technologies are embedded in major global innovation and market systems. The concentration of patent activity in large jurisdictions suggests that access to these technologies may be influenced by the legal, commercial, and institutional structures of those jurisdictions. At the landscape level, jurisdictional analysis therefore provides insight into where inventive activity is being protected and where technology owners may see future market or strategic value.

5.9. Citation Patterns and Knowledge Anchors

The citation map shows that highly cited patents are distributed across older and newer publication years, with a visible concentration of older expired or discontinued patents and some active or pending patents in more recent years.

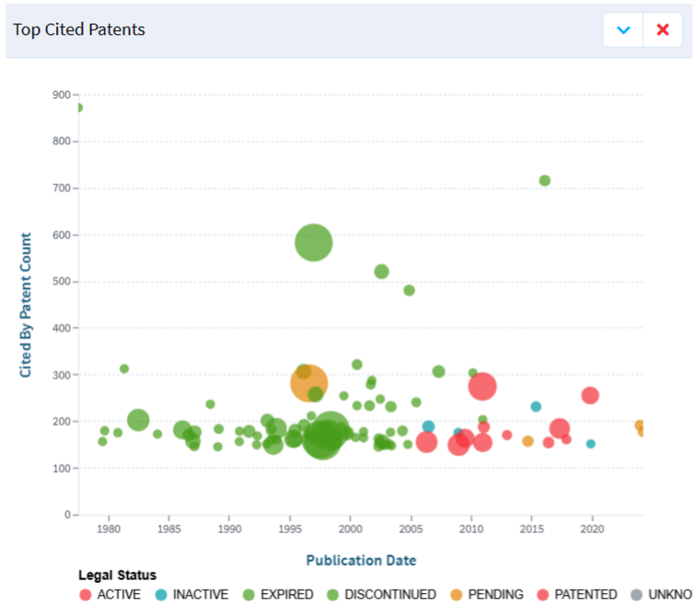

Fig. 10. Top cited patents by publication date and legal status.

Patent citations should be interpreted cautiously. A highly cited patent is not necessarily the most commercially successful, technically superior, or socially useful invention. Citations may reflect examiner practices, prior-art searches, applicant strategies, citation norms, and differences among patent offices. Nevertheless, citation patterns can help identify knowledge anchors: patents or technology families that later inventions repeatedly reference.

The citation pattern suggests that the selected water-security technology landscape contains both older foundational documents and more recent legally active or pending inventions. Older highly cited patents may indicate knowledge bases that have shaped subsequent invention, while more recent cited records may point to emerging areas of technological relevance. At the landscape level, citation analysis helps reveal knowledge linkages within the field, but it should be complemented by narrower subfield analysis before drawing conclusions about specific technologies, markets, or deployment pathways.

6. Discussion

The results show that selected water-security technologies constitute a large, active, and legally structured field of global inventive activity. The most important finding is not merely the size of the patent landscape, but the way technological activity is concentrated around treatment, purification, membrane processes, monitoring, smart systems, climate-adaptation technologies, and infrastructure-sensitive solutions. These patterns are relevant to Iran because the country's water-security challenges are intensifying at the same time that critical water technologies are becoming more knowledge-intensive, patent-protected, and institutionally concentrated. However, the patent landscape does not directly determine national technology priorities, procurement choices, localization strategies, or legal freedom-to-operate conclusions. This section therefore interprets the empirical results as screening-oriented policy intelligence: a way to identify areas where further technical, economic, environmental, legal, institutional, and domestic capability assessments are needed.

6.1. From Water Management to Water-Technology Security.

The patent landscape supports a central policy argument: water security should be treated not only as a resource-management issue, but also as a technology-security and innovation-governance issue. As defined in the theoretical background, technology security refers here to the capacity to access, understand, maintain, adapt, regulate, and selectively develop critical water-related technologies under acceptable legal, economic, environmental, and institutional conditions.

Iran’s water policy has often focused on scarcity, allocation, groundwater depletion, agricultural demand, infrastructure expansion, pricing, and institutional coordination. These dimensions remain essential. However, the patent results indicate that many technologies relevant to future water resilience are embedded in global systems of intellectual property, industrial specialization, supplier concentration, standards, software platforms, and data infrastructures.

