Groundwater Resources in the Mekong Delta: Current Status, Challenges, and Sustainable Approaches under Dual Impacts

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ABSTRACT

This review synthesizes recent evidence on groundwater security in Vietnam's Mekong Delta under the twin pressures of climate change and sustained over-abstraction. Advancing prior work, we (i) integrate disparate findings into an extraction–subsidence–salinization systems frame and (ii) align post-2015 scientific evidence with the latest regulatory reforms to distill implementable pathways. Using a selective but transparent literature strategy focused on peer-reviewed studies (2015–2025) indexed in Scopus/Web of Science and authoritative governmental/international reports, we prioritized sources with explicit methods, georeferenced observations, and reported uncertainties; grey literature without methodological disclosure was screened out. The Delta's multi-aquifer endowment is heavily stressed: recorded withdrawals from centralized wells are approximately 2.0 million $m^3\ d^{-1}$, groundwater heads decline by 0.3–0.5 m y^{-1} across many localities, and land subsidence averages about 1.07 cm y^{-1} with urban hotspots exceeding these values; earlier and deeper saltwater intrusion further jeopardizes domestic supply and agriculture. Water-quality risks—including widespread microbial contamination and geogenic arsenic above WHO guidelines—compound exposure. While recent legal instruments establish clearer mandates for restricted zones, licensing, and extraction charges, implementation is hindered by fragmented monitoring networks, limited metering of household wells, and transition costs for small users. We propose a four-pillar strategy: legally binding, risk-zoned extraction thresholds; phased substitution by interprovincial surface-water conveyance; managed aquifer recharge (e.g., riverbank filtration) in suitable formations; and digital metering coupled with economic instruments and integrated forecasting that co-simulates extraction, subsidence, and salinity. The review also identifies critical evidence gaps—household abstraction inventories, in-situ deformation–pumping linkages, and cost-effectiveness of recharge options—that should anchor near-term research. Collectively, these measures are necessary to arrest the subsidence–salinity feedback loop and restore groundwater resilience in the Mekong Delta.

Keywords: dual impacts, groundwater, land subsidence, saltwater intrusion, the Mekong Delta, water quality

BACKGROUND

The Vietnamese Mekong Delta (MD), one of the largest and most densely populated deltas in the world, plays a strategic role in Vietnam's food security and economic development. With its abundant agricultural potential, the region contributes approximately 50% of the country's rice output, 70% of its fruit production, and 90% of its rice exports (NSO, 2024). However, the MD is currently facing a severe water resource crisis, particularly in terms of groundwater, driven by the "dual impacts" of climate change and excessive human exploitation (Binh & Tien, 2021). In fact, groundwater has been increasingly exploited not only for the purposes of irrigation and industrial activities, but also for domestic use (Danh & Khai, 2015). This degradation not only threatens the livelihoods of millions of residents but also significantly undermines the region's natural ecosystems and infrastructure (MoNRE, 2021a).

This review paper aims to provide a systematic and in-depth overview of the current status of groundwater resources in the MD. Drawing upon a synthesis of recent studies and updated data, the report analyzes the region's hydrogeological characteristics, assesses the extent of groundwater extraction and degradation, and elucidates key consequences such as land subsidence and saltwater intrusion. It also examines existing policies and management strategies, while distilling lessons from international experiences in other major deltas. Finally, the study outlines future research directions and proposes strategic recommendations to ensure the sustainable development of the MD.

Research questions (RQs):

- RQ1: What is the current status and quantifiable extent of groundwater resource degradation in the Vietnamese MD under the dual pressures of sustained over-abstraction and climate change impacts? Specifically, what are the current rates of groundwater head decline and centralized withdrawal volumes?
- RQ2: How can the disparate findings on groundwater stress be integrated into a coherent extraction–subsidence–salinization systems framework?
- RQ3: What are the key elements of the latest Vietnamese regulatory reforms aimed at groundwater governance? Furthermore, what are the primary implementation constraints—both technical and socio-economic—that hinder the effectiveness of these legal instruments?
- RQ4: Based on the synthesis of scientific evidence and policy analysis, what is a distilled and implementable four-pillar strategy necessary to arrest the subsidence–salinity feedback loop and restore groundwater resilience in the MD?

METHODOLOGY

Study design and scope

This review synthesizes post-2015 evidence on groundwater use, land subsidence, and salinization in the MD, with selective inclusion of pre-2015 and grey-literature sources where they are necessary to establish hydrogeologic baselines or regulatory context. The primary horizon is 1 January 2015 to 30 September 2025.

