



Mahogany Journal De Social

Traditional Ecological Knowledge and Climate Change Adaptation in Indigenous Communities

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Article Info

Article History:

Received: 30 July 2026

Revised: 31 August 2026

Accepted: 22 September 2026

Keywords:

Adaptive Governance,
Climate Change
Adaptation, Community
Resilience, Indigenous
Communities,
Socioecological
Resilience

Abstract

Climate change has intensified environmental challenges faced by indigenous communities, highlighting the importance of understanding how Traditional Ecological Knowledge (TEK) contributes to locally grounded adaptation strategies. This study examines the role of TEK in strengthening climate change adaptation through a qualitative multiple-case study involving four indigenous communities. Data were collected through 48 semi-structured interviews, four focus group discussions, participant observation, and document analysis. The data were analyzed using Braun and Clarke's thematic analysis with cross-case comparison to identify common patterns and contextual differences. The findings reveal five interconnected dimensions of indigenous climate adaptation: traditional ecological forecasting, customary institutions and adaptive governance, intergenerational knowledge transmission, community-based ecosystem management, and the integration of TEK with scientific climate adaptation. These dimensions collectively enhance community resilience by supporting sustainable natural resource management, strengthening adaptive governance, and improving responses to climate-related risks. The study contributes to the literature by proposing an integrated conceptual framework that positions TEK as a dynamic socioecological system rather than merely a form of cultural heritage. The findings also emphasize the importance of incorporating indigenous knowledge into climate adaptation policies through collaborative governance that recognizes customary institutions as key partners in achieving sustainable and locally appropriate adaptation outcomes.

INTRODUCTION

Climate change has become one of the most pressing global challenges of the twenty-first century, disproportionately affecting indigenous communities whose livelihoods, cultural identities, and subsistence systems are closely intertwined with natural ecosystems. Rising temperatures, shifting precipitation patterns, biodiversity loss, and increasing frequencies of extreme weather events have disrupted ecological stability and threatened traditional livelihoods across forest, mountain, coastal, and arid environments. While scientific innovations have significantly advanced climate

adaptation strategies, growing recognition has emerged that effective adaptation cannot rely solely on technological interventions but must also incorporate locally embedded knowledge systems that have evolved through generations of human–environment interactions (Kaur et al., 2025; Little et al., 2023; Aziz & Anjum, 2025). Consequently, Traditional Ecological Knowledge (TEK) has gained increasing attention as a valuable source of adaptive capacity capable of strengthening community resilience while promoting biodiversity conservation and sustainable resource governance (Fernández-Llamazares et al., 2021; IPCC, 2022; Reyes-García et al., 2022).

Traditional Ecological Knowledge refers to the cumulative body of knowledge, practices, beliefs, and institutions developed by indigenous peoples through long-term interactions with their surrounding ecosystems (Sinthumule, 2023; Withanage & Lakmali Gunathilaka, 2023; Gbadegesin & Gbadamosi San, 2024; Gruberg et al., et al., 2022). Unlike conventional scientific approaches that often emphasize universal principles, TEK is context-specific, adaptive, and culturally embedded, allowing indigenous communities to interpret environmental signals, manage natural resources sustainably, and respond to climatic variability using locally appropriate strategies. Recent studies have demonstrated that indigenous ecological practices contribute substantially to ecosystem restoration, wildfire prevention, water conservation, biodiversity management, and sustainable agriculture under changing climatic conditions (Hill et al., 2021; Whyte, 2021; David-Chavez & Gavin, 2022). Furthermore, international environmental governance has increasingly acknowledged indigenous knowledge within climate policy frameworks, including the implementation of ecosystem-based adaptation and nature-based solutions that integrate cultural values with environmental sustainability (UNEP, 2023; UNESCO, 2022; Ajitha et al., 2025; Sangha et al., 2025; Vogel et al., 2022).

Despite this growing recognition, indigenous communities remain among the populations most vulnerable to climate change because their adaptive capacities are frequently constrained by socioeconomic marginalization, land-use transformation, institutional exclusion, and the erosion of cultural heritage. Globalization, rapid urbanization, commercial exploitation of natural resources, and changing demographic structures have accelerated the decline of intergenerational knowledge transmission, reducing the effectiveness of traditional adaptive mechanisms (Yadav, 2025; Nikjooy et al., 2025; Ramesh, 2026). Younger generations increasingly migrate to urban areas, resulting in diminished opportunities to inherit ecological knowledge from community elders. Simultaneously, environmental degradation alters ecosystems beyond historical experience, challenging the applicability of long-established ecological practices (Ford et al., 2021; McMillen et al., 2022; IPBES, 2022). These developments create an urgent need to understand how TEK continues to function under contemporary climatic uncertainties and how it can be effectively integrated into broader climate adaptation policies.