This does not mean that patent data can determine Iran’s water-technology priorities by themselves. Rather, the results suggest that water-security planning would benefit from a technology-intelligence layer capable of identifying where further technical, legal, economic, environmental, and institutional assessment is required. Technologies such as wastewater reuse, desalination, membrane systems, water-quality monitoring, leak detection, groundwater observation, and digital water platforms should therefore be treated as candidate areas for structured assessment, not as priorities established solely by patent counts.

The purpose of this argument is not to portray Iran as technologically passive, but to emphasize that existing scientific, engineering, and industrial capacities can be more effectively connected to strategic intelligence, public procurement, and mission-oriented water-technology policy.

6.2. Dependency-Risk Exposure and Legal Assessment Needs

The results on applicants, owners, legal status, and jurisdictions show that selected water-security technologies are shaped by multinational firms, specialized water-technology companies, industrial conglomerates, universities, and major patent jurisdictions. This pattern may create dependency-risk exposure for countries that mainly approach water technologies through import-oriented acquisition, turnkey procurement, or fragmented project-based projects.

However, the present study does not conduct claim-level patent analysis, freedom-to-operate assessment, licensing review, or enforceability analysis. Therefore, the findings should not be interpreted as evidence of actual infringement risk or legal barriers in any specific technology. Their value is more limited but still important: they help identify technological areas, owners, and jurisdictions where further legal and contractual due diligence may be needed before procurement, localization, or partnership decisions are made.

Dependency in water technologies may involve more than hardware. It can also appear in membranes, sensors, proprietary control systems, software platforms, spare parts, maintenance contracts, data formats, cybersecurity architectures, and interoperability standards. Patent intelligence can help make these possible exposure points visible, but it cannot determine by itself whether a technology is legally usable, economically viable, environmentally suitable, or operationally appropriate for Iran.

For Iran, the practical implication is therefore not to reject foreign technologies or assume legal risk in advance. The implication is to integrate ownership mapping, legal-status screening, supplier analysis, and, where necessary, claim-level legal assessment into major technology-acquisition and public-procurement processes.

6.3. Candidate Technology Missions for Further Assessment

The CPC and IPC results show that patenting activity in the dataset is strongly concentrated in treatment, purification, wastewater processing, membrane systems, filtration, reverse osmosis, ion exchange, disinfection, monitoring, and climate-adaptation-related water technologies. These patterns do not establish final national priorities for Iran. They do, however, help identify candidate areas that may deserve deeper mission-oriented assessment.

A cautious interpretation points to several candidate mission areas. The first is wastewater reuse and advanced treatment, especially where reuse can reduce pressure on freshwater resources. The second is desalination and membrane capability, particularly in contexts where coastal, industrial, or brackish-water conditions make these technologies relevant. The third is smart water networks, including leakage detection, pressure management, pipeline monitoring, metering, and operational data systems. The fourth is water-quality and groundwater monitoring, including sensors, observation systems, and data platforms. The fifth is climate-water intelligence, including drought monitoring, flood monitoring, remote sensing, early warning, and decision-support systems.

These areas should not be treated as final priorities based on patent evidence alone. Each requires additional assessment of techno-economic feasibility, environmental impacts, infrastructure compatibility, domestic industrial capability, regulatory requirements, standards, procurement pathways, and operational readiness. The role of patent intelligence is to help structure this assessment agenda by showing where global inventive activity is concentrated and where legal or ownership issues may require further scrutiny.

Therefore, the policy value of this section is not to prescribe a fixed mission portfolio, but to identify a shortlist of technology domains that could be examined through a more comprehensive national assessment process.

6.4. Institutional Design for Patent and Technology Intelligence

The applicant and owner patterns show that water-security innovation is not produced by one type of actor. It involves firms, universities, industrial corporations, specialized water companies, energy actors, and infrastructure-oriented technology providers. This finding suggests that water-technology policy cannot be managed only through university research programs or only through procurement agencies. It requires an interface between water authorities, science and technology policymakers, patent specialists, public utilities, standards bodies, universities, industrial firms, and knowledge-based companies.