Data sources and search strategy

We queried multidisciplinary and domain databases (Scopus, Web of Science Core Collection, Google Scholar—first 200 hits per query for recall), plus institutional repositories (Vietnamese ministries and river-basin authorities). Search strings combined controlled terms and free text around four concept blocks:

- Aquifer/groundwater: "groundwater" OR "aquifer*" OR "pumping" OR "abstraction"
- Impacts: "subsidence" OR "land subsidence" OR "salin* intru*" OR "saltwater intrusion"
- Geography: "Mekong Delta" OR "Đồng bằng sông Cửu Long" OR province names (e.g., "Cà Mau", "Sóc Trăng", "An Giang", "Đồng Tháp")
- Time filter: 2015–2025 (removed when searching for baseline geology or pre-policy history)

Eligibility criteria

Inclusion

- Empirical or modeling studies on the MD that report: (i) groundwater levels/abstraction, (ii) land subsidence, and/or (iii) salinity fronts or chloride/EC metrics.
- Policy and regulatory documents with direct implications for groundwater extraction or coastal salinity barriers (national laws, ministerial circulars, basin-level plans).
- Pre-2015 studies only when they provide baseline hydrogeology (stratigraphy, aquifer properties), or document foundational field methods reused in later work.

Exclusion

- Non-MD geographies; purely conceptual pieces without empirical anchors.
- Duplicated analyses (conference paper superseded by journal article—retain the most complete/peer-reviewed version).
- Grey literature lacking minimal methodological transparency.

Screening and selection workflow

We implemented a three-stage screening modeled on PRISMA:

- De-duplication across databases and repositories.
- Title/abstract screening by two reviewers; disagreements resolved by consensus.
- Full-text assessment for eligibility and data availability (groundwater/ subsidence/ salinity metrics, methods, spatial/temporal coverage).

A total of 177 records were identified (60 from search queries + 117 from citation chaining), in which 51 studies included; 126 excluded.

Data extraction and standardization

For each included item we extracted: study type; spatial unit (province/basin/point); period; data sources (wells, interferometric synthetic aperture radar (InSAR), gauges, modeling); key metrics (e.g., abstraction in $m^3\ d^{-1}$, subsidence in $cm\ y^{-1}$, salinity as $g\ L^{-1}$); methods (e.g., InSAR processing chain, groundwater model specs); and uncertainty statements.

To ensure comparability, units were standardized to SI conventions: $m^3\ d^{-1}$ (abstraction), $cm\ y^{-1}$ (subsidence), and $g\ L^{-1}$ or practical salinity units for salinity. Decimal points use "." and thousands of separators are omitted (e.g., 2.0 million $m^3\ d^{-1}$). Where studies reported ranges, we captured min/median/max. When necessary, we converted legacy units (e.g., ppm to $g\ L^{-1}$) using stated or standard factors and documented all conversions in a data dictionary.

Quality appraisal and evidence weighting

Peer-reviewed studies were assessed with a simplified critical-appraisal checklist (study design clarity, data provenance, method transparency, uncertainty handling, and external validity). Grey-literature (government/ agency reports, technical notes) was appraised using an adapted AACODS framework (Authority, Accuracy, Coverage, Objectivity, Date, Significance). Minimum thresholds:

- Identifiable authorship/institutional authority.
- Traceable data or methods (e.g., well network description, InSAR scenes).
- Publication date or clearly stated data period.

Each source received a quality class (High/Moderate/Low) and a weight (1.0/0.5/0.2) used in narrative synthesis and, where feasible, in weighted summary statistics. Pre-2015 items were only retained if they met one of the justifications in §2.3 and passed quality screening; they were flagged as "baseline evidence" and never used alone to infer post-2015 trends without a post-2015 corroborant.

We conducted sensitivity analyses by (a) excluding Low-quality and pre-2015 items, and (b) using equal weights versus quality weights to test robustness of pooled ranges (e.g., abstraction or subsidence bands).

Synthesis approach

We performed a convergent narrative synthesis structured by the extraction–subsidence–salinization system. Quantitative findings were summarized as pooled ranges/medians by province or sub-basin (with interquartile range (IQRs) where available) and mapped to policy timelines. Where two or more independent data sources overlapped (e.g., InSAR-derived subsidence and global navigation satellite system (GNSS)), we triangulated and highlighted agreements or discrepancies, with hypothesized drivers (e.g., lithologic variability, seasonal pumping).