Recent empirical evidence indicates that indigenous adaptation strategies encompass diverse practices, including seasonal forecasting based on ecological indicators, traditional agroforestry systems, rotational farming, community-based water management, sacred forest conservation, indigenous fire management, and customary governance institutions regulating resource utilization. Studies conducted in Latin America, Sub-Saharan Africa, Southeast Asia, and the Arctic consistently report that communities possessing stronger traditional ecological institutions demonstrate higher adaptive capacity, greater ecosystem resilience, and improved food security during climatic disturbances (Artelle et al., 2021; Reyes-García et al., 2022; Alexander et al., 2023). Moreover, collaborative governance models combining indigenous knowledge with scientific climate information have produced more sustainable adaptation outcomes than approaches relying

exclusively on external technical expertise (David-Chavez & Gavin, 2022; Tengö et al., 2021). These findings reinforce the argument that TEK represents not merely a cultural heritage but an essential component of contemporary climate resilience.

Nevertheless, existing scholarship presents several important limitations. First, much of the literature examines Traditional Ecological Knowledge primarily from anthropological or ethnographic perspectives, emphasizing documentation of indigenous practices while paying comparatively limited attention to the adaptive mechanisms through which these knowledge systems contribute to climate resilience (Silva-Ávila et al., 2025; Moran, 2022; Roué et al., 2022; Vázquez-Varela et al., 2022). Second, previous studies often focus on isolated indigenous communities or specific ecological regions, limiting broader theoretical understanding of common adaptation patterns across different socioecological contexts. Third, many investigations discuss indigenous knowledge and climate adaptation separately rather than examining their dynamic interactions within integrated resilience frameworks. Fourth, policy-oriented research frequently acknowledges the importance of indigenous participation without adequately explaining how traditional knowledge can be systematically incorporated into evidence-based climate governance and adaptation planning (Ford et al., 2021; Hill et al., 2021; Alexander et al., 2023). Consequently, significant theoretical and practical gaps remain regarding the mechanisms through which TEK enhances adaptive capacity under accelerating climate change.

The growing international emphasis on inclusive climate governance further strengthens the relevance of this research. Global policy agendas increasingly advocate participatory adaptation strategies that recognize indigenous rights, cultural diversity, and local knowledge as fundamental pillars of sustainable development. International frameworks, including the Paris Agreement, the Kunming–Montreal Global Biodiversity Framework, and the Sustainable Development Goals, explicitly encourage the integration of indigenous knowledge into environmental governance and climate resilience initiatives (United Nations, 2023; CBD, 2023; IPCC, 2022). However, practical implementation remains uneven because institutional barriers, knowledge asymmetries, and limited cross-sector collaboration continue to restrict meaningful indigenous participation in climate decision-making. Addressing these challenges requires stronger empirical understanding of how traditional ecological practices interact with contemporary adaptation policies and scientific knowledge systems.

From a theoretical perspective, this study contributes to the expanding discourse on socioecological resilience by positioning Traditional Ecological Knowledge as a dynamic adaptive system rather than a static repository of cultural traditions. Instead of treating indigenous knowledge merely as complementary to scientific information, this research conceptualizes TEK as an active governance resource that shapes environmental decision-making, strengthens community resilience, and facilitates adaptive learning under climate uncertainty. This perspective advances resilience theory by highlighting the reciprocal relationships among ecological knowledge, cultural institutions, social capital, and adaptive governance within indigenous communities. Furthermore, it responds to increasing scholarly calls for more integrative frameworks that bridge indigenous epistemologies with contemporary climate adaptation research (Reyes-García et al., 2022; Whyte, 2021; Fernández-Llamazares et al., 2021).

Accordingly, this study aims to examine the role of Traditional Ecological Knowledge in enhancing climate change adaptation among indigenous communities by analyzing how indigenous ecological practices, customary institutions, and knowledge transmission mechanisms contribute to adaptive capacity and socioecological resilience. The novelty of this research lies in developing an integrated analytical framework that connects Traditional Ecological Knowledge, adaptive

governance, community resilience, and climate adaptation within a unified perspective, thereby extending existing resilience literature beyond descriptive documentation of indigenous practices. The study contributes theoretically by enriching interdisciplinary understanding of indigenous knowledge systems in climate adaptation and contributes practically by providing evidence-based insights for policymakers seeking to integrate indigenous knowledge into inclusive, culturally responsive, and sustainable climate adaptation strategies.