For Iran, establishing a dedicated water-technology intelligence function would strengthen strategic coordination. This does not necessarily require creating a large new bureaucracy. It could be organized as a specialized unit, inter-agency platform, or analytical function located at the intersection of water governance, science and technology policy, intellectual-property analysis, public procurement, and standards development.

Such a function would not make final technology decisions on the basis of patent data alone. Its role would be to support early screening: monitoring patent trends, identifying major applicants and owners, tracking legal-status changes, detecting supplier concentration, reviewing expired or discontinued patents, and flagging technologies that require deeper legal, technical, environmental, or capability assessment.

With this institutional bridge, patent intelligence can move beyond academic analysis and become a practical governance instrument. Its value would depend on how well it is connected to hydrological priorities, domestic industrial capabilities, field testing, environmental evaluation, procurement needs, and regulatory decision-making.

6.5. Public Procurement as a Technology-Building Instrument

Public procurement is a major channel through which water technologies enter public systems. Municipalities, utilities, public agencies, industrial zones, treatment plants, and infrastructure projects often shape demand for water technologies. For this reason, procurement can either remain a purchasing mechanism or become an instrument for learning, standard-setting, maintenance capability, and domestic capability accumulation.

The patent results do not prove that any specific procurement model is suitable for Iran. They do, however, show that several water-security technologies are located in legally structured and commercially organized fields. This means that procurement decisions may need to consider not only price and technical specifications, but also maintenance requirements, data access, interoperability, supplier concentration, licensing conditions, standards, and long-term capability development.

If procurement is designed primarily around lowest initial cost, it may limit domestic learning and increase exposure to proprietary technologies. A more strategic approach would treat patent intelligence as an input into procurement preparation. Before major acquisitions in desalination, advanced treatment, smart monitoring, leak detection, or digital water systems, procurement agencies can use patent signals to identify where additional technical, legal, and supplier-risk assessment may be needed.

This does not imply excluding foreign suppliers. In many advanced water technologies, international cooperation may be necessary. The issue is whether procurement creates domestic learning or results in technology acquisition with limited capability accumulation. Patent intelligence can help formulate better procurement questions, but final procurement choices require economic, legal, environmental, operational, and institutional analysis.

6.6. Public-Domain Learning and Selective Localization

The legal-status results show that the patent landscape includes active, pending, discontinued, inactive, and expired records. Active and pending records may indicate areas where further legal review is needed before procurement, localization, or commercial use. Expired, inactive, and discontinued records may provide opportunities for technical learning, but they do not automatically represent usable, current, or locally appropriate technologies.

For Iran, public-domain learning should be treated as a structured assessment process rather than as direct copying. Expired or inactive patents can help researchers and engineers understand design principles, historical technology pathways, component architectures, process configurations, and alternative solution spaces. They may support education, lawful adaptation, reverse engineering within legal limits, and design inspiration.

However, not every expired or discontinued patent is technically valuable. Some may be obsolete, commercially unsuccessful, environmentally unsuitable, or dependent on materials, components, or operating conditions that are not available locally. Therefore, selective localization should be considered only where three conditions overlap: relevance to Iran's water-security challenges, feasible domestic engineering and industrial capability, and manageable intellectual-property and regulatory exposure.

Patent databases should not be used only to identify areas of external technological concentration. They can also help identify learning opportunities. But this requires technical screening, obsolescence review, legal assessment, environmental evaluation, and domestic capability mapping before any localization pathway is selected.

6.7. Governance Risk and Prioritization

One strategic risk for Iran's water-technology policy is dispersion across disconnected projects. Water-security technology is a broad field, and the patent landscape includes many domains: treatment, reuse, desalination, membranes, sensors, monitoring, leak detection, smart systems, remote sensing, and climate-water intelligence. Without prioritization, public funding may be distributed across disconnected projects, reducing the likelihood that research outputs, prototypes, and pilot activities will accumulate into deployable national capability.

The patent results can help reduce this dispersion, but only as a first-level screening tool. They show where inventive activity is concentrated, which actors and jurisdictions are visible, which legal-status categories appear, and which technological domains may require further assessment. They do not determine which technologies Iran should adopt, localize, license, or procure.

