

Maharashtra Groundwater (Development and Management) Act 2009: A Comprehensive Analysis of Legislative Architecture, Institutional Governance, Field Implementation, and Pathways for Transformative Groundwater Sustainability in Semi-Arid Maharashtra

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Abstract - Groundwater constitutes the primary freshwater resource for over 70% of Maharashtra's rural and peri-urban population, underpinning agricultural livelihoods, industrial enterprise, and domestic water security across the state's predominantly semi-arid Deccan Basaltic Trap terrain. The Maharashtra Groundwater (Development and Management) Act, 2009 — enacted under Maharashtra Act No. XXVI of 2013 — represents the most substantive legislative instrument for groundwater governance in the state, establishing a multi-tiered regulatory architecture encompassing the State Groundwater Authority, District Authority, District Watershed Management Committees, Watershed Water Resources Committees (WWRC), and the Groundwater Surveys and Development Agency (GSDA). This paper undertakes a comprehensive, multi-dimensional analysis of the Act's legislative design, definitional framework, institutional mandates, regulatory provisions, enforcement mechanisms, community participation imperatives, and integration with allied policy frameworks including the Maharashtra Water Resources Regulatory Authority Act 2005, and the GEC 2015/2024–25 groundwater estimation methodologies. Drawing upon field observations and institutional research from Solapur District, Maharashtra — one of the most groundwater-stressed and over-exploited districts in peninsular India — the paper critically evaluates the Act's operational efficacy, identifies structural implementation gaps, and proposes a suite of evidence-based reforms. We examine the Act through seven analytical lenses: (i) legislative intent and constitutional grounding; (ii) definitional precision and conceptual adequacy; (iii) institutional design and inter-agency coordination; (iv) notified area regulation and groundwater use planning; (v) drinking water source protection and water scarcity response; (vi) community governance through the WWRC; and (vii) enforcement, penalties, and grievance redressal. Our findings reveal that while the Act provides a robust legislative foundation, persistent implementation deficits, inadequate staffing of GSDA, non-operationalization of WWRCs across critical watersheds, and weak enforcement significantly constrain its transformative potential. The paper concludes with a proposed Integrated Groundwater Governance Reform Framework (IGGRF) and recommends legislative amendments, institutional capacity investments, and technology-driven monitoring innovations to position the Act as a globally exemplary instrument for semi-arid groundwater sustainability.

Key Words: Maharashtra Groundwater Act 2009, Groundwater Governance, Deccan Basalt, Groundwater Regulation

1. INTRODUCTION

Groundwater governs the fate of water security, food production, and economic development across peninsular India. In Maharashtra — India's third-largest state by area and its largest by GDP — approximately 63% of irrigated agriculture, 85% of rural domestic supply, and a significant fraction of industrial water demand depend on groundwater abstraction from Deccan Basaltic aquifers, alluvial formations, and fractured hard-rock terrains [27]. The consequences of unregulated extraction are severe and historically documented: over 56% of Maharashtra's talukas are currently classified as over-exploited, critical, or semi-critical by the Groundwater Estimation Committee (GEC 2024–25), with Solapur District recording some of the most precipitous water table declines in the Deccan plateau in several watersheds [11, 16].

Long-term research from Solapur has documented the socioeconomic dimensions of this crisis. Studies on groundwater depletion in agricultural basaltic terrain identify a spiral of competitive borewell deepening, agrarian distress, and rural migration that has characterised the district for decades [24]. Grounded theory research on social barriers to water scarcity adaptation in Solapur's Deccan terrain reveals entrenched structural, cultural, and institutional impediments that regulatory frameworks must address [8]. The absence of an effective regulatory framework prior to 2009 left vast lacunae around agricultural and industrial extraction, deep-well proliferation, and catchment-scale recharge planning. Against this backdrop, the Maharashtra Groundwater (Development and Management) Act, 2009 (hereafter 'the Act') was enacted, receiving Presidential assent on 3rd December 2013 and representing a paradigm shift from source-centric protection to integrated, community-embedded, and scientifically grounded groundwater governance [38, 39].

Despite its legislative significance, the Act has received limited scholarly examination. This paper addresses that gap through a combined legal-hydrogeological analysis, drawing on the authors' decade-long programme of applied hydrogeological, governance, and socioeconomic research in Solapur and the broader Deccan [2].

1.1 Research Objectives

1. To undertake a section-by-section analysis of the Act's provisions, legislative intent, and definitional framework.
2. To evaluate the institutional architecture and inter-agency coordination mechanisms established by the Act.
3. To critically assess operational implementation in the context of Solapur District's hydrogeological realities.

4. To identify structural gaps, enforcement deficits, and community participation shortfalls.

5. To propose the Integrated Groundwater Governance Reform Framework (IGGRF) as a pathway toward transformative implementation.

1.2 Hydrogeological Context: Deccan Basaltic Terrain

Maharashtra's hydrogeology is dominated by the Deccan Trap Basalts — a laterally extensive flood basalt formation covering approximately 3,08,000 km² of the state. These rocks

are characterised by low primary porosity, with groundwater occurrence dependent on secondary weathering, fracturing, and jointing within vesicular and interflow zones [6, 28]. The seismo-acoustic properties of the Deccan Volcanic Province are increasingly recognised as hydrogeologically significant, influencing fracture connectivity and groundwater flow pathways [6]. Aquifer productivity is accordingly heterogeneous, with borewell yields ranging from 0.5 to 25 m³/hour depending on lithology, structural position, and depth [11, 42].