Bias, limitations, and mitigation

Risk of publication bias (English/Vietnamese language; paywalled journals) and selective reporting in grey literature were mitigated by (i) dual-reviewer screening, (ii) explicit quality weighting, (iii) unit standardization and transparent conversion logs, and (iv) sensitivity tests excluding lower-quality and pre-2015 items. Remaining limitations include heterogeneous spatial granularity and uneven monitoring coverage across provinces.

Hydrogeological Characteristics and Groundwater Potential

Hydrological features

The hydrogeological system of the MD is shaped by three prominent factors: freshwater flows and seasonal flooding during the rainy season, saltwater intrusion during the dry season in coastal areas, and the presence of acid sulfate water in alum-affected soils (VNMC, 2025). These elements contribute to a complex and distinctly stratified ecosystem. Based on these characteristics, the MD is divided into three sub-regions: the upper delta (adapted to flooding), the middle delta (focused on freshwater supply and flood control), and the coastal zone (adapted to saline and brackish water conditions) (CENRC, 2022). Socio-economic development and resource management in each sub-region must adhere to the principle of “living in harmony with nature” to ensure sustainability.

From a hydrogeological perspective, the MD possesses the largest groundwater-bearing system in Vietnam, comprising seven major aquifers within porous sediments and one fractured bedrock aquifer. These aquifers are distributed across various depths, ranging from several tens of meters to as deep as 500–600 m (DWRPIS, 2014).

The principal aquifers include (Fig. 1):

- Pleistocene aquifers: These consist of the Upper Pleistocene (qp_3), Middle–Upper Pleistocene ($qp_{2\text{-}3}$), and Lower Pleistocene (qp_1) layers. They are widely distributed throughout the region. The qp_3 aquifer lies at depths of 18.0–35.8 m and can reach up to 60 m. The qp_1 aquifer is separated from $qp_{2\text{-}3}$ by a clay and silt layer averaging 5–10 m in thickness (DWRPIS, 2014). Notably, the $qp_{2\text{-}3}$ aquifer is the most heavily exploited in Can Tho city (Le, 2025)—the central and biggest city in the MD.

- Pliocene aquifers: These include the Upper Pliocene ($n_{2.2}$) and Lower Pliocene ($n_{2.1}$) layers. Located at greater depths, they are found between 167.5–280.8 m and are separated by a relatively thick clay-silt layer averaging around 35 m (DWRPIS, 2014). These aquifers exhibit moderate to high water-bearing potential (DWRPIS, 2014).

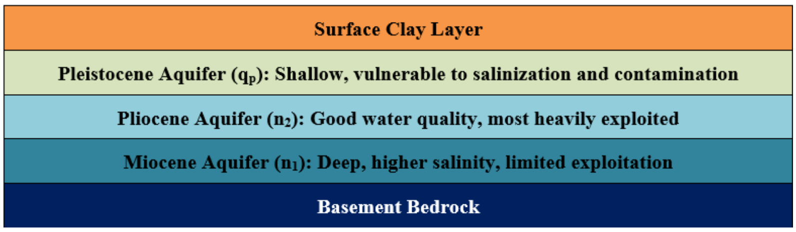

Figure 1. Structure of major aquifers

Groundwater potential and exploitable reserves

The MD possesses abundant potential reserves of freshwater groundwater, estimated at approximately 22.5 million $m^3\ d^{-1}$, with a region-wide safe yield of 4.5 million $m^3\ d^{-1}$ (DWRPIS, 2014). However, in-depth studies have revealed a concerning disparity between theoretical potential and sustainable exploitation. According to a recent assessment, the total volume of freshwater groundwater in the MD is estimated at 867 billion cubic meters—a substantial figure that is currently subject to severe overextraction (Gunnink et al, 2021).

A detailed study of the Middle Pliocene aquifer indicates that its total exploitable potential for fresh water is 4,398,655 $m^3\ d^{-1}$, while the sustainable (safe) yield is only 879,731 $m^3\ d^{-1}$ (DWRPIS, 2014). Notably, the most recent calculations show that the remaining safe yield of this aquifer has declined to just 402,372 $m^3\ d^{-1}$—a figure alarmingly low compared to its initial potential (Tu, 2017).

