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Regulating Groundwater for Agricultural Irrigation in Bali: Environmental Law, Institutional Gaps, and the Role of Subak

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ABSTRACT

This study examined legal and institutional challenges of groundwater use for agricultural irrigation in Bali, with particular attention to Subak as a potential co-governance institution. An exploratory socio-legal approach combined doctrinal analysis of Indonesian water-resource and environmental regulations with qualitative evidence from interviews and field observations summarized in a 2026 institutional research report. The analysis addressed conservation, authorization, monitoring, enforcement, and community participation. The findings indicated that the increasingly detailed regulatory framework remains constrained by incomplete hydrogeological data, inadequate measurement of groundwater abstraction, limited user awareness, fragmented interagency coordination, and insufficient formal integration of Subak. Groundwater served as a supplementary irrigation source during dry periods, while its cumulative ecological effects were difficult for individual users to observe. An adaptive co-governance model was developed around aquifer assessment and zoning, authorization conditions, integrated reporting and metering, structured Subak participation, and periodic compliance review. Sustainable groundwater governance required measurable extraction limits, transparent information, accountable public supervision, and locally embedded participation. The qualitative findings were exploratory and did not establish the measured condition of a specific aquifer.

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INTRODUCTION

Groundwater is a crucial element of agricultural resilience because it can protect water supply when rainfall and surface irrigation are not perfect. Its strategic value is particularly high in agriculture systems facing seasonal shortages, delayed canal delivery, competition among users, or changes in land use. However, recent global research shows that this groundwater sustainability is not possible through efficiency measures alone. Aquifer recovery is usually the result of demand control, enforcement of abstraction limits, monitoring, land use coordination, and institutional commitment (Karandish et al., 2025). Irrigation agriculture is a sector with dispersed wells, privately run pumps, and environmental effects that make extraction difficult to observe and control. Groundwater is a legal input to the process and is therefore not just an ordinary production input.

Groundwater is part of an interrelated hydrological system, supports ecosystems, and is a common-pool resource. If a user takes away from it, it could mean less availability to others, and then the environmental consequences might emerge outside the site and time of extraction. Environmental law requires groundwater use to be evaluated through prevention, precaution, carrying capacity, public participation, and equity of generations. A permit or use approval is necessary, but it can hardly replace reliable hydrogeological information, inspection, reporting, and periodic change in extraction conditions. Indonesia has recently revamped the governance of water resources.

Presidential Regulation No. 37 of 2023 provides national policies for conservation, equitable usage, risk management, public participation, and water information. Government Regulation No. 30 of 2024 is for water-resource management to be fully integrated and environmentally friendly. The Ministry of Energy and Mineral Resources Regulation No. 14 of 2024 regulates groundwater business permits and groundwater-use approvals. In 2026, the Ministerial Regulation No. 4 replaced part of the 2024 regulation with the provisions on groundwater-use approvals, supervision, and administrative sanctions. These improvements provide a better formal basis for authorization and control, but they also create a complex institutional architecture, and central, provincial, and district or municipal authorities need to work together. The Indonesian governance problem, therefore, cannot be explained as an absence of rules. An increasing set of issues such as ambiguity, fragmented responsibilities, weak data integration, and limited participation have been identified in groundwater management (Priadi et al., 2024; Zaidi & Handayani, 2025).

The distinction is crucial. When legal norms are in place but not translated into operational thresholds, monitoring routines, or coordinated enforcement, the real issue is regulatory effectiveness. A legally valid permit system can still fail to protect an aquifer if extraction volumes are not measured, conservation zones are incomplete, reporting is inconsistent, and the responsibilities are shared among institutions with no efficient data dissemination mechanism. Bali is a governance context. Agriculture is supported by Subak, a traditional irrigation institution that coordinates water distribution, collective rules, religious practices, as well as conflict resolution. Recent research indicates that Subak remains relevant to irrigation performance, water allocation, water valuation, and landscape conservation (Ardana et al., 2024; Suamba et al., 2025; Yekti et al., 2026). Groundwater extraction is different from the visible canal water. Wells and pumps can tailor access, make observations less common, and have cumulative effects that are often not visible to other farmers. This raises the need to connect statutory groundwater regulation with Subak-based social organization. Existing studies generally focus on different aspects of the problem.

