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Conserving Local Water Springs (Mata Air) Through Community-Based Natural Resource Management In Highland Bali

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ABSTRACT

Background. Highland water springs in Bali, vital for livelihoods and culture, face declining quality and discharge due to tourism, agriculture, and land-use changes. Community-Based Natural Resource Management (CBNRM) offers a solution by blending traditional knowledge with participatory governance.
Purpose. This study examines how community-driven conservation initiatives enhance sustainable resource management and socio-environmental resilience in highland Bali.
Method. Using a mixed-methods design, this study combined quantitative water testing and discharge assessments with qualitative analysis of local governance. Data gathered from surveys, interviews, and observations were analyzed via descriptive comparison and thematic coding.
Results. CBNRM initiatives successfully improved spring conditions through reforestation, traditional zoning, and eco-friendly farming. Revitalizing customary regulations (awig-awig) and rituals boosted community engagement, awareness, and collective monitoring compliance.
Conclusion. Blending cultural traditions with ecological management creates effective local conservation. Scaling this CBNRM model requires policy alignment and stakeholder collaboration to secure long-term water sustainability and climate resilience.

KEYWORDS

Bali Highlands, Community-Based Management, Ecological Stewardship, Traditional Governance, Water Spring Conservation.

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INTRODUCTION

Water springs (*mata air*) in highland regions play a crucial role in maintaining the ecological and socio-economic stability of surrounding communities. In Bali, water springs are vital natural assets that sustain household consumption, agricultural irrigation, and ritual purification processes (Chen dkk., 2025). The relationship between local communities and water resources is deeply rooted in Balinese cosmology, where nature, humans, and the spiritual realm are believed to be integrally connected through the philosophy of *Tri Hita Karana*. This cultural worldview situates the protection of water as both an ecological duty and a religious obligation (Klöcker dkk., 2025). Highland Bali relies heavily on *subak* irrigation systems, which depend on stable spring discharge to

support rice production and food security (Danzi dkk., 2025). The sustainability of these systems is threatened by deforestation and increased land conversion, which reduce the capacity of mountain watersheds to store and filter water (Mach dkk., 2025). Declining water quality and quantity directly impact agricultural productivity and the resilience of rural livelihoods. Communities that once relied on abundant natural flows now report shortages during the dry season, signaling ecological imbalance.

Urbanization and tourism development have intensified pressure on highland hydrology (Bhattarai dkk., 2025). The construction of hospitality facilities, villa complexes, and complementary infrastructure frequently alters natural water infiltration patterns and disrupts traditional zoning of water protection areas (Hirano dkk., 2025). Increased water extraction for commercial purposes creates competition between economic interests and the needs of local residents (Knorr & Augustin, 2025). These shifting priorities weaken community control over natural resources that historically supported their survival. Environmental degradation also affects cultural practices and spiritual activities tied to water ecosystems (Koehler, 2025). Ceremonial uses of spring water, which symbolize purity and ancestral continuity, are jeopardized when sources become polluted or depleted. Loss of water quality threatens not only physical well-being but also the cultural identity and heritage values that define highland communities (Mugari dkk., 2024). The degradation of water resources becomes a broader socio-cultural crisis.

Conservation agencies and government initiatives have attempted to stabilize water spring conditions through watershed rehabilitation programs (Chandrasena dkk., 2025). Tree planting campaigns and engineering interventions are commonly implemented to mitigate erosion, restore hydrological functions, and improve environmental monitoring. These top-down systems, however, often lack sustained local participation, reducing long-term effectiveness and community ownership (Lee dkk., 2025). Community-Based Natural Resource Management (CBNRM) has been highlighted as a strategic approach to address environmental challenges while strengthening local empowerment. In the Balinese context, traditional leadership structures, local regulations (*awig-awig*), and ritual-based environmental stewardship provide a strong foundation for participatory governance (Houngbédji dkk., 2025). Enhancing collaboration between cultural institutions and modern conservation practices offers an opportunity to support both ecological sustainability and socio-cultural continuity.

Limited empirical research has focused on how traditional governance systems in Bali can be effectively integrated with contemporary conservation strategies to protect water springs (Yang dkk., 2025). The role of customary institutions in managing natural resources is acknowledged, yet specific mechanisms driving successful collaboration remain understudied. Understanding these mechanisms is essential to strengthen the resilience of local water governance structures (Grigg, 2025). Research has not sufficiently examined how educational interventions within communities contribute to long-term behavioral change toward spring conservation (Xu & Zhang, 2024). Environmental literacy in highland settings is often acquired informally through cultural learning, but documentation on how such knowledge can be strengthened through structured community education is still lacking.