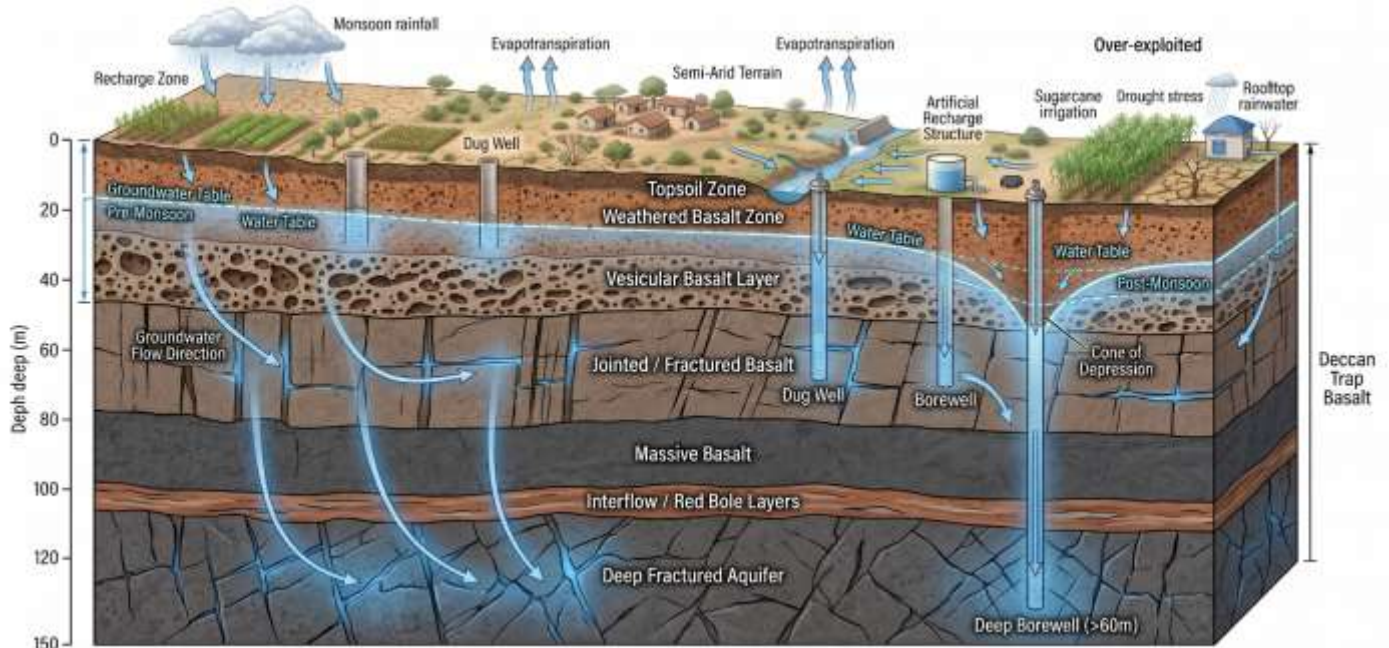


Fig. 1- Hydrogeological Cross-Section of the Deccan Basalt

Solapur District, situated in the semi-arid eastern Deccan, receives mean annual rainfall of 556 mm (IMD, 2023), characterised by high temporal variability and increasing monsoonal deficit in recent decades. Pioneering watershed analysis from the Yerala River Basin — which drains the northern Solapur-Satara interface — established a methodological framework for water stress area prioritisation and artificial recharge zone appraisal in basaltic terrain that underpins the district-level analyses in this paper [28, 29, 31]. Groundwater exploration and assessment across Solapur's semi-arid basaltic terrain has identified the hydrogeological controls governing aquifer potential and the spatial heterogeneity that makes blanket regulatory thresholds challenging to apply. The district hosts 159 GSDA observation wells, of which 89% recorded declining pre-monsoon static water levels between March 2022 and March 2026. The incidence of flood hazard along the Chandrabhaga River near Pandharpur [34] and water scarcity conditions in Osmanabad [30, 33, 35] further illustrate the interconnected water insecurity facing the broader Solapur region.

2. MATERIALS AND METHODS

This research adopts an integrated legal-hydrogeological methodology combining: (i) systematic exegesis of the Act (Maharashtra Act No. XXVI of 2013) and its legislative history; (ii) inter-textual analysis with allied legal frameworks; (iii) institutional ethnography of GSDA Solapur Division field operations grounded in the authors' professional practice; and (iv) secondary analysis of GSDA GEC 2024–25 groundwater

status data, March 2026 OBW datasets, and CGWB national aquifer mapping results.

2.1 Legal Analysis Framework

The Act's provisions were analysed using a four-dimensional framework: (a) textual interpretation of statutory language; (b) purposive analysis aligned with the Act's stated objectives; (c) comparative analysis with the Model Groundwater Bill 2017 [44], Gujarat and Andhra Pradesh frameworks; and (d) constitutional grounding under Article 21, Seventh Schedule Entry 17, and Article 48A.

2.2 Field Data Integration

GSDA Solapur Division's institutional records, groundwater level monitoring datasets (2020–2026), and GEC 2024–25 block-level assessment results were synthesised. GIS and remote sensing methodologies established in the authors' prior work — including watershed characterisation using RS/GIS [31], multi-criteria evaluation for site assessment [26], and GIS-based drinking water zone mapping [32] — provided the spatial analytical foundation for field data integration.

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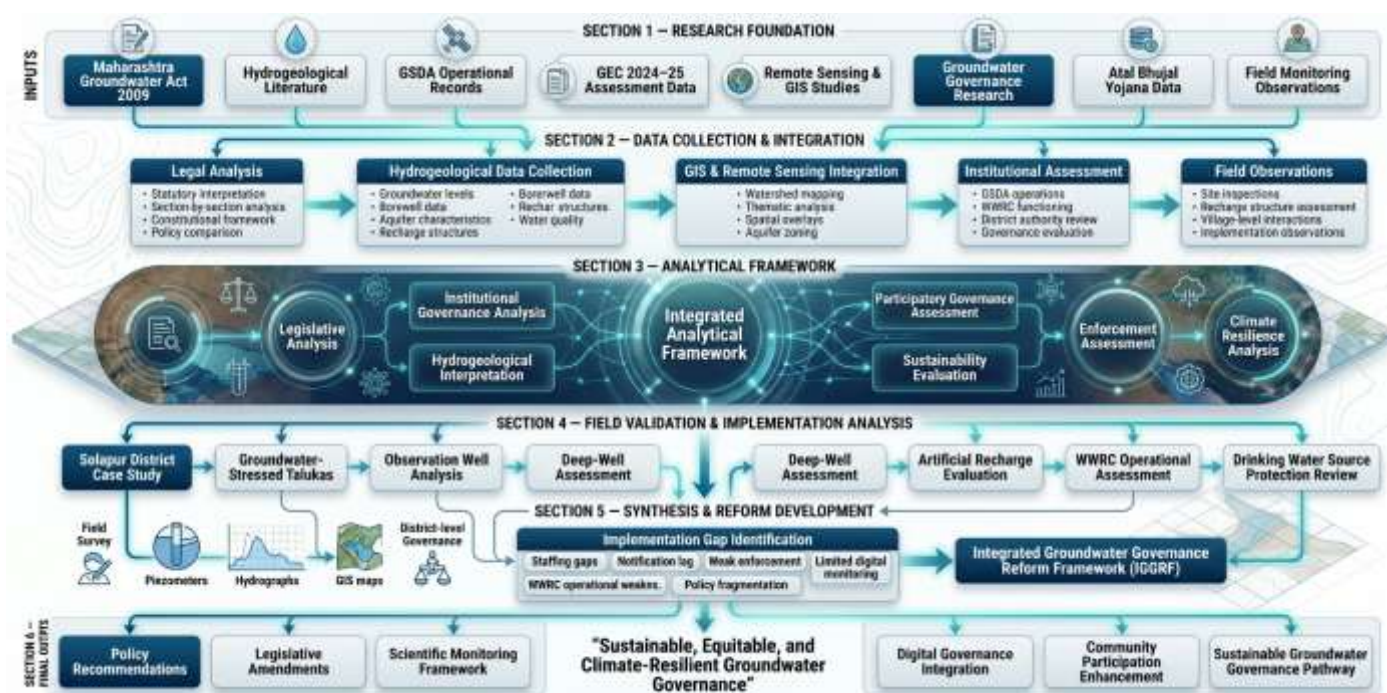