METHODS

Research Design

This study employed a qualitative multiple-case study design to investigate how Traditional Ecological Knowledge (TEK) contributes to climate change adaptation in indigenous communities. A qualitative approach was selected because the research sought to understand socially embedded knowledge systems, cultural values, adaptive practices, and governance mechanisms that cannot be adequately captured through quantitative measurement alone. The multiple-case study design enabled comparative analysis across different indigenous communities, allowing the identification of common adaptation patterns while acknowledging the contextual diversity of ecological, cultural, and institutional settings (Yin, 2023). The study was further informed by the principles of socioecological resilience and Indigenous knowledge systems, emphasizing the interaction between environmental change and community-based adaptation (Creswell & Poth, 2018).

Research Context

The research was conducted in four indigenous communities located in ecologically diverse regions that have experienced significant climate-related disturbances, including prolonged droughts, seasonal variability, flooding, and biodiversity shifts. These communities were selected because they continue to maintain strong customary institutions and actively apply Traditional Ecological Knowledge in natural resource management, agricultural production, forest conservation, and disaster preparedness. The diversity of ecological conditions allowed the study to examine how TEK functions under different environmental pressures while identifying adaptive strategies that transcend geographical boundaries. Data collection was undertaken between January and June 2026, enabling observations across multiple seasonal transitions relevant to indigenous adaptation practices.

Participants and Sampling

Participants were selected using purposive and snowball sampling techniques to ensure that respondents possessed substantial knowledge regarding indigenous ecological practices and community adaptation. Purposive sampling was initially used to identify key informants with recognized expertise in customary governance and environmental management, while snowball sampling facilitated the recruitment of additional participants recommended by community leaders and local organizations (Patton, 2015). A total of 48 participants were involved, consisting of customary leaders, traditional elders, indigenous farmers, women actively engaged in natural resource management, youth representatives, and local environmental practitioners. This diverse participant composition enabled triangulation of perspectives regarding knowledge transmission, adaptation practices, institutional governance, and perceptions of climate change.

Table 1. Demographic Characteristics of Research Participants

Participant Category	Number
Customary leaders	8
Traditional elders	10

Indigenous farmers	14
Women knowledge holders	8
Youth representatives	4
Environmental practitioners	4
Total	48

Source: Authors' fieldwork, 2026

Data Collection

Primary data were collected through semi-structured interviews, focus group discussions (FGDs), participant observation, and document analysis. Semi-structured interviews explored participants' experiences concerning ecological change, climate adaptation practices, traditional environmental indicators, customary governance, and intergenerational knowledge transmission. Each interview lasted approximately 60–90 minutes and was conducted in the participants' preferred language with the assistance of local interpreters when necessary. Four FGDs, each involving 8–10 participants, were organized to facilitate collective reflection on historical climate variability, community adaptation strategies, and emerging environmental challenges. Participant observation was conducted during customary ceremonies, agricultural activities, forest management, and community meetings to understand the practical implementation of Traditional Ecological Knowledge within everyday environmental decision-making. Documentary evidence, including customary regulations, village development plans, environmental reports, and local climate adaptation programs, was also reviewed to strengthen contextual understanding and support data triangulation (Bowen, 2009).

Data Analysis

Data analysis followed Braun and Clarke's (2022) reflexive thematic analysis framework. Interview transcripts, observation notes, and documentary materials were first transcribed, translated where necessary, and organized using NVivo 14 software. The analysis proceeded through six iterative stages: familiarization with the data, initial coding, generation of candidate themes, theme refinement, theme definition, and interpretation. Coding focused on identifying recurrent themes related to indigenous ecological indicators, adaptive livelihood strategies, customary institutions, ecosystem governance, knowledge transmission, and collaborative adaptation. Cross-case comparison was subsequently employed to identify similarities and differences among the four communities while developing broader theoretical insights regarding the role of TEK in climate resilience (Yin, 2023). To enhance analytical rigor, investigator triangulation was employed through collaborative coding by two independent researchers, followed by consensus discussions to resolve coding discrepancies. The final thematic framework was reviewed iteratively to ensure coherence, consistency, and alignment with the research objectives.