Hydrological studies focus on water allocation and ecological thresholds. Governance studies examine regulation, institutional fragmentation, or community engagement. Subak studies focus on irrigation networks, local knowledge, water value, or cultural landscapes. Much less attention has been paid to how Indonesia's most recent groundwater regulations can be applied in agricultural settings through an integrated environmental-law and local-governance lens. The article fills this gap by linking doctrinal analysis with qualitative evidence reported in the institutional research progress report 2026. The study addresses two questions: First, what are the legal and institutional implications of groundwater use for agricultural irrigation in Indonesia in this context of environmental and water resource governance? Second, how do agricultural groundwater practices in Bali work if we have a system of state regulation, hydrogeological data, and Subak involvement? The article presents a current regulatory map, an integrated analysis of normative and empirical gaps, as well as an adaptive co-governance model for agricultural groundwater use.

Groundwater governance is complicated by physical invisibility, uncertain renewal rates, delayed impacts, and dispersed extraction points. These are the elements that limit the ability of users and regulators to recognize cumulative pressure. Meinzen-Dick and Bruns (2024) argue that effective governance is about knowledge, motivation, and agency. Knowledge is about the condition of the aquifer and its behavior. Motivation is about the incentives and norms that govern users' behavior. Agency is about how institutions and users can coordinate, monitor, and enforce a collective decision.

A framework that deals with only one dimension is unlikely to yield sustainable results. The same can be said about recent reviews. Gajurel et al. (2024) identify collective action and local participation as the central themes in groundwater governance research. Custodio et al. (2025) show that groundwater governance should be evaluated on hydrogeological, administrative, socioeconomic, and legal parameters rather than one single metric. Karandish et al. (2025) also demonstrate that aquifer stabilization is rare and can never be successful when policy relies only on one instrument. These studies advocate for a multi-instrument approach that combines legal authorization, extraction control, information, incentives, and participation.

Adaptive governance treats legal conditions as reviewable responses to changing ecological and social circumstances. Groundwater limits should therefore be based on aquifer conditions, seasonal demand, recharge, environmental needs, and cumulative extraction. Regulation should specify how decisions are revised when monitoring shows declining water levels, quality deterioration, or changes

in land use. Guo et al. (2024) illustrate the importance of ecological water levels and spatially differentiated controls in irrigation areas. Their work supports the legal proposition that uniform rules may be inadequate when groundwater conditions vary across zones and seasons.

Participation is not an alternative to regulation. It is a mechanism for improving information, legitimacy, compliance, and local problem-solving. Villada-Canela et al. (2025) identify local water committees, capacity building, and incorporation of non-technical knowledge as effective participation mechanisms. Savari et al. (2025) find that social networks, trust, and norms influence farmers' willingness to reduce groundwater use by improving ecological awareness and water-management knowledge. These findings are relevant to Subak because its institutional strength lies in collective rules, social relations, and routine interaction among farmers.

The analytical framework is based on five environmental-law principles. The prevention principle is required to act before the damage becomes severe. The precautionary principle is the principle that control is possible at the point where scientific uncertainty exists but the possibility of the major damage is not high. The carrying-capacity principle is that the aquifer and surrounding ecosystem are able to sustain the extraction. Public participation is about having access to information and a stake in decisions. Intergenerational equity means that agricultural benefits from the present must be weighed against future water supply.

Subak is considered as a potential co-governance institution rather than a substitute for public authority. The state is still responsible for hydrogeological assessment, authorization, technical standards and sanctions. Subak can offer local knowledge, user identification, social monitoring, education and early conflict resolution. The resulting model combines state authority with local institutional capacity. It tries to make invisible resources visible via information on shared data and collective observation and clear legal duties.

RESEARCH METHODS

This study used an exploratory qualitative socio-legal design. The doctrinal component examined the hierarchy, content, and interaction of Indonesian water-resource and environmental legislation. Primary legal materials included Law No. 17 of 2019 on Water Resources as amended, Law No. 32 of 2009 on Environmental Protection and Management as amended, Presidential Regulation No. 37 of 2023, Government Regulation No. 30 of 2024, Government Regulation No. 26 of 2025, Minister of Energy and Mineral Resources Regulation No. 14 of 2024, and Ministerial Regulation No. 4 of 2026. Government Regulation No. 22 of 2021 was also considered for environmental approvals, supervision, and administrative enforcement. The legal analysis applied statutory, conceptual, and regulatory-coherence approaches.