The significant disparity between the initial safe yield and the remaining exploitable safe yield indicates that groundwater extraction has systematically exceeded sustainable thresholds over an extended period. This trend raises an alarming concern: even the initially abundant resource assessments have become increasingly irrelevant as extraction pressures push the aquifers toward depletion. Overexploitation beyond the natural recharge capacity has rendered theoretical potential figures unrealistic under current conditions. For a more comprehensive overview of groundwater potential and exploitable reserves, refer to Table 1 below.

Table 1. Groundwater reserves in the MD by aquifer layer

Aquifer storage capacity	**The MD**	**Middle Pliocene aquifer**
Potential exploitable yield ($m^3\ d^{-1}$)	22.500.000	4.398.655
Safe yield ($m^3\ d^{-1}$)	4.500.000	879.731
Remaining safe yield ($m^3\ d^{-1}$)	Not available	402.372
Reference source	DWRPIS (2014)	Tu (2017)

Current Status of Groundwater Exploitation and Degradation

Exploitation trends

Dependence on groundwater resources in the MD has increased significantly in recent years, primarily due to the severe deterioration of surface water quality caused by pollution from agricultural, industrial, and domestic activities (CEVIWRPI, 2024). This situation has led to widespread and poorly regulated groundwater extraction (Ha et al., 2020).

According to survey from the National Center for Water Resources Planning and Investigation, in 2020 the region had approximately 9,650 centralized groundwater extraction wells, with a total discharge volume of around 1.97 million $m^3\ d^{-1}$ (Giang, 2025). This figure excludes over one million household-scale private wells, which are estimated to contribute an additional 840,000 $m^3\ d^{-1}$ (Duy, 2021). Experts have also pointed out that the actual volume of groundwater extraction may be substantially higher than reported figures (Khai, 2021). The prevailing conditions of "easy access, low cost, and lax management" (Toan, 2021) have led to the indiscriminate use of this vital resource. Although the officially licensed groundwater extraction capacity stands at 9.9 million $m^3\ d^{-1}$ (Don, 2021), actual oversight remains limited. A detailed study estimates that total groundwater extraction in the MD has exceeded 900 million cubic meters annually (Gunnink et al., 2021).

A particularly concerning issue is the inconsistency in reported data on total groundwater extraction across different sources. The substantial discrepancies between estimates—such as 1.97 million $m^3\ d^{-1}$, 2.0 million $m^3\ d^{-1}$, and the licensed volume of 9.9 million $m^3\ d^{-1}$, as mentioned above—highlight the fact that the current monitoring and statistical systems remain fragmented and insufficiently comprehensive. The lack of accurate data, especially from unregulated household-scale wells, has created a significant gap in policy formulation and in evaluating the effectiveness of management interventions, rendering decision-making scientifically underinformed.

One of the most evident consequences of overextraction is the marked decline in groundwater levels. In several aquifers, water tables have dropped considerably (Don, 2021), with average rates ranging from 0.3 to 0.5 $m\ y^{-1}$

in many localities such as Can Tho city, Long An, Vinh Long, and Ca Mau province (DWRPIS, 2014); the rate is even more severe reaching up to 0.92 m y^{-1} in Lai Vung town of Dong Thap province. This trend indicates that groundwater resources are being depleted at a rate that far exceeds their natural recharge capacity (Fig. 2).

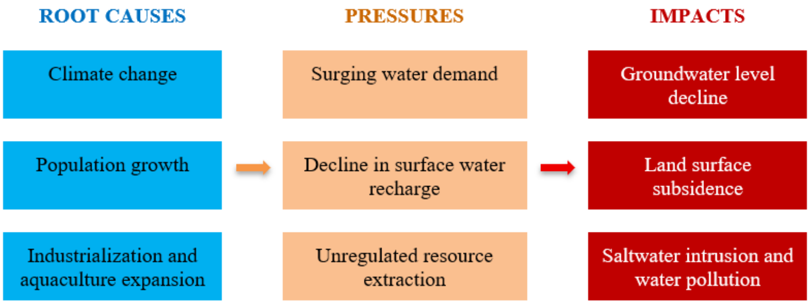

Figure 2. Drivers of the groundwater crisis

Groundwater pollution status

In addition to declining reserves, groundwater quality in the MD is increasingly threatened by complex pollution issues. Contaminants from surface water—polluted by agricultural runoff, industrial effluents (particularly from small-scale industrial activities in Dong Thap), and domestic wastewater—have infiltrated directly into aquifer systems (Giao et al., 2022; Minh et al., 2016; Ty et al., 2023). Unregulated groundwater extraction further facilitates the deep penetration of pollutants, exacerbating water quality degradation (Minh et al., 2015; Ty et al., 2021).