Fig. 2- Integrated Legal – Hydrogeological Methodological Framework

3. LEGISLATIVE ARCHITECTURE AND DEFINITIONAL FRAMEWORK

The Act is structured across 8 chapters and 59 sections, constituting one of the most architecturally sophisticated state groundwater statutes in India. Its preamble articulates a quadruple mandate: sustainability, equity, adequacy, and quality — a formulation that aligns with the human right to water as codified in UN General Assembly Resolution 64/292 (2010) [50] and anticipates India's Jal Jeevan Mission objectives by nearly a decade [1].

3.1 Definitional Innovations (Section 2)

Section 2 of the Act provides 39 definitions establishing a precise conceptual vocabulary essential for regulatory clarity. Several definitions warrant specific analytical attention:

3.1.1 'Groundwater' (Section 2(xi))

The Act defines groundwater as 'water existing in an aquifer below the surface of the ground in the zone of saturation which can be extracted through wells, borewells, tubewells or any other means or emerges as springs and base flow in streams and rivers.' This definition is scientifically robust, explicitly recognising the hydrogeological connection between groundwater and surface water that the groundwater-ecosystem interface literature [12] shows is frequently ignored in regulatory frameworks.

3.1.2 'Deep-Well' (Section 2(iv))

The definition of 'deep-well' as a structure of normally sixty metres or more depth is a critical regulatory threshold. This criterion corresponds to the transition from weathered regolith to fractured basalt aquifers in Deccan terrain — a transition documented extensively in the authors' exploration work in Solapur [11] and Yerala Basin aquifer studies [28]. Field observations from Solapur suggest this threshold may require revision as borewell deepening to 90+ metres becomes routine.

3.1.3 'Notified Areas' (Section 2(xvi))

Notified areas are defined with reference to GEC-based groundwater estimation categories. This definitional linkage to national estimation methodology (GEC 2015, updated to GEC 2024–25) is methodologically sound but creates a temporal lag problem: deteriorating groundwater conditions may not trigger notification until a subsequent estimation cycle [36].

3.1.4 'User of Groundwater' (Section 2(xxxii))

The inclusivity of this definition — encompassing individuals, institutions, companies, Water Users' Associations, co-operative societies, panchayats, and bulk users — ensures that industrial and institutional extraction, a growing concern in peri-urban Maharashtra, falls within the regulatory perimeter. The socioeconomic implications of this broad regulatory ambit — particularly for collective farming arrangements and agricultural groundwater users — have been examined in the Solapur context [4, 41, 42].

3.1.5 'Watershed' and 'Hydrological Year' (Sections 2(xxxiv), 2(xiii))

The watershed as the basic unit of planning — rather than administrative boundaries — represents a paradigmatic advance in Indian water law [37]. The role of state, central, and non-governmental organisations in watershed management, examined in the Maharashtra context [14], provides the governance context within which the Act's watershed-based definitions must be operationalised.

Table 1: Structural overview of key sections of the Maharashtra Groundwater (Development and Management) Act, 2009

Section	Title	Chapter	Key Regulatory Function
3	State Groundwater Authority	II	Establishes MWRRA as State Authority; mandates GSDA Director as special invitee
4	Powers to Notify Areas	II	Basis for declaring over-exploited/critical watersheds as notified areas
6	Protection of Water Quality	II	Prohibition on groundwater contamination; polluter pays principle
7	Registration of Well Owners	II	Mandatory registration statewide; foundation for groundwater census
8	Prohibition on Deep-Wells	II	Prohibition on new agri/industrial deep-wells; cess on existing
9	Rain Water Harvesting	II	Mandates RWH in urban areas $\geq 100 \text{ m}^2$; Integrated Watershed Plans
10	Groundwater Use & Crop Plan	II	Crop planning based on aquifer water budget; water-intensive crops prohibited
17	District Authority	III	Designates Sub Divisional-level officer as enforcement authority of Revenue dept.
21	Area of Influence Protection	III	500m exclusion zone around public drinking water sources
25	Water Scarcity Declaration	IV	Mechanism for declaring scarcity; enabling regulation of extraction
29	WWRC Constitution	V	Multi-stakeholder watershed body; minimum 1/3 women members
32	New Well Permissions	V	WWRC approval required; GSDA technical advice mandatory
35	Sand Mining Regulation	V	WWRC recommends prohibition/regulation to District Authority
52	Offences and Penalties	VIII	Up to ₹25,000 fine; up to 6 months imprisonment for repeat offences
56	Protection of Water Quality	II	Prohibition on groundwater contamination; polluter pays principle

4. INSTITUTIONAL ARCHITECTURE: DESIGN, MANDATES, AND COORDINATION

4.1 The Five-Tier Governance Structure

The Act creates a vertically integrated, five-tier governance architecture for groundwater regulation in Maharashtra. The role of government — state, central, and NGO — in this multi-tier system has been analysed in the Maharashtra watershed management context, providing a governance theory foundation for the institutional analysis below.

4.1.1 Tier 1: State Groundwater Authority (Section 3)

The Act designates MWRRA — established under the Maharashtra Water Resources Regulatory Authority Act, 2005 — as the State Groundwater Authority, integrating groundwater governance into the broader water resource regulatory framework and avoiding institutional duplication. The Commissioner of GSDA is mandated as a special invitee, ensuring technical expertise at the highest decision-making level [39, 40].