The empirical component drew on the field materials summarized in the institutional research progress report. Those materials were collected through interviews, observation, and examination of groundwater-use practices for agricultural irrigation. The report records the perspectives and practices of agricultural users and relevant stakeholders in Bali, but it does not specify a final number of informants, a complete respondent profile, or a single named field site. The empirical evidence was therefore treated as exploratory. It was used to identify implementation themes and institutional problems, not to estimate prevalence or make statistical claims.

The analysis proceeded in three stages. First, legal provisions were coded according to conservation, authorization, allocation, monitoring, information, participation, supervision, and sanctions. Second, the empirical materials were coded under five recurring themes: groundwater as a dry-season buffer, limited awareness of cumulative impacts, incomplete technical data, weak monitoring, and fragmented coordination. Third, the normative and empirical codes were triangulated to identify gaps between legal requirements and field implementation. Recent peer-reviewed studies published mainly between 2024 and 2026 were used to test the consistency of the findings and develop the proposed governance model.

The study has two limitations. It did not perform direct aquifer measurements, pumping tests, water-quality tests, or a quantified water balance. Its conclusions therefore concern legal and institutional governance rather than the measured condition of a specific aquifer. In addition, the progress report does not contain sufficient interview metadata for a conventional qualitative audit trail. The fieldwork location, dates, informant categories, interview count, consent procedures, and research ethics documentation require confirmation from the authors before publication.

RESULTS AND DISCUSSION

Research Findings

A Changing and Layered Legal Architecture

The legal review shows a significant regulatory change. Water-resource governance is now based on a national policy on conservation, equitable use, public participation and information systems. Government Regulation No. 30 of 2024 is the general management framework and explicitly puts sustainability and environmental orientation at the core of water-resource management. This framework is applicable to aquifer-based planning, conservation, utilization, damage control, and institutional coordination. Groundwater authorization is governed by sectoral regulations issued by the Ministry of Energy and Mineral Resources. Regulation No. 14 of 2024 established guidelines for groundwater business permits and groundwater use approvals. Regulation No. 4 of 2026 replaced the provisions of the previous regulation regarding use approvals, capacity building and cooperation, supervision and sanctions. The 2026 regulation also covers administrative fines for regularization of groundwater permits and approvals.

The result is a situation where the legal status of extraction depends on the purposes of use, the authority of the extraction, technical evaluation and requirements for permit or approval. The legal weakness is not that there is no formal authority. It is the operational link between general environmental duties, groundwater authorization, hydrogeological thresholds and local implementation. The regulations require data and supervision, but protection must be in the hands of the authorities; they will need to know aquifer information, maintain a complete registry of wells, ensure extraction reports are accurate and there is the need for joint enforcement. The legal architecture is therefore stronger on paper than the available field systems described in the progress report.

Table 1 Current Legal Framework and Implications for Agricultural Groundwater Use

Instrument	Core regulatory function	Implication for irrigation governance
Law No. 17 of 2019, as amended	State control, allocation priorities, conservation, utilization, and public responsibilities.	Agricultural use must remain consistent with public-interest priorities, sustainability, and government authority over water resources.
Presidential Regulation No. 37 of 2023	National policy on conservation, equitable utilization, risk control, participation, and water-information systems.	Local programs should integrate farmer participation and interoperable water data.
Government Regulation No. 30 of 2024	Comprehensive, integrated, and environmentally oriented water-resource management.	Groundwater use should be linked to basin and aquifer planning, conservation zones, and cumulative impacts.
Ministerial Regulation No. 14 of 2024	Groundwater business permits and the original framework for groundwater-use approvals.	Wells and extraction activities require the correct legal instrument and technical conditions.
Ministerial Regulation No. 4 of 2026	Current guidance for groundwater use approvals, supervision, sanctions, and administrative regularization.	Authorities need updated procedures, reporting, inspection, and enforcement aligned with the 2026 rules.
Environmental Law framework, including PP No. 22 of 2021 and PP No. 26 of 2025	Environmental planning, approvals, quality protection, supervision, information, and sanctions.	Groundwater decisions must be integrated with environmental planning, pollution control, carrying capacity, and restoration duties.

Groundwater as an Agricultural Buffer

We know that farmers are most likely to use groundwater when surface irrigation is poor, for example in dry periods and when there is uneven water distribution. Groundwater thus helps to provide

a buffer between production and the future and to keep farmers going when canal supply is bad. This practical benefit is why the users may choose access and continuity over formal legal or ecological concerns. The buffering part also creates a governance issue.