A defensible prioritization process should combine patent intelligence with explicit criteria: relevance to national water-security challenges, techno-economic feasibility, environmental suitability, domestic absorptive capacity, supplier concentration, patent intensity, legal exposure, deployment potential, standards requirements, and public-procurement leverage. This can help avoid two opposite policy failures. The first is import-oriented acquisition with limited learning, control, or freedom-to-operate assessment. The second is non-selective localization, where domestic development is pursued in areas with limited capability, high cost, or low strategic return.

Therefore, the policy contribution of this article should be understood as a screening framework rather than a final prioritization model. Final decisions about technology missions, procurement, localization, or legal-risk management require additional evidence beyond the patent landscape.

Table 3.
From patent-landscape signals to policy decisions: a screening-oriented framework for Iran.

Patent-landscape signal	What it can indicate	What it cannot establish	Required complementary assessment	Permissible policy use
Large and growing patent activity in a technology area	Rising inventive activity, increasing international attention, and possible strategic relevance	Technical superiority, market success, affordability, or suitability for Iran	Market analysis, expert review, technology-readiness assessment, and relevance to Iran's water-security needs	Identify candidate areas for further monitoring and assessment
Concentration in CPC/IPC classes such as treatment, purification, reuse, membranes, monitoring, or climate-water technologies	Dominant technological domains within the patent landscape	Final national priorities or proof that these technologies should be adopted domestically	Techno-economic assessment, environmental evaluation, infrastructure compatibility analysis, and domestic capability mapping	Support preliminary prioritization and selection of subfields for deeper study
High visibility of active or pending patents	Possible legal protection, recent inventive activity, and potential licensing sensitivity	Actual infringement risk, enforceability, or freedom to operate	Claim-level legal analysis, jurisdiction-specific patent review, and licensing assessment	Flag areas where legal due diligence may be required before procurement or localization
Presence of expired, inactive, or discontinued patents	Possible public-domain knowledge, historical technology pathways, and learning opportunities	Technical usefulness, current relevance, or deployment feasibility	Technical screening, obsolescence review, environmental assessment, and engineering validation	Identify learning resources for education, lawful adaptation, and design inspiration
Difference between applicants and owners	Possible separation between filing activity and current control of patent assets	Full ownership control, licensing conditions, or commercial availability	Ownership verification, patent-family review, company portfolio analysis, and contract/legal assessment	Inform supplier mapping, technology-transfer review, and partnership screening
Concentration among specialized firms, industrial corporations, universities, and major jurisdictions	Institutional structure of inventive activity and possible supplier or knowledge concentration	Domestic dependency, monopoly power, or actual market control in Iran	Market-structure analysis, procurement history review, domestic firm mapping, and supply-chain assessment	Identify actors and jurisdictions requiring strategic monitoring
Uneven jurisdictional distribution	Where applicants seek protection and where markets or legal environments	Water vulnerability, deployment geography, or actual	Jurisdiction-specific legal review, market analysis, standards assessment, and geopolitical risk review	Guide monitoring of major patent jurisdictions and partnership risks

	may be strategically important	technology availability		
Citation concentration around older or newer patents	Possible knowledge anchors, prior-art importance, or technology trajectories	Patent quality, social usefulness, commercial success, or technological superiority	Normalized citation analysis, expert technical review, patent-family value analysis, and network analysis	Select subfields or patent families for deeper technical and citation-based analysis
Frequent appearance of digital, smart, remote-sensing, or drought/flood terms within the filtered dataset	Possible intersection between water technologies and data-driven water management	Comprehensive coverage of all digital-governance or intelligence technologies	Separate digital-water query design, software/platform analysis, data-governance assessment, and cybersecurity review	Treat digital-water findings as preliminary and require dedicated subfield analysis

The table clarifies that the main value of patent intelligence is not simple patent counting and not direct policy prescription. Its value lies in structuring a sequence of questions: where is inventive activity concentrated, who appears to control or protect relevant technologies, which areas may require legal or technical due diligence, and what complementary evidence is needed before policy decisions are made. For Iran, this means that patent intelligence should be used as an early screening mechanism within a broader decision process that also includes hydrological priorities, domestic industrial capabilities, environmental constraints, legal assessment, standards, procurement needs, and institutional feasibility.

