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THE ROLE OF BALI'S HYDROLOGICAL CIVILISATION IN SUPPORTING SUSTAINABLE TOURISM UNDER DEVELOPMENT PRESSURE

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ABSTRACT

Water constitutes the foundation of both ecological sustainability and cultural continuity in Bali. However, rapid and often unregulated tourism development has increasingly disrupted traditional hydrological civilisation systems, threatening the resilience of Bali's hydrological civilisation. This study examines how land conversion, water-use competition, and socio-economic transformation affect the sustainability of Balinese hydrological civilisation that underpin cultural heritage and tourism. Employing a qualitative research design supported by secondary sustainability indicators, the study integrates field observations, semi-structured interviews, and document analysis to explore traditional ecological knowledge, community-based governance, and hydrological landscapes, particularly in South Bali. The findings reveal that while socio-cultural dimensions—such as ritual practices, water temples, and subak institutions—remain relatively resilient, ecological and economic dimensions exhibit significant vulnerability. Accelerated land conversion, declining agricultural viability, and competition between tourism and agriculture have weakened water distribution systems and reduced the adaptive capacity of subak communities. Secondary sustainability indices indicate that socio-cultural resilience outperforms ecological and economic dimensions, highlighting an imbalance that threatens long-term sustainability. The study argues that Bali's hydrological civilisation should be understood not merely as cultural heritage but as a living socio-ecological system essential for

sustainable tourism. Strengthening cultural values, protecting hydrological landscapes, integrating customary law with formal governance, and promoting eco-cultural tourism are identified as key strategies for enhancing resilience. By situating Bali within broader debates on hydrological civilisation, traditional ecological knowledge, and sustainable tourism, this research contributes to a more integrated framework for managing hydrological civilisation amid increasing development pressures.

KEYWORDS: Hydrological Civilisation, Traditional Ecological Knowledge, Sustainable Tourism, Resilience, Bali..

1. INTRODUCTION

Globally, water has become a strategic resource that determines the sustainability of both ecosystems and cultural heritage. Tourism, one of the fastest-growing industries, exerts considerable pressure on freshwater resources, particularly in small islands and heritage destinations where natural and cultural systems are intertwined (Hadjikakou et al., 2015). Scholars have increasingly recognised that the sustainability of tourism depends not only on economic and ecological management but also on the resilience of cultural systems that shape human–nature interactions (Lu et al., 2020). Within this context, the concept of hydrological civilisation—the integration of water management, belief systems, and spatial organisation—offers a critical lens for understanding how societies maintain balance between environmental use and cultural continuity (Van Schaik et al., 2015).

Across Asia, several civilisations, from Angkor in Cambodia to the aflaj systems in Oman, illustrate the centrality of water in sustaining both life and cultural identity (Mithen, 2010). However, modern tourism, urbanisation, and climate change increasingly disrupt these systems, necessitating adaptive strategies rooted in traditional ecological knowledge (TEK) and participatory governance (Martin et al., 2010; Cole & Browne, 2015). In recent years, research in eco-cultural tourism has emphasised the need to integrate heritage conservation and ecological resilience into a single sustainable framework (Folgado-Fernández et al., 2018).

Within this global discourse, Bali stands as a living model of hydrological civilisation, where Hindu philosophy and environmental ethics are interwoven through the concept of Tri Hita Karana—harmony among humans, nature, and the divine. This worldview is reflected in Balinese cultural systems such as subak (irrigation cooperatives) and taman sari (royal water gardens), which embody the island's adaptive response to environmental constraints (Lansing, 1987). These systems not only ensure food security and ecological stability but also shape Bali's cultural landscape, recognised by UNESCO as a World Cultural Heritage site.

Rapid and poorly managed tourism development has intensified land conversion and water consumption, undermining the ecological and socio-cultural balance upon which Balinese civilisation depends. Agricultural land conversion in Bali continues to rise; recent analyses by the Central Statistics Agency (Bali Province Statistics Agency, 2025) show an annual loss of 1,200–1,500 hectares of rice fields in the southern region—particularly in Badung, Denpasar, Tabanan, and Gianyar. These areas also experience the highest tourism density, revealing a structural conflict between tourism expansion and water-based cultural systems. The sustainability index of water resource management currently stands at 65% (Geria et al., 2023), indicating a fragile state of resilience that requires urgent intervention.

This condition is visually evident in several southern coastal regions, where large portions of subak land have been converted and acquired by tourism investors, particularly in the Kediri area of Tabanan (see Figure 1).

Figure 1: Portions of Subak Land in Bali Are Now Owned by Investors, Including Areas Along the Coast of Kediri, Tabanan.
Source: Authors (2025).