Studies have identified various types of contaminants (see Table 2):

- Coliform: Over 80% of water samples surveyed in An Giang, Dong Thap, and Can Tho showed severe coliform contamination; high bacterial densities are likely linked to leakage from fecal sources such as latrines, wastewater pipelines, livestock waste, or burial pits for diseased animals (Giao et al., 2022; Thu, 2023; Ty et al., 2023).

- Heavy metals and other pollutants: A comprehensive review reported ammonium contamination in Bac Lieu, and nitrate and chloride in Soc Trang (Giao et al., 2022; Ty et al., 2023). In some areas, groundwater is also contaminated with iron (Fe) and exhibits excessive hardness, although parameters such as pH, nitrate, mercury (Hg), and lead (Pb) generally remain within acceptable limits (Giao et al., 2022; Ty et al., 2023).

- Arsenic: Arsenic pollution is geogenic in origin, resulting from naturally occurring anoxic conditions within aquifer layers (Nguyet et al., 2025), raises major concerns for community health in Dong Thap and An Giang provinces as over 70% of sampled tube-wells had arsenic concentrations exceeding the value of 500 µg L^{-1} (Oanh & Lap, 2016). Although WHO has lowered the safe limit for arsenic in drinking water from 50 µg L^{-1} to 10 µg L^{-1}, many countries have yet to adopt this revised standard (Guo et al., 2024).

Table 2. Major contaminants and their sources in groundwater in the MD

Contaminant type	**Contamination level**	**Source of pollution**	**Typical affected areas**
Coliforms	Over 80% of samples severely contaminated	Domestic wastewater, livestock waste, fecal sources leakage	An Giang, Dong Thap, Can Tho
Iron and water hardness	Some areas exceed national standards	Small-scale industrial activities, polluted surface water	Dong Thap
Nitrate and Chloride	No specific records	Agricultural wastewater, excessive fertilizer use	Soc Trang

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Arsenic	No specific records	Unknown	An Giang
Ammonium	No specific records	Unknown	Bac Lieu

(Source: Compiled from multiple sources)

Major Consequences of Groundwater Overexploitation

Land Subsidence

Land subsidence has been identified as one of the most severe consequences of excessive groundwater extraction in the MD (Khai, 2021). This phenomenon is occurring at a rate significantly faster than sea level rise, thereby increasing the risk of permanent inundation across the region (Thien, 2021).

- Subsidence rate: Monitoring data indicate that the average subsidence rate across the delta was 1.07 cm y^{-1} during the period 2014–2019 (An, 2024). However, in urbanized areas, this rate can reach 2–4 cm y^{-1}, while agricultural zones experience rates of 0.5–1.0 cm y^{-1} (Neussner, 2019). Other studies have shown that groundwater levels declined by an average of 2.85 m between 2001 and 2010, with a clear correlation between groundwater depletion and land surface subsidence (Khai, 2021).

- Hotspots: Ca Mau Peninsula and Can Tho city have been identified as the fastest-subsiding areas (DWRPIS, 2014). In particular, Can Tho has recorded subsidence rates exceeding 5 cm y^{-1} (MoNRE, 2021b).

- Impacts: Land subsidence causes extensive damage to infrastructure, leads to land loss, and heightens the risk of flooding and erosion (Arcadis et al, 2021). During the dry season of 2023–2024, more than 2,000 subsidence incidents affecting dikes and transportation routes were reported, resulting in serious damage (Chuong, 2024). Research has also shown that subsidence permanently reduces the storage capacity of aquifers, rendering them incapable of full recovery even when recharge occurs (Ndahangwapo et al, 2022).

Saltwater Intrusion

Saltwater intrusion presents a dual challenge for the MD, driven not only by climate change and sea level rise but also by groundwater extraction (Giang, 2025). The dynamics of groundwater systems are directly linked to this phenomenon: extraction lowers water levels and reduces hydraulic pressure within aquifers, thereby facilitating deeper penetration of seawater into the soil and aquifer layers (Giang, 2025).