Individual extraction is rational at farm level but cumulative abstraction creates collective risk. Farmers can check if a well draws water, but they cannot easily see changes in aquifer storage, recharge, or the impact on neighbors. The progress report indicates that groundwater is perceived as available for use as long as it is physically obtainable. This is not only a short-term view but also a view that is different from sustainability.

Data, Monitoring, Awareness, and Coordination Gaps

Four implementation gaps were consistently identified. First, technical data are incomplete or difficult to access. The report notes limitations concerning groundwater levels, abstraction volumes, and aquifer conditions. Without these data, authorities cannot reliably define extraction limits, identify cumulative pressure, or evaluate compliance. Second, monitoring of wells and abstraction is weak. A permit register without metering or reporting provides limited evidence of actual use.

Third, legal and ecological awareness varies among users. Farmers generally understand the production value of groundwater, but may have limited knowledge of authorization duties, cumulative abstraction, recharge, water-quality risks, or long-term ecological effects. Fourth, coordination is fragmented because groundwater intersects environmental management, agriculture, public works, energy and mineral resources, local government, and community institutions. The need to consult several sectors delays data collection and can blur operational responsibility.

These findings are consistent with recent Indonesian research. Priadi et al. (2024) identify fragmented responsibilities and implementation gaps in groundwater governance. Zaidi and Handayani (2025) emphasize regulatory ambiguity, the need for integrated data, and stronger public participation. The field evidence adds an agricultural dimension: governance failures occur where seasonal production needs interact with incomplete data and limited collective control over pumping.

Table 2 Integrated Normative and Empirical Findings

Normative expectation	Observed implementation issue	Environmental risk	Required response
Aquifer-based planning and conservation	Limited baseline data on groundwater levels, recharge, and extraction.	Limits cannot be calibrated; cumulative depletion may remain undetected.	Complete aquifer inventories, conservation zoning, and periodic water-balance review.
Legal authorization with technical conditions	Users may focus on practical access and may not fully understand approval duties.	Unregistered or non-compliant extraction and unequal access.	Simplified compliance guidance, registration support, and clear differentiation of use categories.
Monitoring and reporting	Abstraction volume and well activity are not consistently measured.	Enforcement becomes reactive and evidence is weak.	Metering proportional to risk, digital reporting, and targeted inspection.
Public participation and information	Groundwater is treated as an individual source rather than a shared aquifer.	Low collective awareness and delayed response to degradation.	Public data access, farmer education, and participatory monitoring.
Institutional coordination	Responsibilities span several agencies and local institutions.	Duplicated action, data gaps, or no agency taking operational ownership.	A formal coordination protocol, shared database, and designated lead authority.

Subak's Institutional Capacity and Formal Mandate

The progress report identifies Subak as a strategic partner. Its advantages include routine farmer interaction, locally legitimate rules, knowledge of irrigation patterns, and experience in water distribution and dispute resolution. These features can support user identification, communication of permit obligations, observation of new wells, reporting of unusual pumping, and collective conservation measures.

Recent Bali-based studies reinforce this potential. Ardana et al. (2024) demonstrate the value of spatial assessment for Subak irrigation networks. Suamba et al. (2025) show that water valuation and farmers' willingness to pay can support more efficient irrigation management. Yekti et al. (2026) demonstrate that indigenous irrigation practices and hydrological modelling can be integrated to improve allocation and resilience. These studies suggest that Subak can connect technical and social forms of water management.

Subak nevertheless has limitations. Its authority traditionally concerns irrigation distribution rather than state groundwater permits, aquifer modelling, or administrative sanctions. Membership may not cover every groundwater user, especially where land conversion or non-agricultural use occurs. Formal co-governance therefore requires a defined legal role, access to relevant information, technical support, and safeguards against unequal influence within local decision-making.

Proposed Adaptive Co-governance Model

The integrated findings support a five-pillar model. The model begins with hydrogeological knowledge and ends with adaptive review. It does not transfer state authority to Subak. It assigns complementary functions according to institutional competence.