Figure 1 depicts a stretch of fertile subak land in Kediri, Tabanan, extending toward the southern Balinese coastline. At first glance, the image portrays an orderly and productive agricultural landscape sustained by traditional irrigation networks. Yet, beneath this idyllic scenery lies a quiet tension: the proximity of the fields to the coastline—an area increasingly targeted for tourism development—reveals the vulnerability of Bali's hydrological civilisation. The photograph symbolises the transitional moment between preservation and transformation, in which inherited agrarian values rooted in Tri Hita Karana coexist uneasily with capitalist land speculation. The visual contrast between the green paddy terraces and the open horizon of the sea underscores the competing spatial logics of cultivation and commodification. Hence, the image does not merely document an agricultural scene; it embodies the contested landscape where cultural sustainability, ecological balance, and tourism expansion intersect, illustrating the fragile boundary between cultural heritage and modern investment pressures in Bali's southern region.

Water has long held a central and sacred role in Balinese civilisation, forming the foundation of both

ecological balance and spiritual life. The Balinese worldview—rooted in Tri Hita Karana—emphasises harmony among humans, nature, and the divine. This philosophy is materialised through water management systems such as subak and taman sari, which reflect a unique integration of culture, ecology, and social governance. These systems demonstrate that water is not merely a physical resource but a cultural heritage that sustains livelihoods and reinforces community identity (Wright, 1966; Lansing et al., 2009).

Historical and archaeological evidence indicates that water management in Bali was institutionalised within royal and community structures. Ancient kingdoms located sacred and functional sites—such as temples and bathing areas—along rivers and lakes to ensure watershed conservation and ritual sanctification (Remmington, 2018). As illustrated in Figure 2, the spatial distribution of temples along the Pakerisan Watershed demonstrates the long-standing integration of hydrological and religious functions in Balinese civilisation. This spatial configuration reveals how sacred geography historically governed water use, spatial planning, and social organisation—laying the ecological and cosmological foundation of Bali's hydrological civilisation.

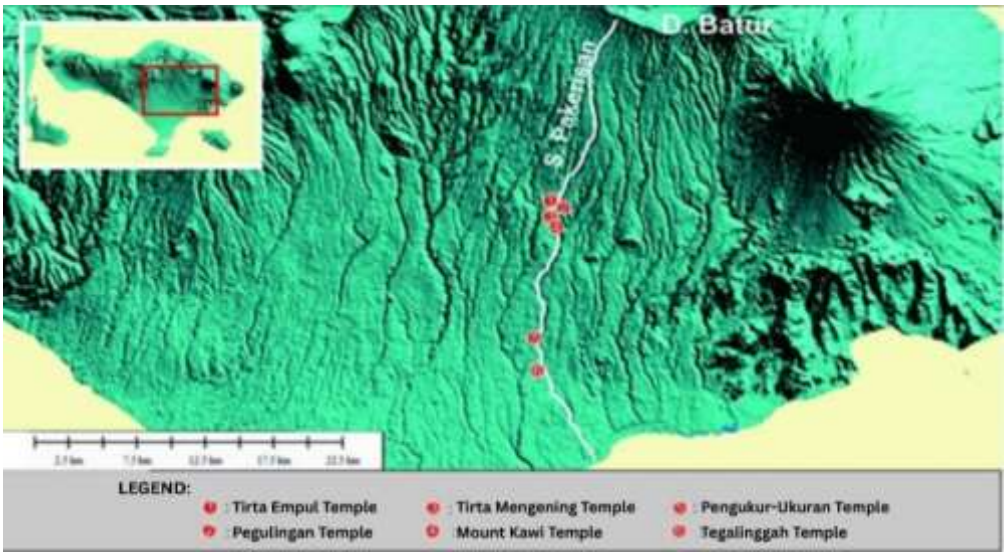


Figure 2: Map of Temple Locations along the Pakerisan Watershed.
Source: Authors (2025).

The map in Figure 2 shows the distribution of major temples situated along the Pakerisan River in central Bali, including Tirta Empul, Tirta Mengening, Pengukur-Ukuran, Pegulingan, Mount Kawi, and Tegalinggah Temples. These sites are spatially aligned following the watershed's flow from the volcanic uplands near Mount Batur toward the lowlands, reflecting a sacred hydrological axis that integrates ritual practice with water management. The configuration demonstrates how Balinese civilisation organised its religious landscape in harmony with ecological processes, forming a cultural network that links spiritual sanctity with environmental sustainability.

The hydrological networks created during the Warmadewa and later dynasties exemplify an early form of ecological engineering for social well-being and food security (Asdak, 2023). These cultural systems have evolved into living heritage that continues to sustain both agriculture and tourism. From a sustainability perspective, subak and taman sari are not only historical artefacts but also dynamic socio-ecological institutions. They embody TEK that maintains water balance through community-based regulation, ritual practice, and spatial planning (Parimin, 1986). The subak operates as a form of hydrological governance, while sacred sites and forests function as natural catchments supporting ecosystem services. However, the rapid growth of tourism and land conversion in South Bali—particularly in Denpasar, Badung, Gianyar, and Tabanan—has disrupted these functions and weakened water sustainability (Geria et al., 2023).