- Current status: Saltwater intrusion is now occurring earlier and with greater intensity than the multi-year average; the 4‰ salinity boundary on major rivers in Ca Mau has advanced inland by 60–70 km (Lam, 2025). A recent study revealed that shallow aquifers are significantly affected by seasonal factors and land use practices, while deeper aquifers are primarily influenced by ancient saline water and localized extraction activities (Hoan et al., 2025). Historical drought-salinity crises, such as those during the dry seasons of 2015–2016 and 2019–2020, caused severe damage to rice production and forced many households to migrate (Kien & Tuan, 2023).

- Impacts: Saltwater intrusion has serious consequences for both livelihoods and agricultural productivity. During the 2024 dry season, nearly 74,000 households experienced shortages of domestic water, and thousands of hectares of rice suffered yield losses or complete crop failure (An, 2024).

Land subsidence and saltwater intrusion are not isolated phenomena; rather, they are intricately interrelated, forming a dangerous feedback loop of degradation. Excessive groundwater extraction leads to land subsidence, lowering the elevation of the entire delta region (Thien, 2021). This, in turn, makes the MD increasingly vulnerable to sea level rise and saltwater intrusion. Conversely, as surface water becomes scarce due to salinization, communities intensify groundwater extraction, further accelerating subsidence (CEVIWRPI, 2024). This vicious cycle exacerbates the groundwater crisis in the MD and underscores the urgent need for an integrated management approach, rather than addressing each issue in isolation. For a quantitative perspective, refer to Table 3 below.

Table 3. Land subsidence rates and groundwater levels in the MD

Areas	Rate of land subsidence	Rate of groundwater level decline	Study timeline	Sources
The whole MD	1.07 cm y^{-1}	0.3–0.5 m y^{-1}	Not specified	DWRPIS (2014)
Urban areas	2.0–4.0 cm y^{-1}	Not specified	2014 - 2019	Neussner (2019)
Rural areas	0.5–1.0 cm y^{-1}	Not specified	2014 - 2019	Neussner (2019)
Can Tho city	5.0 cm y^{-1}	Correlation with land subsidence	2014 - 2019	Khai (2021)

Solutions and Policies for Groundwater Governance

Existing Legal and Policy Framework

Groundwater resource management in Vietnam, and particularly in the MD, is structured through a multi-tiered system involving central and local authorities, with participation from various agencies. The primary legal foundation is the Law on Water Resources No. 28/2023/QH15, passed by the National Assembly in 2023 (Official Gazette, 2023). Two of the most critical implementing documents are Decree No. 53/2024/ND-CP, which details the enforcement of several provisions of the Water Resources Law, and Decree No. 54/2024/ND-CP, which regulates groundwater drilling practices, declaration, registration, licensing, water resource services, and the payment for water exploitation rights. Decree 53/2024/NĐ-CP elaborates on key aspects of the 2023 Law, including baseline groundwater investigations; delineation of prohibited and restricted groundwater extraction zones; assessment of artificial recharge potential; development of water source scenarios under normal, scarce, and severely scarce conditions to inform quota adjustments; and the establishment of a national water resource information and database system (Prime Minister, 2024a). Meanwhile, Decree 54/2024/NĐ-CP standardizes drilling practices and the declaration/registration/licensing process for households and introduces a payment mechanism for exploitation rights with provisions for reduction or exemption in cases of forced cutbacks or drought/salinity intrusion (Prime Minister, 2024b). It also clearly assigns the role of commune-level People’s Committees in inventorying groundwater structures and updating the database. In addition, the National Water Resources Planning (Prime Minister, 2022b) and its Implementation Plan (Prime Minister, 2024) set interregional allocation ceilings; while the Mekong Delta Regional Plan (Prime Minister, 2022a) guides the transition of water supply sources and interprovincial surface water infrastructure development, and the integrated planning for the Mekong River Basin (Prime Minister, 2023) focus on gradually restoring groundwater levels in areas experiencing excessive depletion

The groundwater governance apparatus in the MD is divided into three levels: intra-provincial, inter-provincial, and regional. At the provincial level, the Departments of Agriculture and Environment play a central role in overall management, licensing, resource protection, irrigation planning, rural water supply, and groundwater extraction control. At the regional level, organizations such as the Mekong Delta Regional Coordination Council assist the Prime Minister in directing regional linkages and sustainable development; and the Vietnam Mekong River Commission coordinates interprovincial, intersectoral, and international activities to ensure water security.