4.1.2 Tier 2: Empowered Committee and State Watershed Management Council (Sections 15–16)

The State Water Board serves as the Empowered Committee responsible for integrating Watershed Development and Management Plans across the state. In practice, this integration function has rarely been operationalised, a governance gap documented in the broader Maharashtra watershed management literature [14].

4.1.3 Tier 3: District Authority and District Watershed Management Committee (Sections 17–19)

The Act designates an officer Sub Divisional Officer of Revenue Department as the District Authority — a pragmatic choice given the revenue administration's access to land records essential for well registration and land-use regulation. The District Watershed Management Committee, chaired by the Guardian Minister, elevates groundwater governance to the highest district political levels.

4.1.4 Tier 4: Watershed Water Resources Committee (Sections 29–37)

The WWRC is the Act's most innovative institutional creation. By integrating elected representatives, technical personnel, Water Users' Association representatives, NGO invitees, and a mandatory one-third women membership requirement, the Act operationalises principles of community-based natural resource management [47]. The WWRC's powers span groundwater use planning (Section 30), quality protection (Section 31), new well approvals (Section 32), community participation (Section 33), and sand mining regulation (Section 35).

4.1.5 Groundwater Surveys and Development Agency (Chapter VII)

GSDA — the specialist hydrogeological agency of the Maharashtra Government — is the technical backbone of the entire governance architecture. Sections 41–46 assign GSDA responsibilities spanning watershed and aquifer delineation, area of influence mapping, WWRC technical assistance, Integrated Watershed Plan preparation, hydrogeological studies, and Panchayat advisory services. GSDA Solapur's operational experience across these mandates — from deep hydrogeological surveys in basaltic terrain to IEC-based awareness programmes

as done under Atal Bhujal Yojana [23, 25] and continuous monitoring through piezometers and Automatic Water Level

Recorders [20] — demonstrates the breadth and operational intensity of this mandate.

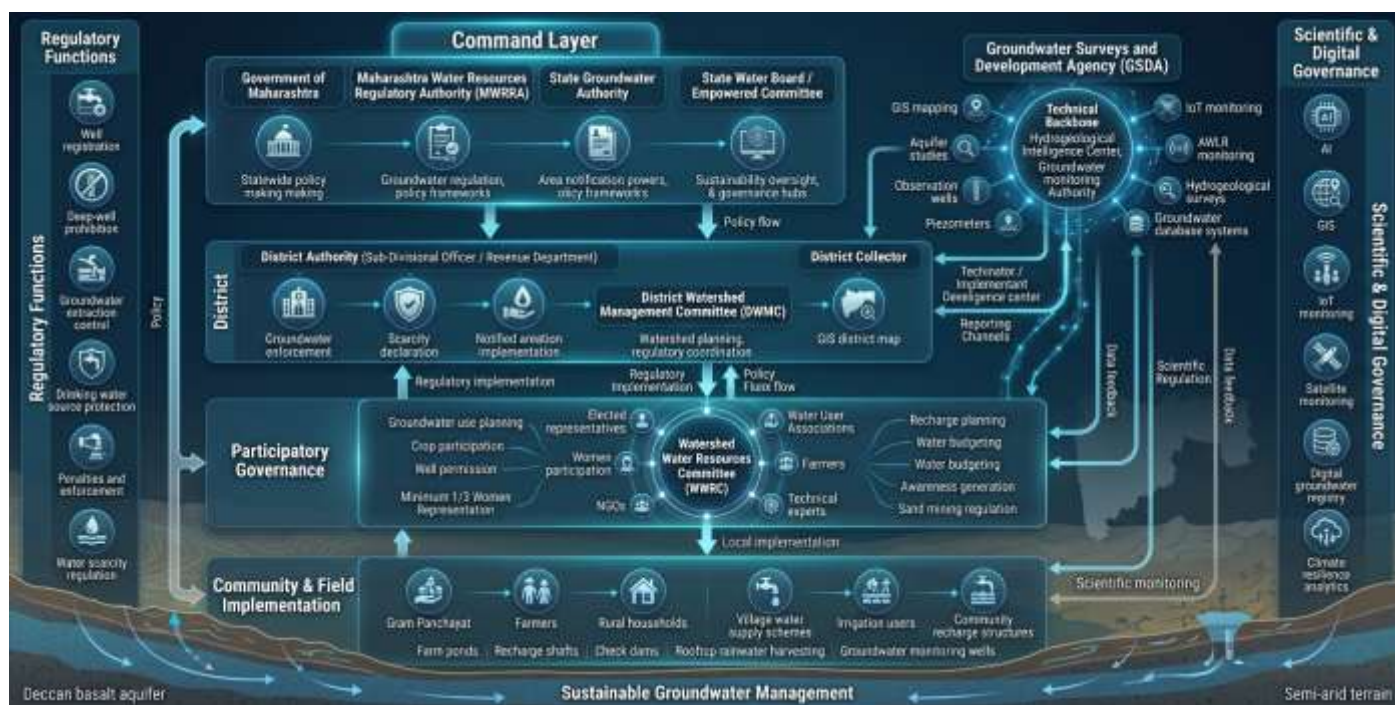


Fig. 3 - Five Tier Institutional Architecture under the Maharashtra Groundwater Act 2009

Table 2: Institutional architecture under the Act — roles, accountability, and field status in Solapur Division

Institution	Key Powers	Accountability	Field Status
State Authority (MWRA)	Notification, quality protection, well registration, deep-well ban	State Govt	Partially operational; area notifications pending review
Empowered Committee	Integration of watershed plans	State Water Council	Largely dormant in practice
District Authority (SDO Revenue)	Enforcement, scarcity declaration, well	District Collector	Active but understaffed
DWMC	Integrated Watershed Plan preparation	Guardian Minister	Constituted; irregular meetings
WWRC	Groundwater use planning, well approvals, crop plans	District Authority	Partially constituted; functionally

Institution	Key Powers	Accountability	Field Status
GSDA	Technical surveys, monitoring, advisory	Director GSDA	Active; significant capacity gaps

5. CORE REGULATORY PROVISIONS : ANALYSIS AND FIELD ASSESSMENT

5.1 Notified Area Mechanism (Sections 4–5)

The notified area concept is the cornerstone of the Act's regulatory strategy. In Solapur District, where GEC 2024–25 assessment reveals widespread over-exploitation — particularly in Mohol, Malshiras, Sangola, and Akkalkot talukas — the activation of notified area provisions is both legally warranted and operationally urgent. The de-notification provision (Section 5), triggered when groundwater availability and quality improve, creates a scientifically grounded dynamic regulatory model.