Multiple studies show that uncontrolled tourism development, pollution, and declining agricultural land contribute to water stress and the erosion of cultural values (Roth, 2014). The loss of subak landscapes has direct implications for tourism resilience, as these landscapes serve not only as productive agricultural systems but also as world-

recognised cultural heritage.

In this context, understanding Bali's hydrological civilisation as a heritage-based sustainability model becomes essential. Linking traditional water management with sustainable tourism indicators enables a more integrated interpretation of resilience. As summarised in Table 1, cultural practices such as subak and taman sari contribute simultaneously to hydrological function and sustainable tourism benefits—reinforcing the interdependence of cultural identity, environmental integrity, and economic viability.

Table 1: Conceptual Linkage between Cultural Hydrological Civilisation and Tourism Sustainability.

Cultural Heritage Practice	Hydrological Function	Tourism Sustainability Benefit
Subak (community irrigation system)	Water governance and equitable distribution	Eco-cultural tourism resilience; agricultural landscape preservation
Taman Sari (royal water garden)	Water storage, purification, and aesthetic landscape	Cultural heritage attraction; environmental education site
Pura Ulun Danu and water temples	Watershed protection and ritual sanctification	Strengthened spiritual tourism and conservation ethics
Hutan Kekeran (village forests)	Rainwater catchment and micro-climate regulation	Biodiversity conservation and green tourism development
Tulak Sumur / Kertamasa (agricultural cycles)	Pest control and soil–water management	Sustainable agro-tourism and ecosystem stability

Previous studies have examined the cultural philosophy of Tri Hita Karana and the socio-religious function of water in Balinese society. The few studies that discuss the degradation of the subak systemdo not fully articulate the mechanisms of resilience or the policy implications for sustainable tourism. Consequently, there remains a significant research gap in understanding how the Balinese hydrological civilisation adapts to tourism-induced pressures while maintaining cultural and ecological equilibrium.

Contemporary challenges further expose the fragility of Bali's hydrological civilisation amid tourism-driven pressures. Studies on water conflict (Strauß, 2011) reveal tensions between agricultural and tourism sectors, while Hadjikakou et al. (2015) highlight global water scarcity as a structural threat to sustainable tourism. These analyses converge on the need for integrative, justice-oriented management strategies that combine technology, policy, and traditional knowledge. In this regard, Bali's subak-based hydrological civilisation provides a valuable living model for reconciling economic growth, cultural continuity, and ecological balance (Sirtha, 2002). Recent work by Geria et al. (2023), Water Management Built Environment from the Ancient Bali Era, argues that Bali's hydrological legacy embodies sustainability principles yet remains vulnerable without stronger institutional and community collaboration. His findings reinforce the need to conceptualise Balinese hydrology not only as heritage but as an evolving system of civilisational resilience.

Taken together, the reviewed studies demonstrate that Balinese society has long integrated water management, spirituality, and social organisation into a coherent cultural system. However, most research remains either descriptive or sectoral—religious, archaeological, or managerial—without constructing a unifying analytical model. While previous studies have examined subak as an irrigation or socio-religious system, few have interpreted it as part of a broader hydrological civilisation that integrates ecological, spiritual, and governance dimensions within a sustainable tourism framework. This study therefore aims to synthesise these perspectives, developing a conceptual model of hydrological civilisation that situates Bali within global debates on hydrological civilisation, highlighting its relevance for contemporary sustainability transitions.

This study focuses on South Bali, a region where the tension between rapid tourism development and the endurance of traditional ecological systems is most apparent. The research seeks to explore how hydrological civilisation adapts to these pressures, identify the socio-cultural, ecological, and economic factors shaping its resilience, and examine how traditional ecological knowledge and community-based governance can be mobilised to support sustainable tourism policy. The primary aim of this study is to analyse how interconnected pressures—particularly land conversion, economic disparities, and the weakening of community institutions—affect the sustainability of Balinese water management systems that underpin cultural continuity and tourism resilience. These questions guide the analysis presented in this paper, which integrates secondary sustainability indicators with qualitative interpretation of Balinese traditional

ecological knowledge to identify adaptive pathways for maintaining hydrological and cultural sustainability amid growing tourism demands.

2. METHODS

2.1. Research Design

This study employs a qualitative research design supported by secondary quantitative indicators obtained from previous hydrological sustainability studies in Bali. The qualitative approach is particularly suitable for examining how cultural practices, TEK, and local governance mechanisms shape the resilience of Bali's hydrological civilisation within the context of tourism development. Quantitative sustainability indices derived from earlier research are used solely as contextual evidence to support interpretation, rather than as analytical calculations generated by this study. Accordingly, the research design integrates field-based qualitative inquiry with the use of secondary numerical indicators related to ecological and socio-cultural sustainability.