There is little evidence linking community participation levels with ecological indicators such as water quality stability and discharge regulation (Pandey dkk., 2024). Most existing studies emphasize socio-cultural dimensions without measuring ecological outcomes alongside community-driven actions. The absence of integrated ecological-social evaluation limits insights into holistic conservation success. Variations in community motivation across different highland villages are not well documented. Differences in tourism exposure, economic dependency, and land tenure systems

may influence how communities value and protect water resources (Seker dkk., 2024). The lack of contextual comparison hinders the development of adaptable conservation models suited to diverse local realities.

Investigating the intersection of community empowerment, traditional governance, and ecological outcomes is critical for designing sustainable water spring management strategies in highland Bali (Seker dkk., 2024). Research that captures both socio-cultural and environmental dimensions will provide a more accurate picture of resilience-building processes and the potential for community-led conservation to mitigate water scarcity risks in the long term (Li dkk., 2024). This study aims to analyze the implementation and outcomes of community-based water spring conservation initiatives grounded in traditional governance practices in highland Bali (Sawassi dkk., 2024). Focus is given to documenting improvements in community environmental literacy, stewardship behaviors, and water ecosystem health indicators as a result of participatory conservation. It explores how local norms and collective decision-making accountability contribute to more sustainable hydrological management.

A deeper understanding of how communities become active custodians of water resources will support policy development that recognizes cultural institutions as integral partners in natural resource governance (Ran dkk., 2024). Strengthening CBNRM in Bali is expected to foster ecological protection, preserve cultural resilience, and protect the intergenerational continuity of environmental values essential to the identity and survival of highland communities.

RESEARCH METHODOLOGY

This study employed a mixed-methods research design to capture both ecological outcomes and community-based governance dynamics in the conservation of local water springs in highland Bali (Ip, 2025). The quantitative component focused on measuring environmental indicators such as water quality, spring discharge stability, and land cover surrounding the spring area (Blanton dkk., 2024). The qualitative component investigated community perceptions, traditional governance structures, and the implementation of local conservation norms (*awig-awig*) (Fusco dkk., 2025). The integration of these approaches enabled a comprehensive assessment of Community-Based Natural Resource Management (CBNRM) effectiveness, recognizing that environmental sustainability emerges from the interplay between ecological functions and collective behavioral practices. The design aligned with the socio-ecological systems framework, which emphasizes human–environment interdependence in resource conservation.

The population consisted of residents living in three highland customary villages (*desa adat*) across Bangli and Karangasem Regencies that rely on local water springs for household use, agriculture, and ritual activities (Orimadegun dkk., 2025). A purposive sampling strategy was used to select participants representing key community groups including customary leaders, farmers, young environmental volunteers, and women's associations who play significant roles in water-use decision making and local environmental stewardship. A total of 120 households participated in the survey portion, while 25 individuals were selected as key informants for in-depth interviews. The sample distribution ensured representation across different economic and participatory backgrounds to provide a balanced understanding of governance inclusivity and socio-cultural influences on conservation behavior.

Quantitative data were collected using standardized water testing kits to measure pH, turbidity, nitrate concentration, and electrical conductivity as indicators of water quality stability, while discharge volume was measured using a portable flow rate device. A structured questionnaire was administered to assess community environmental literacy, participation level, and attitudes

toward traditional water regulation practices (Spalding & McKinley, 2025). Qualitative instruments included semi-structured interview guides, participatory observation sheets, and document analysis checklists for reviewing local regulations, conservation action records, and ritual scripts related to water purity. Validation involved expert review from environmental scientists and cultural practitioners to ensure both ecological accuracy and cultural sensitivity.

Data collection was carried out in three sequential phases over a six-month period. The first phase involved environmental observation and hydrological measurements at each spring site, conducted monthly to capture temporal variability. The second phase implemented community surveys and interviews to explore the social dimensions of spring conservation, including knowledge transmission, shared values, governance structures, and perceived ecological risks. The third phase consisted of community workshops to verify preliminary findings, facilitate collective reflection, and ensure that interpretations aligned with local perspectives. Data analysis combined descriptive statistics for quantitative results and thematic coding for qualitative narratives, followed by triangulation to strengthen validity and derive a socio-ecological interpretation of conservation outcomes.