5.2 Deep-Well Regulation (Section 8)

Section 8 is among the most consequential provisions of the Act. It establishes a blanket prohibition on drilling new deep-wells ($\geq 60\text{m}$) for agricultural or industrial use, directly addressing the most significant driver of aquifer depletion in Deccan terrain. Research on groundwater depletion in agricultural basaltic terrain in Solapur documents the trajectory of competitive deepening and its consequences for water security [16]. The cess mechanism on existing deep-well use in non-notified areas (Section 8(3)) represents a demand-management instrument that remains unimplemented across Maharashtra — a significant policy failure [43].

Field assessment in Solapur reveals Section 8 enforcement has been inconsistent. Registration of drilling rigs (Section 12) — a prerequisite for effective deep-well regulation — remains incomplete. The M-Sand policy analysis [7] provides a comparative lens: Maharashtra's experience with aggregate extraction regulation illustrates the institutional challenges of regulating diffuse, economically incentivised extraction activities that parallel the deep-well enforcement challenge.

5.3 Groundwater Use Plans and Crop Planning (Sections 10–11)

The Act's requirement for aquifer-based Groundwater Use Plans — prepared by WWRCs with GSDA technical support and covering both recharge and withdrawal accounting — represents a globally progressive approach to demand-side management. The crop plan provision, which renders non-observance a cognizable offence, extends regulatory reach into agricultural decision-making. Research on groundwater management and sustainable farming practices in Solapur [24] and economic impacts of collective farming in drought-prone regions [4] illuminate the socioeconomic context within which crop plans must be implemented. The groundwater-ecosystem interplay [12] provides the ecological rationale for water-intensive crop restrictions in notified areas.

In Solapur's sugar belt talukas, where sugarcane accounts for disproportionate groundwater withdrawal, the celebrity-driven water conservation initiative analysis [3] provides a cautionary evidence base: popular advocacy and voluntary conservation, however well-intentioned, cannot substitute for the structural demand regulation that crop plans represent.

5.4 Drinking Water Source Protection (Sections 20–24)

Chapter III's provisions for Public Drinking Water Source notification and protection represent the Act's most operationally active provisions in Solapur. Section 21's 500-metre exclusion zone provides a clear spatial regulatory boundary. Research on GIS-based drinking water zone mapping in Akkalkot Taluk [32] offers a methodology for systematically identifying and prioritising public drinking water sources for notification under Section 20. The connection between groundwater quality and public health [15], and the role of water quality testing infrastructure in Solapur District [22], underscore the urgency of Section 23's contamination prevention mandate.

5.5 Water Scarcity Declaration and Response (Sections 25–27)

Chapter IV's water scarcity provisions create a responsive management framework for drought years. The District Authority's power to regulate extraction within one kilometre of public drinking water sources during declared scarcity periods is critical for Maharashtra's drought-prone districts. Research on water scarcity mitigation strategies for Solapur [21] and on anticipating water scarcity impacted areas and their duration in Osmanabad District [35] provide empirical foundations for the scarcity declaration and response protocols. The mapping of water scarce zones in Osmanabad using groundwater level and rainfall analysis [33] demonstrates the spatial analytical methodology that should inform District Authority decisions under Section 25.

5.6 Rain Water Harvesting and Artificial Recharge (Section 9)

Section 9 mandates Integrated Watershed Development and Management Plans for artificial recharge, with priority for notified areas, and requires urban local bodies to mandate

rooftop rainwater harvesting for buildings ≥ 100 m². The importance of water harvesting techniques for drought mitigation in Solapur [18] is well established. Field documentation of artificial recharge zone appraisal in the Yerala Basin [28] and successful recharge shaft development at Shetphal — from site selection through to community handover [5] — provide replicable operational models for Section 9 implementation. Feasibility assessment of artificial recharge structures on over-exploited mini-watersheds of Osmanabad District [30] demonstrates that the technical methodology for GUP-linked recharge planning is mature and field-validated.

Section 9(9)'s mass awareness mandate is directly addressed by GSDA Solapur's IEC-based groundwater awareness programme under Atal Bhujal Yojana [25] and the agency's innovative exhibitions-based awareness model [23]. These institutional initiatives, developed within the Act's operational framework, represent the kind of community engagement that Section 9(9) envisions and that the AI-IEC integration model in Solapur seeks to scale [19].

6. COMMUNITY PARTICIPATION AND THE WWRC MODEL

6.1 WWRC as a Model of Participatory Groundwater Governance

The Watershed Water Resources Committee is the Act's most conceptually innovative institutional creation. By embedding groundwater governance in a multi-stakeholder body with a statutory gender equity requirement, the Act operationalises principles of community-based natural resource management [47]. The transparent, participatory IEC approach demonstrated in GSDA Solapur's Atal Bhujal Yojana groundwater awareness programme [25] and the hydroinformatics framework integrating AI and IEC for conservation [19] illustrate the community engagement modalities that effective WWRC functioning requires.

6.2 Implementation Assessment: WWRC Operationalization in Solapur

Field assessment in Solapur Division reveals uneven WWRC operationalisation. Meeting regularity is inconsistent; technical capacity is limited; and watershed-based GUP preparation remains incomplete in the majority of constituted WWRCs [48, 49, 51]. The AI-GIS-IoT framework proposed for climate-resilient Maharashtra [9] points toward the digital tools that could support WWRC planning and monitoring functions if institutional capacity constraints are addressed.

6.3 Community Ownership and the Rights of Small and Marginal Farmers

Section 33 explicitly mandates the WWRC to promote community ownership of groundwater and the rights of small and marginal farmers. The socioeconomic analysis of groundwater management and sustainable farming in rural Solapur [24] reveals the structural inequities in groundwater access that WWRCs must confront, while the grounded theory investigation of social barriers to water scarcity adaptation [8] identifies the cultural and institutional impediments that community governance must overcome.

7. ENFORCEMENT, PENALTIES, AND GRIEVANCE REDRESSAL

7.1 Enforcement Powers (Section 28)

Section 28's thirteen enforcement powers — from pumping tests and geophysical surveys to well sealing and equipment seizure — constitute one of the most expansive enforcement toolkits in Indian environmental and water law. Field assessment in Solapur reveals that while District Authorities have used well-closure and notice powers, the more coercive enforcement powers have been rarely invoked due to socially sensitive conditions in agrarian communities and the procedural complexity of coordinating multi-agency action. Remote sensing and GIS advances for groundwater monitoring [13] and the smart watersheds AI-GIS-IoT framework [9] point toward technology-enabled enforcement monitoring that could supplement field inspection capacity.