2.2. Study Area and Sampling

This study focuses on South Bali, particularly Denpasar, Badung, Gianyar, and Tabanan, where tourism expansion, land conversion, and competition over water resources are most pronounced. These areas also contain significant cultural landscapes and water temples that are closely associated with subak irrigation networks. Qualitative data were collected using purposive sampling, targeting individuals with direct knowledge and experience of water management and tourism dynamics. The informants included subak leaders and members, temple custodians, farmers and local households, tourism workers, village leaders and representatives of local cultural institutions, as well as government officials involved in water resource management, land-use regulation, and tourism planning.

2.3. Data Collection

Data collection was conducted using three qualitative techniques. Field observations were carried out at subak agricultural fields, water temples, water gardens, and tourism-impacted landscapes, with attention given to land-use change, water distribution practices, ritual activities, and local ecological conditions. Semi-structured interviews were conducted to capture local perceptions of hydrological governance, cultural values, traditional ecological knowledge, tourism-related pressures, and institutional challenges. In addition, document and archival analysis was undertaken, including the review of archaeological maps, historical manuscripts, land-use statistics published by Statistics Indonesia and the Ministry of Agriculture, subak records, and regional planning documents. Furthermore, quantitative sustainability indices previously published by Geria et al. (2023) were incorporated as secondary data to contextualize ecological, socio-cultural, and economic vulnerabilities. No new statistical calculations or multidimensional scaling (MDS) modeling were performed in this study.

2.4. Data Organization and Operationalization

Qualitative data derived from interviews, field notes, and documentary sources were systematically organized into thematic categories reflecting hydrological practices, cultural and ritual functions, land-use transformations, ecological pressures, tourism-related changes, and institutional governance. Secondary numerical indicators from previous studies, including sustainability scores for ecological, socio-cultural, and economic dimensions, were used solely to support interpretation rather than as primary data for empirical modeling. Accordingly, this study does not employ scoring systems, index construction, or statistical ordination techniques. Instead, existing sustainability metrics are interpreted within a cultural–ecological analytical framework to elucidate the resilience and challenges of Bali's hydrological civilization.

2.5. Data Analysis

Data were analyzed using a combination of thematic analysis, triangulation, and interpretative integration of secondary indicators. Interview transcripts and field notes were systematically coded to identify recurring themes related to water governance, traditional ecological knowledge, ecological resilience, and tourism-related impacts. Triangulation was applied by cross-checking findings across observations, interviews, and documentary sources to ensure consistency and reliability. In addition, sustainability indices reported by Geria et al. (2023) were incorporated to strengthen the interpretation of ecological and economic pressures. These indicators were not recalculated, and no MDS, Monte Carlo simulations, leverage analysis, or goodness-of-fit diagnostics were performed. Overall, the analytical process integrates local narratives, cultural interpretation, and contextual quantitative evidence to elucidate the resilience and challenges of Bali's hydrological civilisation.

Overall, this study contributes an original

qualitative approach to sustainability assessment by positioning hydrological civilisation as an interpretative analytical framework. Rather than recalculating indices, existing ecological, socio-cultural, and economic sustainability indicators are reinterpreted through TEK, ritual governance, and hydrological landscapes, allowing sustainability to be understood as a lived and relational socio-ecological process. This approach offers a replicable pathway for assessing hydrological civilisation sustainability in tourism-pressured regions.

3. RESULTS AND DISCUSSION

3.1. Results: The Condition of Bali's Hydrological Civilisation under Tourism Pressure

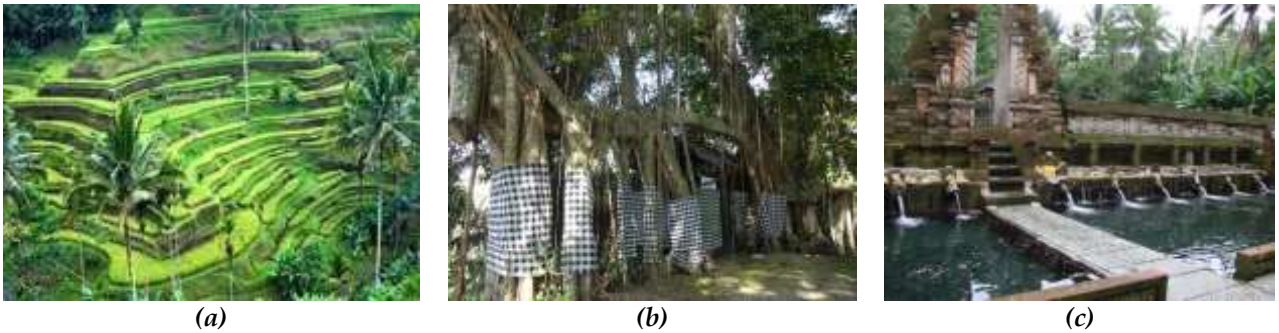
This study aims to analyse how land conversion, tourism-driven water demand, and institutional change influence the sustainability of Bali's hydrological civilisation. Consistent with the qualitative research design, the results are derived from field observations, semi-structured interviews, and document analysis, supported by secondary sustainability indicators from previous studies (Geria et al., 2023).