Despite the existence of a well-defined and generally sound legal framework, the implementation of groundwater policies faces numerous challenges. It is estimated that hundreds of thousands of groundwater structures exist in rural areas; and millions of people in rural MD regions still lack access to stable surface water supplies (Tung & Xuyen, 2020). Table 4 summarizes the feasibility of groundwater governance implementation through key constraints: data availability, surface water infrastructure, and socio-economic drivers.

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Table 4. Readiness to implement groundwater management operations

Criteria	Assessment	Causes
Legal framework and authority	Good	Provisions regarding restricted zones, databases, scenarios, and licensing are clear (Official Gazette, 2023, 2024a).
Data and monitoring	Average	Lack of meters/telemetry at wells; household well records are scattered; the commune level is now responsible for counting and updating the database (Official Gazette, 2024b).
Alternative sources (surface water)	Below average	Transition to surface water requires interprovincial projects aligned with regional planning and the National Water Resources Planning, involving large investments and long timelines (Prime Minister, 2022a).
Local political economy	Below average	Households and small-scale facilities bear the cost of well sealing/ connection; without subsidies, compliance is likely to be low.
Interprovincial governance	Average	Water source scenarios are based on river basins, but licensing/restrictions are imposed by provinces; a practical coordination mechanism is needed (Official Gazette, 2024a).
Inspection and violation handling	Average	Provisions for suspension, revocation, or reduction of water use rights fees exist, but inspection forces and real-time data remain limited (Official Gazette, 2024b).

To address these shortcomings, future implementation of groundwater management policies should focus on the following solutions:

- Establishing "extraction thresholds" and legally binding zoning: In accordance with Decree No. 53/2024/ ND-CP, provinces and centrally governed cities must finalize maps of prohibited and restricted groundwater zones, determine extraction thresholds by aquifer, and annually update water source scenarios. When water conditions shift to "scarce" or "severely scarce," extraction quotas must be tightened in line with the published scenarios. Restricted zones 2 and 3 in urban areas and industrial parks with centralized water supply should be publicly disclosed; new permits for wells of levels 3–5 should be suspended or scaled down, and a schedule should be set for sealing household wells in coastal low-tide zones vulnerable to salinity intrusion (Official Gazette, 2024a).

- Transitioning supply sources from groundwater to interprovincial surface water: Priority should be given to investing in and connecting surface water conveyance projects from the Hau River and the Cai Lon–Cai Be system to replace groundwater use in provinces such as Ca Mau, Bac Lieu, Soc Trang, and Kien Giang. This aligns with regional planning principles and the adaptive spirit of Resolution 120 (Prime Minister, 2017). Provinces must commit to a phased reduction, decreasing centralized groundwater supply by at least X% annually, shifting toward raw water purchases and regional linkages. Precedents for groundwater reduction in major urban areas already exist (Minh et al., 2015; Vang & Ty, 2017).

- Economic instruments and licensing: Payment for exploitation rights should follow the fee structure outlined in Decree No. 54/2024/ND-CP, supplemented by local surcharges in restricted zones. Fee reductions should apply to facilities that reuse or recycle ≥20% of water or switch to surface sources. Mandatory metering and online data transmission must be enforced; non-compliance may result in suspension or revocation of permits, depending on water source conditions and regulatory authority. Households in restricted zones must declare their groundwater use and be subject to volume and duration limits (Official Gazette, 2024b).

- Demand management and livelihood models: Efficient irrigation practices, seasonal adjustments, and restructuring of crop-livestock systems should be adopted in line with water source scenarios. Groundwater should not be used for industrial shrimp farming in areas sensitive to land subsidence and salinity. Mandatory connection to centralized water supply is required where services are available; new internal wells must be prohibited, and a roadmap for sealing old wells in urban and industrial zones should be implemented.

- Water equity and household support: The MD still has over one million small-scale household wells. To encourage households to abandon these wells, connection subsidies, free smart meters, and exemption/ reduction packages for exploitation rights upon conversion must be provided (Giang, 2025).