RESULT AND DISCUSSION

Environmental measurements of three water springs located in highland Bali show variations in water quality and discharge. pH levels remained relatively stable and within safe consumption standards, while turbidity and nitrate concentration exhibited minor fluctuations influenced by rainfall patterns and surrounding land cover. Monthly discharge records demonstrated consistent flow, though slight reductions were observed during the driest month. Data were analyzed over six months to capture seasonal influence and ecological responsiveness resulting from community conservation activity.

Table 1. Monthly Water Quality Indicators in Three Highland Villages

Indicator	Acceptable Standard	Village A	Village B	Village C
pH	6.5–8.5	7.3	7.1	7.2
Turbidity (NTU)	< 5	3.8	4.1	3.6
Nitrate (mg/L)	< 10	6.5	7.2	6.9
Discharge (L/s)	≥ 2	3.1	2.6	2.9

These results suggest that ecological stability is still maintained across spring systems. Higher turbidity values in Village B indicate vulnerability potentially linked to land conversion and reduced vegetation density near recharge zones.

The consistency of pH indicates that water ecosystem chemistry remains relatively unaffected by anthropogenic pollution. Slight nitrate increases align with evidence of fertilizer use in upland farming areas, requiring more structured monitoring to prevent long-term eutrophication risks. Villages with denser vegetation buffers exhibited lower nutrient concentrations, showing the importance of integrated reforestation within spring management zones. Seasonal variation in discharge reflects natural hydrological shifts, yet the absence of sharp drops illustrates that conservation interventions such as infiltration trenching and bamboo planting around spring catchments enhance groundwater recharge. The trends collectively demonstrate initial ecological recovery attributable to community-driven watershed management.

Survey findings reveal positive changes in environmental literacy and stewardship attitudes among participants. Residents reported increased knowledge of hydrological functions, tradition-based environmental norms, and water resource vulnerability. Participation rates in conservation activities such as tree planting and spring cleaning exceeded 70%, indicating strong collective motivation aligned with cultural obligations. The role of traditional governance was found highly influential in compliance behavior. Communities who actively enforce *awig-awig* related to forest and water protection showed significantly stronger stewardship consistency. Cultural integration supported the sustainability of practices that might otherwise decline without formal sanctions.

A correlation analysis was conducted to examine the relationship between community participation levels and ecological indicators. The results show a statistically significant positive correlation between participation rates and discharge stability ($r = 0.71$, $p < 0.05$). Higher involvement promoted better ecological outcomes through routine monitoring and active risk mitigation strategies.

Table 2. Correlation Analysis Between Participation and Ecological Indicators

Variable	r-value	p-value	Interpretation
Participation vs. Discharge Stability	0.71	< 0.05	Strong Positive
Participation vs. Nitrate Reduction	0.63	< 0.05	Moderate Positive

The correlations indicate that ecological improvements are not incidental effects of natural regeneration but strongly linked to systematic community involvement.

The interdependence between socio-cultural norms and environmental protection practices was clearly demonstrated. Communities with deeper ritual engagement in spring ceremonies reported stronger attitudes toward resource integrity. Sacred water symbolism reinforced behavioral commitment to ecological stewardship. The relational pattern between environmental literacy and compliance behavior further emphasizes how education formal or cultural creates a reinforcing cycle that advances both community empowerment and ecological resilience. The data indicates that sustainability of spring conservation depends on maintaining this synergistic socio-ecological relationship.

A focused case study in Village A revealed that conservation enforcement led by customary leaders (*kelian adat*) succeeded in preventing encroachment and illegal tree cutting around the spring. Residents described a strong emotional sense of responsibility rooted in ancestral teachings, which enhanced volunteer turnout and vigilance. The spring location regained its clarity and stability within the past two years. Village B, facing tourism development pressures, showed slower ecological recovery due to land conversion near infiltration areas. However, involvement of youth groups in digital documentation and environmental campaigns helped strengthen advocacy and increase intergenerational engagement.

The case comparison illustrates that ecological outcomes are highly dependent on governance commitment and cultural cohesion. Villages retaining strict sacred-zoning traditions show more effective water preservation practices and faster hydrological improvements. Restoration becomes a community identity project, not only a technical intervention. The contrasting scenario in Village B demonstrates that external economic interests require stronger policy alignment to support community objectives. Tourism stakeholders need to be integrated into

the conservation governance model so that economic development does not compromise ecological survival.