3.1.1. Traditional Ecological Engineering in Water Resource Management

Field observations and interviews indicate that Bali's hydrological civilisation is sustained through an integrated system of TEK, ritual practices, and spatial governance grounded in the philosophy of Tri Hita Karana (Parimin, 1986; Lansing, 1987). This philosophical framework conceptualises water (tirta) not merely as a physical resource but as a sacred medium that mediates relationships between humans, nature, and the divine. As such, water management in Bali is inherently normative and ethical, shaped by religious values, social obligations, and ecological awareness rather than by technical efficiency alone (Wright, 1966). This worldview establishes moral boundaries on water use, reinforcing restraint, reciprocity, and collective responsibility in managing hydrological resources.

At the institutional level, water governance is enacted through a constellation of interconnected socio-ecological institutions, including subak irrigation associations, water temples (pura tirta), taman sari (royal water gardens), village forests (hutan kekeran), and household-scale water catchment and infiltration systems. Together, these institutions function as a multi-scalar hydrological network that regulates water flow from upstream catchments to downstream agricultural fields, preserves ecological balance, and sustains social cohesion (Lansing et al., 2009). Field evidence shows that this network operates through gravity-based distribution, seasonal synchronisation of cropping cycles, and ritual coordination, ensuring equitable water allocation while minimising ecological stress and pest proliferation.

Figure 3 visually captures this integrated hydrological civilisation by illustrating the spatial interconnection between sacred water infrastructure, vegetation management, and downstream irrigation systems within the Pakerisan watershed. The figure serves as visual field evidence of how ritual space and hydrological engineering operate as a unified governance system rather than as separate cultural and technical domains. The gravity-based flow depicted in Figure 3 reinforces the role of sacred geography in protecting upstream catchments and ensuring equitable downstream water distribution.



(a) *(b)* *(c)*

Figure 3: Ecological Engineering in Water Management, as Exemplified by the Tirta Empul Pond (a), Tree Cultivation (b), and Subak (c), Represents a Downstream Extension of Hydrological Civilization.

Source: Authors (2025).

Interviews with subak leaders and temple custodians further confirm that water governance is embedded in ritual calendars, awig-awig, and collective deliberation mechanisms. Decision-making regarding water allocation, maintenance of irrigation infrastructure, and ritual obligations is

conducted communally, reflecting deeply rooted moral commitments to environmental stewardship and social justice. These practices illustrate how governance authority in Bali is decentralised yet coordinated, relying on ritual legitimacy and social consensus rather than coercive enforcement (Fox, 2012).

Archaeological and spatial evidence strengthens this interpretation by demonstrating that hydrological governance in Bali has long been institutionalised through sacred geography. The spatial alignment of water temples along the Pakerisan watershed reveals a deliberate integration of hydrological engineering and religious cosmology, where temples function simultaneously as spiritual centres and hydrological regulators (Lansing & de Vet, 2012). By situating sacred sites along river systems and near springs, ancient Balinese societies protected upstream catchments, controlled water quality, and ensured equitable downstream distribution (Cole & Browne, 2015).

These findings support and extend earlier arguments that Bali's irrigation system operates as a hydrosocial network in which water, power, and belief systems are inseparable (Ahdar, 2023). Rather than being a static cultural relic, Bali's hydrological civilisation emerges as a dynamic governance system that continuously reproduces ecological balance and social order through the interaction of material infrastructure, ritual practice, and shared cosmological values. This integrated system provides the foundation for both agricultural sustainability and the cultural landscapes that underpin Bali's tourism economy.

3.1.2. Land Conversion, Tourism Development, and Ecological Vulnerability

Despite the continued vitality of ritual practices and cultural institutions, qualitative evidence from South Bali—particularly in Denpasar, Badung, Gianyar, and Tabanan—reveals an accelerating conversion of agricultural and hydrological landscapes into tourism-related infrastructure. Field observations document the progressive transformation of subak rice fields into hotels, villas, restaurants, and ancillary facilities that serve the tourism economy. These land-use changes are frequently legitimised through formal land transactions and spatial planning instruments that prioritise economic development, often at the expense of customary authority and communal water governance systems (subak) (Roth, 2014; Strauß, 2011).

This process has direct and cumulative ecological consequences. The conversion of permeable agricultural land into built-up areas disrupts irrigation connectivity, reduces groundwater recharge and infiltration capacity, and alters natural drainage patterns. As a result, downstream water availability becomes increasingly uncertain, particularly during the dry season. Field observations indicate that irrigation channels are often fragmented or diverted to accommodate tourism facilities, weakening the functional integrity of subak networks and undermining their capacity to regulate water equitably across agricultural landscapes.