7.2 Penalties (Section 52)

The penalty structure — ₹10,000 for first offence and up to six months imprisonment with ₹25,000 for subsequent offences — reflects 2009 legislative norms but is increasingly inadequate for commercial groundwater extraction where economic gains from violation dwarf the penalty. A volume-linked penalty structure would create proportionate deterrence.

7.3 Appeals Structure (Section 56)

The two-tier appeals structure — WWRC/Panchayat decisions to District Authority (60 days), and District Authority decisions to State Authority (60 days, final) — provides an accessible grievance pathway. The policy-to-practice governance challenge [1] in analogous rural water infrastructure programmes suggests that appeals mechanisms require active monitoring to ensure accessibility for marginal communities.

8. CRITICAL IMPLEMENTATION GAPS AND REFORM IMPERATIVES

8.1 Identified Structural Gaps

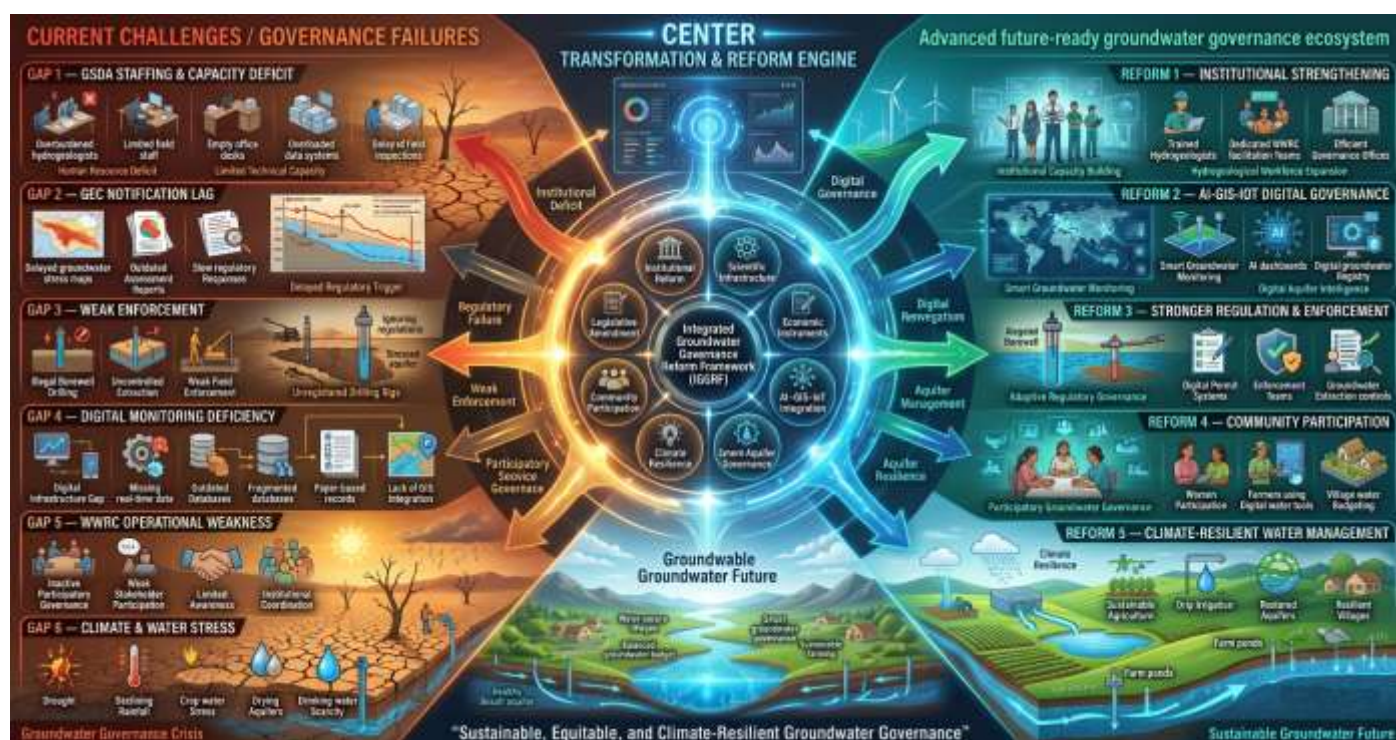


Fig. 4 - Implementation Gaps and Reform Pathways for Sustainable Groundwater Governance in Maharashtra

Based on the foregoing analysis and field observations from Solapur Division, the following critical implementation gaps are identified:

Gap 1: GSDA Staffing and Capacity Deficit

GSDA's mandate spans statewide well registration, area of influence delineation, WWRC technical support, drilling agency registration, Integrated Watershed Plan preparation, and hydrogeological studies — a breadth of mandate that the authors' own agency experience confirms is far beyond current staffing levels. A comprehensive staffing review and cadre expansion is an urgent prerequisite for Act implementation. Future directions for AI-augmented groundwater resource management at GSDA Solapur [10] suggest that AI tools can partially offset staffing constraints but cannot substitute for qualified hydrogeological personnel.

Gap 2: GEC Notification Lag

The linkage of notified area declaration to GEC estimation cycles creates a structural lag between groundwater deterioration and regulatory response. The GEC 2024–25 results document widespread over-exploitation in Solapur talukas [11, 16, 36]; a mechanism for provisional notification based on GSDA monitoring data between GEC cycles should be legislatively enabled.

Gap 3: Cess Mechanism Non-Implementation

The cess on existing deep-well use in non-notified areas (Section 8(3)) — a potential source of both conservation finance and demand-management signals — has not been implemented in any district of Maharashtra. A standardised cess notification and collection mechanism, integrated with agricultural

electricity tariff billing, could operationalise this provision rapidly.

Gap 4: Digital Monitoring Integration

The Act predates the widespread availability of digital water level monitoring, satellite-based aquifer monitoring, and mobile-based reporting. The smart watershed governance model incorporating AI, GIS, and IoT [9] and advances in remote sensing and GIS for sustainable groundwater monitoring [13] provide a technology roadmap for integration. The continuous monitoring experience from piezometers and AWLRs under Atal Bhujal Yojana in Solapur [20] demonstrates that GSDA Solapur already possesses operational capacity that should be systematically linked to WWRC planning cycles. AI applications in groundwater management [10, 17] and the AI-IEC integrated model [19] offer further tools for enhancing the Act's scientific implementation capacity.