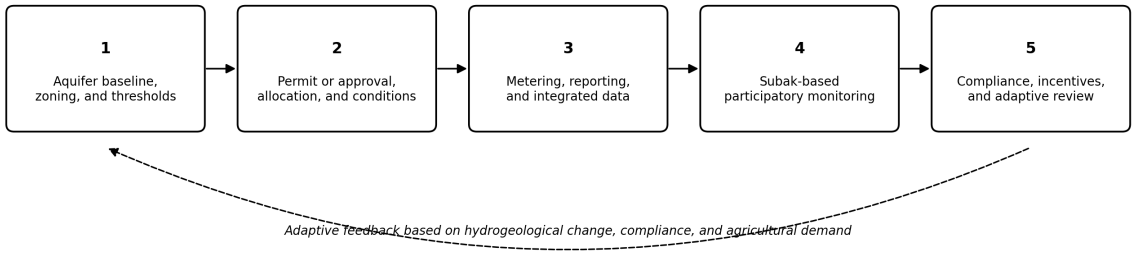


Figure 1 Adaptive Co-governance Model for Agricultural Groundwater Use

Table 3 Governance Pillars, Responsible Actors, and Indicators

Pillar	Primary actors	Operational measures	Minimum indicators
1. Aquifer baseline and zoning	Competent groundwater authority, environmental agency, technical institutions	Inventory wells, assess recharge and water levels, identify conservation and risk zones.	Mapped wells; monitoring points; updated groundwater-level series; zoning decision.
2. Authorization and extraction conditions	Central or local government according to competence	Issue the correct permit or approval, set purpose, volume, depth, monitoring, and conservation duties.	Valid legal instrument; technical conditions; extraction ceiling; review date.
3. Metering and integrated data	Permit holders, government agencies, data-system administrator	Use risk-based metering, periodic reporting, shared registries, and public summaries.	Reported volume; reporting compliance; interoperable database; anomaly flags.

Pillar	Primary actors	Operational measures	Minimum indicators
4. Subak participation	Subak, farmers, village institutions, extension officers	Education, local observation, user verification, complaint channels, and conflict mediation.	Training sessions; verified users; community reports; resolved disputes.
5. Compliance and adaptive review	Inspectors, permit authority, environmental agency, Subak liaison	Inspection, warnings, sanctions, incentives, recharge measures, and periodic revision of limits.	Inspection coverage; corrective actions; sanction follow-up; trend in groundwater condition.

Discussion

Regulatory Density and Environmental Effectiveness

The findings refine the original progress-report conclusion that groundwater regulation is scattered. The current framework has become more specific since 2024, particularly in relation to water-resource management, groundwater permits, use approvals, supervision, and sanctions. The more precise diagnosis is regulatory layering combined with an implementation deficit. The legal instruments create authority, but environmental effectiveness depends on the information and administrative systems that convert authority into measurable control.

This distinction has practical consequences. A licensing campaign can improve formal compliance while leaving aquifer pressure unchanged if extraction volumes are not measured. An inspection program can identify visible violations while missing cumulative overuse across many individually lawful wells. A conservation-zone rule can remain ineffective when the zone has not been delineated or updated. The relevant performance question is therefore not how many permits have been issued, but whether authorization conditions correspond to aquifer capacity and whether actual extraction remains within those conditions.

Karandish et al. (2025) find that groundwater stabilization is rare when governance relies on one type of intervention. The proposed Bali model follows that evidence by combining legal, technical, informational, social, and enforcement measures. The model also recognizes the risk of a rebound effect. Improved irrigation efficiency can lower the water used per unit of output but may encourage expansion of irrigated area or longer pumping unless total abstraction is capped and monitored.

Operationalizing Environmental-law Principles

The prevention and precautionary principles must be translated into decision rules. Prevention requires authorities to identify foreseeable degradation and impose controls before damage becomes severe. Precaution becomes relevant when aquifer data are incomplete but extraction pressure, declining yields, salinity, contamination, or user conflict indicate credible risk. In such circumstances, uncertainty should justify monitoring and temporary limits rather than regulatory inaction.

Carrying capacity should be expressed through technical conditions that can be reviewed. The legal instrument should specify the approved location, purpose, extraction ceiling, depth or screened interval where relevant, monitoring duties, reporting frequency, recharge or conservation obligations, and conditions for suspension or revision. The same conditions should not apply uniformly to every user. Risk-based differentiation can account for extraction volume, aquifer vulnerability, cumulative density of wells, environmental sensitivity, and availability of surface-water alternatives.

Government Regulation No. 26 of 2025 strengthens the planning context by requiring environmental inventory, ecoregion determination, and environmental protection and management plans. Groundwater planning should be connected to these instruments. This connection can prevent authorization decisions from being isolated from land-use change, ecosystem services, agricultural expansion, and pollution risks.