Technical and Infrastructural Solutions

In addition to governance policies, technical solutions are being actively researched and implemented. One promising approach is managed aquifer recharge (MAR), which involves the controlled replenishment of groundwater (Mäkinen, 2024). Decree No. 53/2024/ND-CP authorizes the assessment of artificial recharge potential; pilot projects have been initiated in provinces using infiltration ponds and corridors located at urban fringes and freshwater transition zones. These systems utilize not only pre-treated floodwater or low-tide peak flows to recharge safe aquifers, but also the rainfall is also considered an important recharge source for shallow groundwater (Day et al., 2018). Accompanying these efforts are protective recharge belts that prohibit wastewater discharge and new drilling activities

The Viet–MAR cooperation program between Vietnam and Finland (2018–2023) represents a significant initiative to enhance sustainable groundwater management under climate change conditions (Truc & Thanh, 2023). The program successfully piloted techniques such as riverbank filtration and MAR experiments in confined aquifers across selected localities. Several studies have also recommended reducing groundwater extraction and expanding artificial recharge infrastructure, while prioritizing surface water utilization as a substitute (Duong et al., 2017).

Traditional infrastructure solutions have also been proposed, including the construction of dikes, water reservoirs, and salinity control canal systems (Giang, 2025). In parallel, the development of centralized water supply systems is considered a key strategy to alleviate pressure on groundwater resources for domestic and industrial use (CEVIWRPI, 2024).

Groundwater drilling practices are regulated under No. 54/2024/ND-CP, which stipulates that only licensed and qualified entities may conduct drilling, rehabilitation, or sealing of wells. Well construction standards must include sealed caps to prevent saline intrusion. Campaigns to seal abandoned wells—especially in coastal areas, which serve as long-term gateways for salinity intrusion—are being organized (Giang, 2025).

Monitoring and Research Projects

The lack of data and monitoring remains a major obstacle (Khai, 2021) necessitating the prioritization of groundwater research and observation initiatives. The Vietnam–the Netherlands cooperation project on subsidence governance and groundwater management was piloted in four provinces (Can Tho city, and provinces of Ben Tre, Soc Trang, and Kien Giang) during the 2020–2021 period to support policy development (Arcadis et al, 2021). The Ministry of Agriculture and Environment has also proposed comprehensive investigation programs and the establishment of a land subsidence monitoring network to improve data accuracy (Cuc, 2019).

Articles 78–80 of Decree No. 53/2024/ND-CP mandate the implementation of a groundwater monitoring network covering water levels, salinity, and quality; synchronization of local data with the national database; and the integration of satellite imagery to track subsidence and inform risk-based licensing decisions. Annual water source scenarios must be published on provincial and interregional information portals, serving as a basis for adjusting extraction quotas, water supply planning, and infrastructure operations.

CONCLUSION AND RECOMMENDATIONS

Groundwater resources in the MD are undergoing severe degradation in both quantity and quality due to excessive and uncontrolled exploitation. This deterioration has led to two urgent consequences: land subsidence occurring at a rate significantly faster than sea level rise, and increasingly deep and early saltwater intrusion.

These two phenomena are causally interlinked, forming a vicious cycle that exacerbates the regional water crisis. Although Vietnam has introduced important policies, implementation remains challenging due to fragmented data systems, overlapping institutional mandates, and policy design shortcomings.

Based on a comprehensive analysis, several strategic recommendations are proposed to address the resource crisis in the MD:

- Conduct in-depth research on hydraulic mechanisms and aquifer interactions, including the dynamics between groundwater and surface water, to develop comprehensive hydrogeological models (Schmidt, 2015).

- Pilot and evaluate the MAR solutions, assessing their cost-effectiveness, technical performance, environmental impact, and socio-economic benefits to determine feasibility and scalability. MAR represents a promising approach for restoring depleted aquifers. From these evaluations, geologically and economically suitable locations in the MD should be identified for model replication.

- Develop integrated forecasting models linking groundwater extraction, land subsidence, and saltwater intrusion, to generate future scenarios and support proactive, long-term policy planning (Schmidt, 2015). In particular, machine learning models such as Artificial Neural Networks (ANN) or other algorithms can be employed to predict trends in groundwater decline and subsidence risk, thereby enhancing resource management effectiveness (Duong et al., 2017; Ty et al., 2018). These models should be trained using historical data on rainfall, river levels, extraction rates, and geological parameters to improve predictive accuracy.

- Establish a regional cooperation framework, recognizing that major aquifers in the MD are hydraulically connected with Cambodia and Thailand. This framework should include the formation of joint technical working groups, cross-border community consultations, transboundary monitoring networks, and real-time data sharing. Such collaboration must be grounded in principles of transparency, equity, and sustainability, serving as a prerequisite for water security and long-term regional development.

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