Interviews with farmers and subak members further reveal a socio-economic feedback loop that exacerbates ecological vulnerability. As tourism-related employment offers higher and more stable income, participation in agriculture continues to decline, leading to reduced collective maintenance of irrigation infrastructure and erosion of communal responsibilities. This trend, also documented by Cosens et al. (2014), diminishes the social foundations of water governance, making hydrological civilisation more susceptible to mismanagement and conflict.

Consequently, competition between agricultural and tourism water use has intensified, particularly in areas where tourism facilities extract groundwater or divert surface water without coordination with subak institutions. Such competition contributes not only to hydrological stress—manifested in declining water tables and seasonal shortages—but also to social tension between user groups, reflecting broader patterns of water inequity in Bali's tourism-dominated regions (Cole & Browne, 2015).

Secondary sustainability indicators reinforce these qualitative findings. Previous studies report that the ecological dimension of Bali's water resource management remains only moderately sustainable, with persistent vulnerabilities linked to land conversion, pollution, and water overextraction (Geria et al., 2023). Although these indicators are not recalculated in the present study, they provide critical contextual evidence that situates local observations within a broader pattern of declining hydrological resilience in tourism-intensive areas.

Overall, these findings demonstrate that land conversion driven by tourism development represents a structural threat to Bali's hydrological civilisation. While cultural practices may continue symbolically, the material and ecological foundations that sustain them are increasingly eroded. This condition highlights a growing mismatch between cultural resilience and ecological

sustainability, underscoring the urgency of integrating land-use planning, water governance, and tourism policy to prevent further degradation of Bali's hydrological civilisation.

3.1.3. Socio-Cultural Resilience and Economic Imbalance

The socio-cultural dimension of Bali's hydrological civilisation remains comparatively resilient, as evidenced by the continued practice of water-related rituals, ceremonial cycles, and communal cooperation embedded within subak institutions.

Field observations and interviews indicate that ritual obligations, collective maintenance activities, and the moral authority of water temples continue to reinforce shared responsibility for water management, even in contexts where agricultural production has declined (Kunen et al., 2006). These practices function as important forms of social capital, sustaining trust, cooperation, and collective identity among subak members.

Figure 4 provides visual evidence of the contemporary reproduction of hydrological civilisation within the tourism context. The figure shows tourists participating in water-based rituals (panglukatan) at sacred sites, illustrating how hydrological heritage continues to function as a living cultural practice rather than a static monument. This interaction reflects the growing role of eco-cultural tourism in mediating relationships between local communities, visitors, and sacred water spaces.

However, while Figure 4 highlights opportunities for cultural transmission and tourism-based awareness, it also points to emerging risks. Without appropriate governance and regulation, increased tourist participation may intensify pressure on sacred water sites and exacerbate water overuse. This visual evidence reinforces interview findings that socio-cultural resilience persists alongside economic imbalance, as local farming communities receive limited material benefits from tourism despite maintaining the hydrological landscapes that sustain its appeal (Roth, 2014; Cole & Browne, 2015).

(a) ***(b)***

Figure 4. Tourists Engaging in Water Tourism Must Appreciate the Local Culture and Traditions That Preserve the Ecosystem, Cultural Identity, and Environment. Location: Mengening Temple (a) and Tirta Empul (b).

Source: Authors (2025).

Interviews further confirm that subak identity and religious obligations remain socially significant, particularly in village governance, ceremonial life, and land relations. Participation in rituals and communal meetings persists even when farming is no longer the primary livelihood for many members. This indicates that the socio-cultural foundations of hydrological civilisation remain deeply embedded within Balinese society, reflecting the enduring influence of Tri Hita Karana as a normative framework for human–nature relations.

However, this cultural resilience is not matched by economic sustainability. Despite their central role in maintaining agricultural landscapes and hydrological civilisation that underpin Bali's tourism appeal, farmers and subak communities receive limited direct economic benefits from tourism development (Roth, 2014; Cole & Browne, 2015). Interviews reveal that tourism revenues are largely captured by external investors and urban-based actors, while agricultural livelihoods face declining profitability and increasing marginalisation.

Secondary economic sustainability indicators reinforce these qualitative findings. Previous studies report persistently low income levels among farmers, limited value-added from agricultural production, and weak institutional mechanisms to support subak-based livelihoods (Geria et al., 2023). These

economic constraints reduce the capacity of subak communities to maintain irrigation infrastructure, invest in adaptive strategies, or retain younger generations in agriculture, further weakening the material foundations of hydrological civilisation.

This imbalance between strong socio-cultural continuity and weak economic support creates a condition of structural vulnerability. Cultural institutions and rituals continue to function symbolically, yet their long-term viability is threatened by the erosion of economic and institutional foundations. In this context, hydrological civilisation risks being reduced to a form of "symbolic resilience," where cultural expressions persist while their ecological and material bases deteriorate. This finding underscores the importance of integrating economic justice and livelihood support into strategies aimed at sustaining Bali's hydrological civilisation within a tourism-dominated economy.