7. Conclusion

This article examined the global patent landscape of selected water-security technologies and interpreted its relevance for Iran's science, technology, and innovation policy. The central argument is that water security should not be understood only as a matter of hydrological scarcity, infrastructure expansion, allocation reform, or demand management. These dimensions remain essential, but they are incomplete without attention to the technological and intellectual-property structures that increasingly shape future water resilience.

The patent analysis showed that selected water-security technologies form a large, active, and legally structured field of global inventive activity. Patent activity in the dataset is strongly concentrated in water and wastewater treatment, purification, filtration, membrane processes, reverse osmosis, reuse, monitoring systems, smart water networks, remote sensing, and climate-related water technologies. The findings also showed that this field is shaped by a diverse but institutionally concentrated set of actors, including specialized water-technology firms, multinational industrial companies, universities, energy-sector actors, and major innovation jurisdictions.

The main contribution of the article is not to determine final technology priorities for Iran, but to show how patent intelligence can support preliminary screening for water-technology governance. Patent indicators can help identify where inventive activity is concentrated, which actors and jurisdictions are visible, which legal-status categories are present, and which technological areas may require further technical, economic, environmental, legal, institutional, and domestic capability assessment. In this sense, patent intelligence provides an early-warning and agenda-setting function rather than a complete basis for policy decisions.

For Iran, the results suggest that water technologies should be treated as strategic capabilities and not only as objects of technology acquisition. However, the study does not claim that patent data alone can justify specific missions, procurement decisions, localization strategies, or freedom-to-operate conclusions. Rather, the patent landscape helps identify candidate areas for further assessment, including wastewater reuse, desalination, membrane capability, smart monitoring, leakage detection, groundwater observation, and climate-water intelligence. Final prioritization in these areas requires additional evidence on techno-economic feasibility, environmental suitability, infrastructure compatibility, legal exposure, supplier concentration, standards, public-procurement needs, and domestic absorptive capacity.

The article therefore reframes patent intelligence as one layer within anticipatory water-technology governance. It does not replace hydrological planning, engineering evaluation, environmental regulation, institutional analysis, market assessment, or claim-level legal review. Its value lies in making the global technology and intellectual-property landscape more visible before major policy, procurement, or localization decisions are made. This visibility can help policymakers ask better questions, identify assessment gaps, and avoid both unexamined technology acquisition and non-selective localization.

The study has several limitations. The search strategy was deliberately broad and may include some records only indirectly related to water security, while excluding relevant inventions that use different terminology or classifications. The selected CPC/IPC filters also anchor the dataset strongly in treatment, water-supply, and climate-adaptation categories; therefore, the results should not be read as a complete representation of all governance-oriented, digital-platform, or intelligence-oriented dimensions of water security. The analysis depends on the coverage and metadata quality of Lens.org. Patent counts and simple citation indicators do not directly measure technological effectiveness, patent quality, economic feasibility, environmental suitability, market success, deployment readiness, or social acceptance. The study also does not conduct claim-level legal analysis, freedom-to-operate assessment, design-around assessment, techno-economic evaluation, environmental assessment, or empirical mapping of Iran’s domestic technological capabilities.

Future research should therefore move from broad landscape analysis to focused subfield studies. Priority areas for deeper investigation include membrane desalination, wastewater reuse, smart water systems, groundwater monitoring, leakage detection, remote sensing, and climate-water intelligence. Such studies should combine patent analysis with expert interviews, market data, technology-readiness assessment, environmental evaluation, claim-level legal review where necessary, procurement analysis, and domestic capability mapping. Comparative studies of Iran’s firms, universities, utilities, standards bodies, and public-procurement mechanisms would also help determine how global patent signals can be translated into feasible national technology strategies.

Overall, the findings suggest that Iran's future water resilience will depend not only on managing scarcity, but also on governing the technologies that make monitoring, treatment, reuse, desalination, and digital water management possible. Patent intelligence offers a practical starting point for strengthening Iran's water policy through anticipatory, capability-based governance, provided that it is used as a screening tool and combined with complementary technical, legal, environmental, institutional, and capability assessments.

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