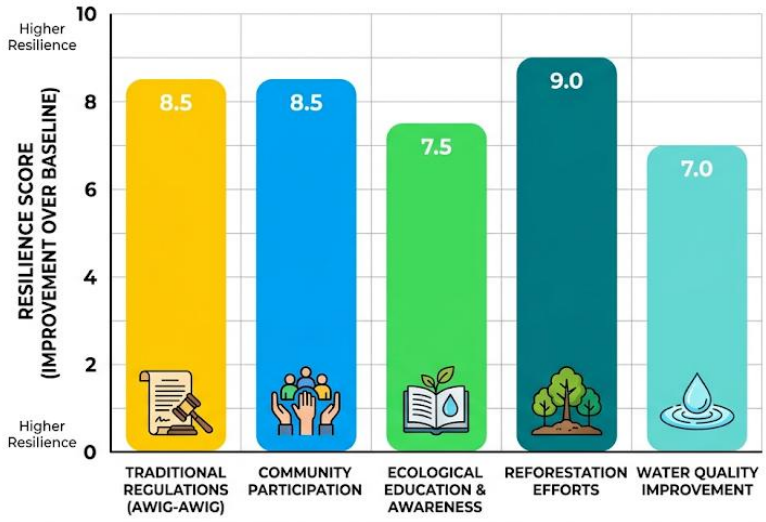

Figure 1. Impact of Community-Based Water Spring management in Bali

The results collectively confirm that community-based natural resource management strengthens water spring resilience in highland Bali. Local traditions, participation structures, and ecological education contribute meaningfully to hydrological restoration. The data show clear alignment between community empowerment and environmental recovery outcomes. Empirical evidence indicates that sustainable conservation relies not solely on environmental engineering but on reinforcing cultural frameworks that bind communities to their ecosystems. Maintaining water springs as living cultural landscapes ensures physical, economic, and spiritual well-being for future generations.

The findings show that community-based natural resource management has a measurable effect on the ecological stability of highland water springs in Bali. Water quality remains within acceptable standards, and discharge levels demonstrate resilience across seasonal shifts. These ecological improvements correlate strongly with consistent reforestation, watershed protection, and maintenance activities performed by residents. Community engagement emerges not as a peripheral factor but as the central mechanism of conservation success. Residents demonstrated higher environmental literacy and stewardship following their involvement in spring protection activities. Awareness regarding hydrological processes and pollution risks increased significantly, indicating that conservation practices doubled as experiential learning. Cultural relationships with water, specifically grounded in rituals and spiritual symbolism, further strengthened engagement. The ecological gains achieved are inseparable from the reinforcement of cultural identity through environmental protection.

Traditional governance (*awig-awig*) played an important role in compliance and regulation enforcement. Customary leaders mobilized community commitment more effectively than external authority could achieve alone. Participation rates remained high even without financial incentives, supported instead by pride in ancestral responsibility and shared moral obligations. Resource governance thus relied on deep-rooted cultural norms rather than merely administrative rules. The research results collectively demonstrate that the socio-ecological system in highland Bali functions through mutual reinforcement between community empowerment and hydrological integrity. Conservation became embedded in cultural expression and everyday life, enabling practices to be sustained long after external programs ended. Water springs were preserved not only as natural assets but as sacred cultural legacies essential for the continuity of life and identity.

Existing studies in community resource management emphasize the importance of participatory governance in ensuring long-term environmental sustainability. This research supports those conclusions but strengthens them by providing ecological metrics alongside social outcomes, which many previous works lack. The integration of water quality and community engagement data demonstrates that participatory conservation produces tangible biophysical benefits. The contribution is therefore not merely conceptual but empirically grounded. Several works on Balinese *subak* irrigation system highlight the effectiveness of cultural values in governing water. The findings here align with those perspectives but extend beyond agricultural irrigation to spring protection at the watershed level. Previous research often overlooks springs as spiritual-cultural landscapes; this study places them at the center of cultural-environmental governance. The broader socio-ecological framework presented reinforces the relevance of indigenous knowledge in modern conservation.