3.2. DISCUSSION

3.2.1. Hydrological Civilisation as a Socio-Ecological Governance System

The findings demonstrate that Bali's hydrological civilisation functions as a socio-ecological governance system in which water management practices, cultural values, and institutional arrangements are deeply intertwined across multiple spatial and temporal scales. Rather than operating as a purely technical irrigation system, Bali's water governance emerges as a historically embedded configuration of material infrastructure, ritual authority, and social norms. This interpretation aligns closely with hydrosocial theory, which conceptualises water as an active medium that shapes social relations, power dynamics, and governance structures, rather than as a neutral biophysical resource subject only to technical control (Bakker, 2012).

Within this framework, traditional ecological knowledge embedded in subak institutions, water temples, and ritual calendars represents a historically adaptive governance mechanism that successfully maintained ecological balance, coordinated agricultural production, and promoted social equity over long periods (Zen et al., 2024). The synchronisation of cropping cycles, collective maintenance of irrigation infrastructure, and ritualised decision-making processes enabled subak systems to regulate water flows efficiently while embedding ecological constraints within moral and cultural obligations. These mechanisms illustrate how governance authority in Bali was historically decentralised yet highly coordinated, relying on shared values and ritual legitimacy rather than formal state enforcement.

However, the findings also reveal that tourism-driven land conversion and commercial water use have significantly disrupted these hydrosocial relations. The fragmentation of irrigation networks, diversion of water toward tourism facilities, and prioritisation of land for commercial development reflect a broader shift from communal water governance toward commodified water regimes. In this emerging regime, water is increasingly treated as an economic input to be allocated according to market logic, marginalising customary institutions and weakening collective control over hydrological resources (Roth, 2014). This transformation alters not only the physical flow of water but also the social relations and power structures that historically governed its distribution.

The coexistence of persistent socio-cultural practices with declining ecological and economic sustainability points to a condition of partial or uneven resilience. Cultural institutions such as subak and water temples remain symbolically strong and socially respected, yet their functional capacity to govern water effectively is increasingly constrained by external economic pressures and institutional marginalisation. This condition supports earlier critiques that resilience without adequate material, economic, and institutional support risks becoming performative rather than transformative, preserving cultural expressions while failing to address underlying structural vulnerabilities (Folgado-Fernández et al., 2019).

3.2.2. Implications for Sustainable Tourism Governance

From a sustainable tourism perspective, the findings reveal a clear structural disconnect between tourism development and the conservation of Bali's hydrological heritage. Although tourism in Bali extensively capitalises on cultural landscapes shaped by subak irrigation systems, water temples, and sacred waterscapes—recognised globally as outstanding cultural heritage—these hydrological civilisation receive limited institutional protection, regulatory priority, or economic compensation. As a result, the ecological and cultural foundations that sustain Bali's tourism appeal are increasingly exposed to degradation under tourism-driven development pressures.

The findings suggest that tourism governance in Bali has largely treated hydrological civilisation as a passive aesthetic and symbolic asset rather than as an

active socio-ecological system requiring continuous protection and collective management. This governance gap is particularly evident in land-use planning and water allocation policies, where tourism infrastructure development often proceeds without systematic integration of subak institutions or awig-awig. Such exclusion undermines the adaptive capacity of traditional water governance and accelerates the commodification of water resources.

Based on the findings, several policy-relevant implications emerge for strengthening sustainable tourism governance by repositioning Bali's hydrological civilisation as a central socio-ecological asset rather than a peripheral cultural feature. These implications highlight the need for institutional alignment between tourism development, water governance, and heritage conservation.

First, regional tourism and land-use policies should explicitly recognise subak systems, water temples, and associated hydrological landscapes as active socio-ecological infrastructure that underpins both environmental sustainability and tourism resilience. This requires moving beyond symbolic heritage designation toward functional recognition within spatial planning instruments, zoning regulations, and tourism master plans. By acknowledging hydrological civilisation as essential infrastructure—comparable to roads or utilities—planning authorities can ensure that tourism expansion does not undermine the water systems and cultural landscapes upon which it depends.

Second, the findings demonstrate that awig-awig continues to function as a legitimate and effective mechanism for regulating water use, land relations, and collective responsibilities within subak communities. Strengthening its legal and institutional status through formal recognition in regional water governance and spatial planning frameworks would enhance coordination between state-led policies and community-based management. Such integration can reduce conflicts over water allocation, limit unregulated extraction by tourism facilities, and reinforce participatory governance models that align with local cultural norms and ecological realities.

Third, spatial zoning regulations should prioritise the conservation of rice fields, springs, river corridors, and watershed forests that sustain downstream tourism areas. The study shows that the conversion of agricultural and upstream landscapes represents a structural threat to hydrological connectivity and long-term water availability. Protecting these areas is therefore not only an agricultural or environmental concern, but a strategic investment in tourism sustainability. Policies should restrict conversion in ecologically sensitive zones and promote landscape-scale protection that recognises the interdependence between upstream hydrological functions and downstream economic activities.