Subak's Contribution to Knowledge, Motivation, and Agency

The knowledge, motivation and agency framework explains why Subak participation can enhance implementation. Subak can bring in local knowledge about irrigation shortages, planting schedules, well locations, and user behavior. It can help sustain motivation and promote it through collective norms and visible conservation behaviors. It can act as an agent in the process of organizing meetings,

communicating duties, checking local knowledge and mediation of conflict. These roles are consistent with recent research. Gajurel et al. (2024) emphasize collective action in groundwater governance. Villada-Canela et al. (2025) suggest local committees and capacity-building as good ways to promote participation. Savari et al. (2025) show that social capital influences conservation-oriented behavior. Meinzen-Dick and Bruns (2024) note that when users are not motivated or lack motivation to act, information alone is insufficient.

A Subak-based approach can thus fill the gaps of implementation so that a centralized permit system cannot be effectively applied. Participation needs to be thoughtful. Local institutions can carry on to have unequal power, exclude non-participants, or put agricultural needs ahead of aquifer protection. The state should provide minimum procedural safeguards. These include access to groundwater information, adequate representation of the users affected, recorded decisions, complaint mechanisms and technical review by the competent authority. Subak recommendations should inform decisions but should not replace statutory hydrogeological assessment or enforcement.

Practical Implementation Sequence

Implementation can proceed incrementally. The first phase should create a verified inventory of wells and users, classify extraction by purpose and risk, and identify monitoring gaps. The second phase should align existing permits and approvals with the current 2026 framework. Authorities should provide a clear transition pathway for users who need registration or regularization. The third phase should install or require metering for higher-risk abstraction and establish a digital reporting mechanism that can be accessed by relevant agencies.

The fourth phase should establish Subak liaison arrangements. Each participating Subak can designate a groundwater contact, maintain a local list of agricultural wells, receive simplified monitoring information, and transmit complaints or observed changes. Extension programs should explain aquifer behavior, legal duties, conservation practices, and the difference between physical availability and sustainable yield. The fifth phase should introduce adaptive review. Extraction conditions should be revised when monitoring shows declining levels, reduced dry-season reliability, water-quality deterioration, or excessive cumulative demand.

Incentives can complement sanctions. Farmers who adopt water-saving schedules, recharge measures, shared wells, or alternative surface-water arrangements can receive technical support, administrative facilitation, or program priority. Sanctions should remain available for unauthorized construction, false reporting, obstruction of inspection, or repeated violation of extraction conditions. The purpose of enforcement is not only punishment. It is to maintain fairness between compliant and non-compliant users and preserve the credibility of the governance system.

Theoretical and Policy Contributions

The article contributes to groundwater-governance scholarship by linking environmental-law principles with a locally embedded irrigation institution. It shows that the common distinction between state regulation and community management is too rigid. Sustainable groundwater use requires a division of labor. Public authorities provide legal authority, hydrogeological standards, data systems, and enforcement. Local institutions provide social knowledge, legitimacy, communication, and collective observation.

The policy contribution is a testable governance framework. Each pillar contains responsible actors and minimum indicators. This allows future research and government programs to evaluate whether co-governance improves well registration, reporting compliance, farmer knowledge, complaint resolution, and groundwater trends. The model can also be adapted to other Indonesian regions that have farmer groups, water-user associations, or village institutions capable of supporting state supervision.

CONCLUSION

Groundwater use for agricultural irrigation in Bali has a legitimate resilience function, but its cumulative ecological impact must be managed by the public. Now Indonesia has a much more mature legal framework for water resource management, permits, use approvals, supervision and sanctions. The biggest weakness is implementation. Poor hydrogeological data, deficient metering, scattered awareness and lack of coordination prevent legal norms from objectively controlling the reality of abstraction. This means that authorization has to be linked to aquifer capacity, environmental planning, transparent data and periodic review.

Groundwater should not be a single well or farm asset. It should be a shared hydrological resource. The empirical implication is that farmers need real compliance policies and credible information about cumulative risk. The institutional implication is that Subak can support monitoring, education, user verification, and conflict resolution, but the formal mandate and technical support in place at that time need to be made clear. The five steps should be followed: complete the well and aquifer inventory; align permits and approvals with the current framework in 2026; use risk-based metering and integrated reporting; institute formal Subak engagement with procedural safeguards; and conduct adaptive compliance review based on groundwater trends. To this end, these measures can help to create agriculture and protect the ecosystem and intergenerational access to water within the context of ecological sustainability and the need for sustainable access to water.

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