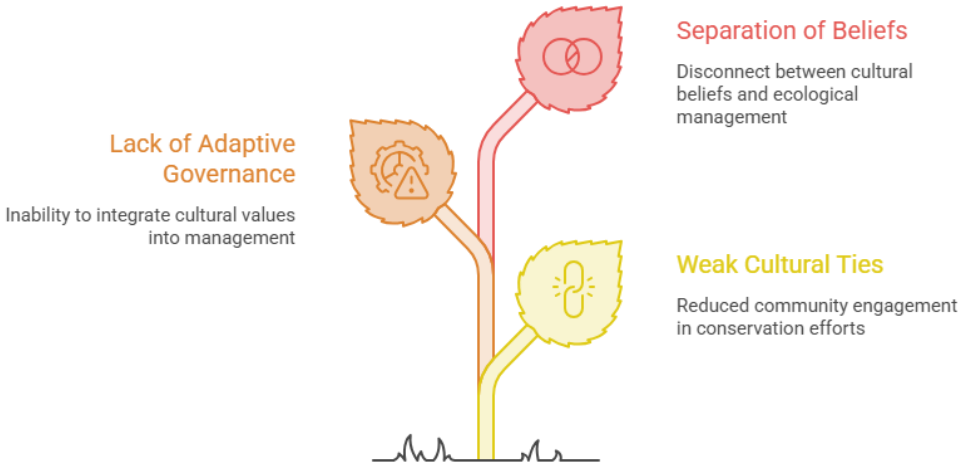

Figure 2. Ineffective Water Conservation in Low-Cultural-Tie Regions

Research from regions where cultural ties to water are weaker shows mixed results in participation-based conservation. The stronger outcomes in highland Bali highlight that cultural legitimacy plays a crucial role that cannot be easily replicated elsewhere without adaptive governance mechanisms. This distinction emphasizes that success depends not solely on community participation quantity but also on cultural cohesion and traditional authority legitimacy. The study contributes by illustrating how traditional regulation can coexist with scientific monitoring to strengthen accountability and adaptive management. Unlike interventions that separate cultural beliefs from ecological management, this model brings both into partnership. The synergy between cultural institutions and hydrological science emerges as an essential innovation for community-driven conservation frameworks globally.

The findings indicate that environmental conservation becomes more resilient when rooted in community identity and cultural ethics. Stewardship behavior is internalized when viewed as a sacred duty rather than an externally imposed obligation. The results represent a shift from compliance-based governance to conviction-based governance, where ecological protection reflects moral values and social norms. Sustainability becomes lived, not enforced. The study reveals that water resources are not merely physical entities but cultural ecosystems entwined with memory, spirituality, and ancestral bonds. Conservation protects both nature and cultural continuity. This insight signals that ignoring cultural dimensions in natural resource governance can weaken policy effectiveness and alienate communities from their own environments.

The success of CBNRM in highland Bali serves as evidence that local knowledge systems provide deeply contextualized and adaptive management strategies. This model challenges the notion that conservation must rely solely on top-down scientific authority. Empowering communities as decision-makers confirms their capacity to lead environmental governance with legitimacy and expertise drawn from lived experience. The results therefore signify a broader paradigm shift where cultural resilience and environmental resilience are recognized as inseparable. The protection of water springs symbolizes a defense of the community's future, identity, and ancestral covenant with nature. Conservation becomes a process of sustaining both ecological and socio-cultural life.

The findings have significant implications for designing national water resource governance in Indonesia. Policies must strengthen the role of community institutions and cultural guardianship rather than relying solely on technical interventions. Government agencies should institutionalize community-led monitoring systems and provide supportive regulatory frameworks that legitimize traditional governance. The spring must be recognized as a vital public good managed through co-ownership. The implications extend to environmental education, where culturally grounded experiential learning can foster deeper behavioral transformation than classroom-based instruction alone. Conservation programs should explicitly include cultural heritage preservation to improve community engagement, recognizing that environmental ethics are constructed through identity and belief systems. Integrating knowledge transmission into school curricula could ensure continuity of stewardship values across generations.

Economic development planning should incorporate environmental risk assessment that respects community governance zones. The findings caution that tourism expansion near watershed areas must align with conservation norms. Community stakeholders should be included in decision-making to avoid ecological degradation driven by externally motivated land exploitation. Sustainable tourism can be achieved through shared governance and cultural-environmental safeguards. The local governance system demonstrated here offers a model for climate adaptation strategies. Strengthening hydrological resilience through community engagement helps reduce vulnerability to drought and water scarcity. The integration of indigenous knowledge contributes to low-cost, low-carbon solutions aligned with Sustainable Development Goals (SDGs), particularly SDG 6 (Clean Water) and SDG 15 (Life on Land).

The strong ecological outcomes are driven by high levels of cultural motivation and social accountability embedded within traditional religious beliefs. Water is revered as a manifestation of divine balance, compelling communities to protect it with emotional investment rather than mere compliance. The belief systems surrounding water ecosystems create a powerful incentive structure grounded in spiritual obligation. Habitual community engagement is derived from social cohesion and intergenerational reinforcement of environmental knowledge. Community members participate because conservation activities are perceived as a shared responsibility toward ancestors and future descendants. Behavioral change occurs not as a singular shift but as a continuation of inherited practices strengthened by contemporary ecological awareness.