Fourth, tourism development strategies should incorporate eco-cultural tourism models that generate tangible economic benefits for subak communities responsible for maintaining hydrological landscapes. Benefit-sharing mechanisms—such as conservation fees, community-based tourism initiatives, or payments for ecosystem services—can help address the economic imbalance identified in the findings. By linking tourism revenues directly to the maintenance of irrigation systems, ritual sites, and agricultural landscapes, such models can strengthen local livelihoods while incentivising long-term stewardship of hydrological civilisation.

Fifth, effective governance of Bali's hydrological civilisation requires sustained coordination among tourism authorities, hydrological civilisation agencies, cultural heritage institutions, and local communities. Capacity-building initiatives should focus on enhancing institutional literacy regarding traditional ecological knowledge, hydrological interdependencies, and participatory governance mechanisms. Cross-sectoral coordination platforms can facilitate information sharing, joint planning, and conflict resolution, ensuring that tourism development and hydrological civilisation are pursued as mutually reinforcing objectives rather than competing priorities.

4. CONCLUSION

This study set out to analyse how interconnected pressures—particularly land conversion, tourism-driven water demand, and institutional change—shape the sustainability of Bali's hydrological civilisation, which underpins both cultural continuity and tourism resilience. Employing a qualitative research design supported by secondary sustainability indicators, the study examined the roles of TEK, community-based hydrological civilisation in South Bali, one of the most tourism-intensive regions of Indonesia.

The findings demonstrate that Bali's hydrological civilisation continues to exhibit strong socio-cultural resilience. Ritual practices, water temples, and subak institutions remain actively maintained and socially meaningful, reflecting the enduring influence of Tri Hita Karana as a normative framework guiding water governance. These cultural mechanisms

operate as critical forms of social capital, sustaining collective responsibility, cooperation, and moral restraint in hydrological civilisation. Even in contexts where agricultural productivity has declined, cultural identity and ritual obligations linked to water remain deeply embedded in local governance and everyday social life.

However, this socio-cultural resilience is increasingly undermined by mounting ecological and economic vulnerabilities. Accelerated land conversion, declining agricultural viability, and intensifying competition between tourism and agricultural water use have disrupted hydrological connectivity, reduced groundwater recharge, and weakened the adaptive capacity of subak systems. Secondary sustainability indicators corroborate these qualitative findings, revealing that ecological and economic dimensions of hydrological civilisation remain only weakly to moderately sustainable, particularly in tourism-intensive areas of South Bali. This growing imbalance exposes a condition of structural fragility in which cultural institutions persist symbolically, while the material and ecological foundations that sustain them continue to erode.

The study therefore concludes that Bali's hydrological civilisation should not be understood merely as cultural heritage or symbolic identity, but as a living socio-ecological governance system that is essential to sustainable tourism. Its long-term continuity depends on the integrity of hydrological landscapes, the viability of community-based governance institutions, and the equitable distribution of economic benefits derived from tourism. Without stronger institutional recognition, spatial protection of hydrological civilisation, and meaningful economic integration of local communities, Bali's hydrological civilisation risks becoming a performative cultural relic rather than a functioning governance system.

From a policy perspective, sustaining Bali's hydrological civilisation requires integrated governance strategies that align tourism development with hydrological civilisation conservation. Key priorities include protecting agricultural land and watershed areas from uncontrolled conversion, reinforcing subak institutions through the formal recognition and integration of awig-awig within land-use and water governance frameworks, and promoting eco-cultural tourism models that generate tangible and equitable benefits for farming communities. By repositioning water as both a cultural and ecological asset—rather than solely an economic input—Bali can enhance tourism resilience while safeguarding its hydrological civilisation for future generations.

Despite its contributions, this study has several limitations that should be acknowledged. First, the research relies primarily on qualitative methods, including field observations and semi-structured interviews, which provide in-depth contextual insights but limit the generalisability of findings across all regions of Bali. While the focus on South Bali is analytically justified due to its high tourism intensity, hydrological conditions and governance dynamics may differ in less-developed or upstream regions. Second, the study draws on secondary sustainability indicators to contextualise ecological and economic conditions without recalculating or statistically modelling these indicators. As a result, the analysis emphasises interpretative depth rather than quantitative measurement of change over time. Future research could complement this approach by integrating hydrological modelling, remote sensing data, or longitudinal economic analysis to strengthen empirical robustness. Third, although the study examines institutional change and governance dynamics, it does not systematically analyse the roles of private sector actors or detailed political–economic power relations within tourism development. A more explicit political ecology or institutional economics approach could further illuminate how power asymmetries influence hydrological civilisation and land-use decisions. Future research could adopt a more integrated socio-environmental framework to examine how multiple stressors interact to shape the sustainability of Bali's tourism-dependent hydrological civilisation.

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