Gap 5: Sand Mining — Regulatory Ambiguity

Section 35's provision for WWRC recommendation of sand mining prohibition in notified areas leaves non-notified areas unaddressed, despite documented impacts on riverine groundwater recharge. Maharashtra's M-Sand policy experience [7] provides both a regulatory model and an evidence base: the transition to manufactured sand reduces river sand extraction pressure and should be systematically linked to the Act's sand mining regulatory framework.

Gap 6: Penalty Quantum

The maximum penalty of ₹25,000 (2009 values) is insufficient as a deterrent for commercial extraction or industrial violations. A legislative amendment linking maximum penalties to extraction volume and commercial nature of offence would create proportionate deterrence.

9. INTEGRATED GROUNDWATER GOVERNANCE REFORM FRAMEWORK (IGGRF)

Based on the foregoing analysis, this paper proposes the Integrated Groundwater Governance Reform Framework (IGGRF) — a five-pillar reform pathway grounded in the principle that legal innovation must be matched by institutional investment, scientific infrastructure, community capacity, and adaptive policy mechanisms.

Pillar I: Institutional Strengthening

- Expand GSDA staffing by minimum 50% at District and Taluka level within five years, with priority for hydrogeologist which includes Assistant Geologist, Junior Geologist, Surveyors, Technical Officers and GIS specialist recruitment [10, 41].
- Establish dedicated WWRC Facilitation Units within each GSDA Division, drawing on the IEC facilitation model demonstrated in Solapur's Atal Bhujal Yojana programme [23, 25].
- Mandate annual WWRC performance audits and operationalise the Empowered Committee's watershed plan integration function [14].

Pillar II: Scientific and Digital Infrastructure

- Expand the GSDA observation well network and install IoT-enabled automated water level recorders — scaling the piezometer/AWLR monitoring model established as under Atal Bhujal Yojana in Solapur [20].
- Develop aquifer-specific digital GUPs using NAQUIM data integrated with GEC 2024–25 assessments, applying remote sensing and GIS methodologies [13] proven in the Deccan basaltic terrain context.
- Establish a statewide groundwater digital registry integrating well registration, drilling rig registration, and extraction monitoring, enabled by the AI-GIS-IoT framework [9] and AI innovations in groundwater management [10, 17].

Pillar III: Legislative Amendments

- Amend Section 8 to lower the deep-well regulatory threshold to 45m in designated over-exploited talukas, consistent with Deccan aquifer depth profiles documented in Solapur field studies [11].
- Enable provisional notification (Section 4) based on GSDA and CGWB monitoring data between GEC estimation cycles.
- Revise penalty quantum in Section 52; extend Section 35 sand mining regulation to non-notified areas using the M-Sand policy framework [7] as a regulatory complement.

Pillar IV: Economic Instruments

- Immediately notify and implement the cess mechanism under Section 8(3) integrated with agricultural electricity tariff collection.
- Establish a Maharashtra Groundwater Conservation Fund, financed by cess revenues, for WWRC-managed recharge infrastructure — building on the artificial recharge zone appraisal and recharge shaft methodology developed for Solapur and Osmanabad [5, 28, 30].
- Develop groundwater credit schemes incentivising farmers who implement on-farm recharge structures, with economic impact assessed using the collective farming research framework [4].

Pillar V: Community Capacity and Awareness

- Mandate annual WWRC capacity building on GUP preparation and water budgeting; integrate groundwater governance education into school curricula.
- Scale GSDA Solapur's exhibitions-based and IEC-tool-based awareness model [23, 25] across all 36 districts; critically evaluate and learn from celebrity-driven conservation initiatives [3] to distinguish effective community mobilisation from superficial engagement.
- Establish a Women in Water Governance programme to strengthen substantive participation of women WWRC members, addressing the social barriers to adaptation [8] identified in grounded theory research. The Act creates a vertically integrated, five-tier governance architecture for groundwater regulation in Maharashtra. The role of government — state, central, and NGO — in this multi-tier system has been analysed in the Maharashtra watershed management context, providing a governance theory foundation for the institutional analysis below.

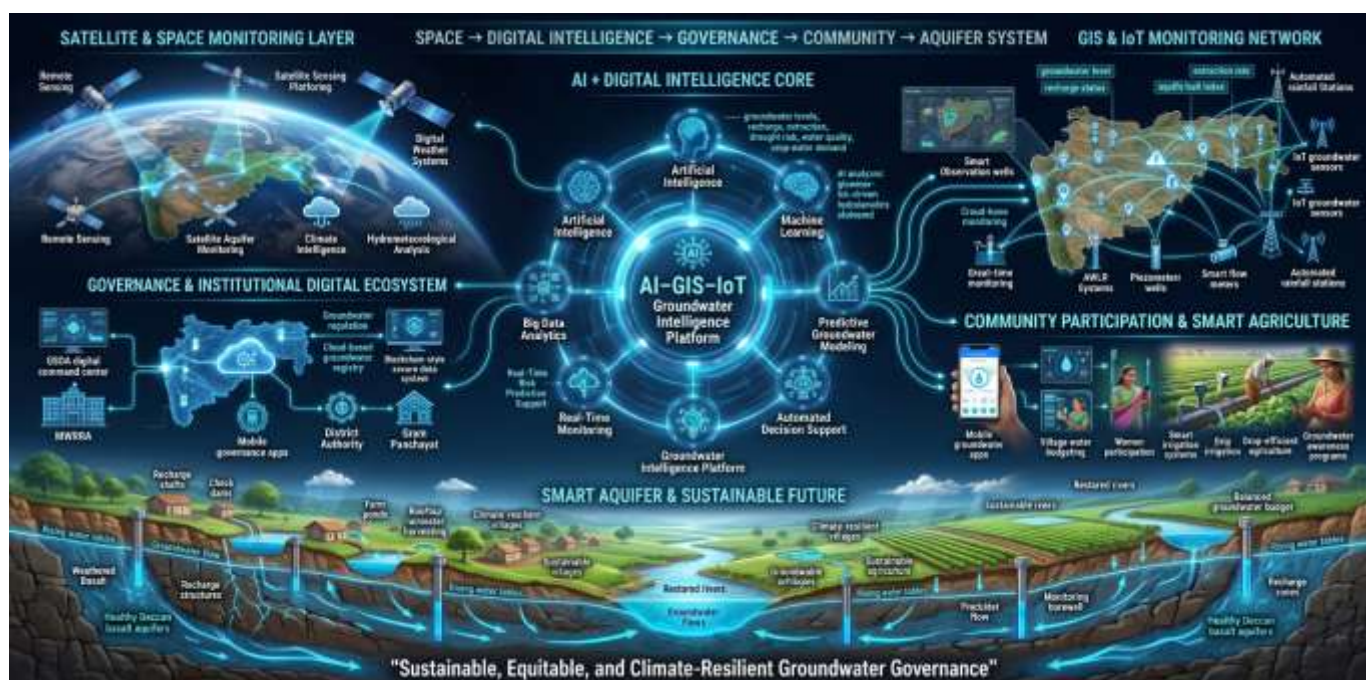


Fig. 5 Future Digital Groundwater Governance Ecosystem

Table 3: Integrated Groundwater Governance Reform Framework (IGGRF) — pillars, key interventions, lead agencies, and indicative timelines