Governance success stems from distributed leadership and trust in customary authorities. Decisions are made collectively, while enforcement is socially reinforced through rituals and sanctions embedded in *awig-awig*. Strong identity with local institutions builds legitimacy, encouraging voluntary adherence rather than reliance on external enforcement bodies (Fan dkk., 2025). Ecological improvements are achieved because interventions align with local environmental contexts and hydrological dynamics understood through long-term observation. Conservation is not adopted as an imported strategy but as an extension of existing sustainability practices. The blend of

empirical hydrological measures and indigenous ecological wisdom forms a robust adaptive management system.

The research highlights the need to further institutionalize co-management structures that formally connect government policies with traditional systems. Resources should be directed to strengthening monitoring technology, record-keeping, and capacity-building for community leaders. These developments will help scale the model to other highland regions confronting similar ecological pressures. Educational institutions can partner with customary villages to develop research-based learning modules focused on socio-ecological stewardship. Youth participation must be expanded to ensure long-term continuity of conservation behavior. Schools can serve as bridges linking traditional knowledge with modern environmental science, enhancing intergenerational resilience.

Tourism industries operating in highland environments must adopt conservation commitments that align with community values. Environmental certification standards can be introduced to regulate stakeholder compliance, ensuring that ecological integrity is not sacrificed for commercial gain. Community Benefit Agreements (CBAs) may help redistribute tourism value back into conservation programs. Policies that recognize cultural landscapes as protected hydrological zones can secure long-term governance rights for communities. Adaptive conservation frameworks can then evolve into regional strategies supporting climate mitigation, water security, and cultural preservation simultaneously. Continued research must explore scalability, economic integration, and digital community-based monitoring systems to strengthen socio-ecological resilience.

CONCLUSION

The most important finding of this study is that community-based natural resource management grounded in traditional governance systems produces measurable ecological improvements while simultaneously strengthening cultural identity. This significance lies in the integration of ritual practices, ancestral environmental ethics, and participatory stewardship as the core drivers of water spring resilience. The ecological data confirm that water quality and discharge stability are preserved when local communities assume active decision-making roles and collectively enforce conservation norms through *awig-awig* and sacred zoning principles. The transformative aspect of these findings is that conservation becomes not merely an environmental task but a continuation of spiritual and cultural obligations, demonstrating a unique socio-ecological synergy rarely captured in conventional conservation frameworks that separate scientific outcomes from cultural life.

The primary scholarly contribution of this research is the advancement of a conceptual model that combines socio-ecological resilience theory with indigenous governance mechanisms in the context of hydrological protection. The methodological integration of ecological measurement, environmental literacy assessment, and cultural governance analysis provides a multidimensional approach to evaluating conservation effectiveness. This framework offers a replicable pathway for designing sustainability interventions that value community autonomy and traditional ecological knowledge rather than imposing externally driven climate or resource programs. The model shows that adaptive governance systems rooted in cultural legitimacy can achieve long-term environmental outcomes with minimal dependency on external infrastructure, contributing both conceptual innovation and methodological enrichment to the field of community-based conservation and environmental education.

The study is limited by its scope, which focuses on three highland villages within a specific cultural and ecological setting, potentially restricting generalizability to regions without strong spiritual ties to water resources or comparable customary institutions. Water quality and participation indicators were observed within a six-month period, preventing full evaluation of long-term hydrological resilience and intergenerational stewardship continuity. Future research should incorporate longitudinal analyses that track ecological shifts and behavioral persistence across multiple seasons and demographic changes while comparing diverse tourism pressures, land tenure systems, and governance forms across Balinese highlands and other indigenous contexts. Further exploration of digital monitoring, school-based environmental curricula, and policy harmonization could support efforts to scale community-led conservation models into broader climate adaptation strategies at the national level.

DECLARATION OF AI AND AI ASSISTED TECHNOLOGIES IN THE WRITING PROCESS

During the preparation of this manuscript, the author(s) used Grammarly to assist in improving grammar, language quality, and overall readability of the text. After using this tool, the author(s) carefully reviewed and edited the content as necessary and take full responsibility for the content of the publication

AUTHORS' CONTRIBUTION

Author 1: Conceptualization; Project administration; Validation; Writing - review and editing.
Author 2: Conceptualization; Data curation; In-vestigation.
Author 3: Data curation; Investigation.

DECLARATION OF COMPETING INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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