IGGRF Pillar	Key Interventions	Lead Agency	Timeline
Institutional Strengthening	GSDA expansion; WWRC Facilitation Units; Empowered Committee activation	GSDA / Govt of Maharashtra	0–3 years
Scientific Infrastructure	IoT well monitoring; aquifer-specific digital GUPs; groundwater registry	GSDA / CGWB	1–5 years
Legislative Amendments	Revised penalty quantum; provisional notification; climate adaptation clause	Law & Judiciary Dept	1–2 years
Economic Instruments	Cess implementation; Conservation Fund; credit schemes	State Authority / Finance	0–2 years
Community Capacity	WWRC training; school curricula; social media awareness scale-up	GSDA / Education Dept	Ongoing
IGGRF Pillar	Key Interventions	Lead Agency	Timeline

10. POLICY INTEGRATION: ACT INTERFACE WITH ALLIED FRAMEWORKS

10.1 Atal Bhujal Yojana (ABY)

The Atal Bhujal Yojana — India's flagship ₹6,000 crore centrally sponsored scheme for community-led groundwater management — provides a significant financial and institutional complement to the Act's operational framework. ABY's requirements for Gram Panchayat-level Water Security Plans,

water budgeting, and participatory data collection align directly with the Act's WWRC and GUP provisions [46]. GSDA Solapur's sustained ABY implementation — including piezometer and AWLR-based continuous monitoring [20], groundwater awareness exhibitions [23], and IEC-tool-based awareness programmes [25] — provides an operational model for Act-ABY integration that should be systematised district and statewide.

10.2 GEC 2015/2024–25 Groundwater Estimation Methodology

The Act's definitional linkage to GEC-based categorisation makes the periodic GEC estimation exercise central to the Act's regulatory trigger mechanism. The GEC 2024–25 methodology — incorporating revised recharge coefficients for Deccan Basalt and improved irrigation return flow estimation — provides a more scientifically refined basis for notified area declarations. GSDA's groundwater exploration and assessment work across Solapur's basaltic terrain [11] and the earlier Osmanabad mini-watershed assessment [30] exemplify the site-specific hydrogeological knowledge that supplements GEC block-level assessments.

10.3 Maharashtra Water Resources Regulatory Authority Act, 2005

The Act's institutional design is deeply integrated with the MWRRA framework — the State Groundwater Authority is MWRRA itself. The effectiveness of groundwater governance therefore depends partly on MWRRA's broader institutional capacity [40].

10.4 Jal Jeevan Mission (JJM)

Maharashtra's Jal Jeevan Mission commitments — achieving functional household tap connections to all rural households — depend substantially on the sustainability of groundwater sources feeding village water supply schemes. The governance case study of rural water supply implementation under JJM [1] reveals critical policy-to-practice gaps in scheme sustainability that the Act's drinking water source protection provisions (Sections 20–24) and water scarcity response framework (Sections 25–27) are directly positioned to address.

A formal protocol for GSDA technical support to JJM source sustainability assessments — grounded in the Act's legal framework — would strengthen both programmes.

11. COMPARATIVE LEGISLATIVE ANALYSIS

Situating the Maharashtra Act within the landscape of Indian state groundwater legislation reveals both its distinctive innovations and areas where it may benefit from learning from other frameworks.

11.1 Comparison with Model Groundwater Bill 2017

The Central Government's Model Groundwater (Sustainable Management) Bill 2017 [44] incorporates provisions more advanced than the 2009 Act: explicit recognition of the right to water, a dedicated Groundwater Regulatory Authority, mandatory aquifer management plans for all areas, and groundwater market provisions. Maharashtra's Act, while predating the Model Bill, provides a more operationally grounded community governance model through the specific WWRC constitution and the gender equity requirement.

11.2 Gujarat and Andhra Pradesh Frameworks

WALTA's registration and licensing system for groundwater extraction is more comprehensive than Maharashtra's selective registration focus. Maharashtra's unique innovation remains the WWRC's explicit community ownership mandate, gender equity provisions, and the integration of cropping pattern regulation — provisions that go beyond comparable state frameworks.

12. CONCLUSIONS

The Maharashtra Groundwater (Development and Management) Act, 2009 represents a legislative landmark in India's groundwater governance journey. Its multi-tier institutional architecture, watershed-based planning philosophy, community governance innovation through the WWRC, explicit equity provisions for small and marginal farmers, and integration with the broader MWRRA framework collectively constitute one of the most sophisticated state groundwater regulatory instruments in the country.

Yet the Act's transformative potential remains substantially unrealised, constrained by GSDA staffing deficits, incomplete WWRC operationalisation, non-implementation of the cess mechanism, GEC notification lag, and insufficient enforcement investment. Solapur District — Maharashtra's most acutely groundwater-stressed region — exemplifies both the urgency and the feasibility of stronger Act implementation. The authors' decade-long research programme from Solapur — spanning hydrogeological field studies, socioeconomic analysis, governance research, AI-technology integration, and community awareness innovation — demonstrates that the scientific, social, and institutional knowledge required for transformative Act implementation is available and field-validated.

The Integrated Groundwater Governance Reform Framework (IGGRF) proposed in this paper charts a five-pillar pathway: institutional strengthening, scientific and digital infrastructure, legislative amendment, economic instruments, and community capacity. These reforms, pursued in concert, can position the Act as a globally exemplary model of integrated, equity-oriented, and scientifically grounded groundwater sustainability governance — one that is urgently needed as Maharashtra faces the compounding pressures of climate

change, agrarian demand, and rapid urbanisation in its Deccan heartland.

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