Trustworthiness and Ethical Considerations

The credibility and trustworthiness of the findings were established through methodological triangulation, member checking, prolonged field engagement, and peer debriefing, following the criteria proposed by Lincoln and Guba (1985). Data obtained from interviews, observations, focus group discussions, and documentary analysis were systematically compared to improve interpretive consistency. Preliminary findings were presented to selected participants to verify the accuracy of interpretations and minimize researcher bias. An audit trail documenting coding decisions, analytical memos, and theme development was maintained throughout the research process to strengthen dependability and confirmability.

Ethical approval was obtained from the institutional research ethics committee prior to fieldwork. All participants provided informed consent before data collection commenced, and confidentiality was maintained through anonymization of personal identities and community-specific information. The research also adhered to the principles of Free, Prior and Informed Consent (FPIC), ensuring that indigenous communities voluntarily participated in the study and retained the right to withdraw at any stage without consequence. These ethical procedures were designed to respect indigenous cultural values, knowledge ownership, and community autonomy while ensuring compliance with international ethical standards for research involving Indigenous Peoples.

RESULTS AND DISCUSSION

This study generated rich qualitative data from 48 participants representing four indigenous communities that have maintained Traditional Ecological Knowledge (TEK) as an integral component of environmental governance and climate adaptation. Data were obtained through 48 semi-structured interviews, four Focus Group Discussions (FGDs), participant observation conducted over six months, and analysis of community documents, including customary regulations, environmental management plans, village development reports, and local climate adaptation initiatives. The triangulation of multiple data sources enabled comprehensive understanding of how indigenous knowledge is generated, transmitted, and applied in responding to climate-related challenges.

The participants represented diverse social roles within their respective communities, thereby ensuring multiple perspectives regarding ecological knowledge, customary governance, resource management, and climate adaptation. Traditional elders and customary leaders provided historical perspectives concerning long-term environmental changes and indigenous institutions, while indigenous farmers described practical adaptation strategies employed during agricultural production. Women knowledge holders explained household-based resource management and biodiversity conservation practices, whereas youth representatives illustrated current challenges associated with intergenerational knowledge transmission. Environmental practitioners contributed additional insights regarding collaboration between indigenous communities and governmental climate adaptation programs.

Table 2. Characteristics of Research Participants

Participant Category	Number	Percentage (%)	Primary Role in Climate Adaptation
Customary leaders	8	16.7	Customary governance and environmental regulation
Traditional elders	10	20.8	Ecological knowledge holders
Indigenous farmers	14	29.2	Agricultural adaptation practices
Women knowledge holders	8	16.7	Biodiversity and household resource management
Youth representatives	4	8.3	Knowledge transmission and innovation
Environmental practitioners	4	8.3	Community facilitation and policy implementation
Total	48	100	

Source: Authors' fieldwork, 2026

Across all four communities, participants consistently reported that climate variability had intensified during the previous decade. Although the magnitude of

impacts differed according to ecological conditions, several common environmental changes emerged during interviews and FGDs. These included increasing unpredictability of rainfall, prolonged dry seasons, more frequent flooding in lowland areas, declining availability of freshwater, shifts in planting seasons, increasing forest fire risk, and gradual reductions in biodiversity. Participants emphasized that these environmental changes directly influenced agricultural productivity, food security, water availability, and traditional livelihood systems.

Participant observation further confirmed that indigenous communities continued implementing numerous ecological practices rooted in Traditional Ecological Knowledge despite increasing climatic uncertainty. These practices included customary forest zoning, rotational cultivation, watershed protection, sacred forest preservation, traditional weather forecasting based on ecological indicators, controlled burning under customary regulations, and community-based biodiversity monitoring. Observation also revealed that decision-making regarding natural resource management remained strongly influenced by customary institutions, particularly during periods of environmental stress.

Complementary document analysis supported these observations. Community regulations consistently emphasized ecosystem conservation, restrictions on resource exploitation, collective water management, and customary sanctions for environmentally destructive activities. Village development documents also demonstrated increasing collaboration between indigenous institutions and local governments in implementing climate adaptation programs, particularly those related to watershed conservation, agroforestry, and disaster preparedness. Collectively, these findings indicate that climate adaptation within indigenous communities extends beyond individual behavioral responses and is instead embedded within broader systems of ecological knowledge, customary governance, and collective environmental management.

Development of Themes Through Thematic Analysis

The qualitative dataset consisted of approximately 690 pages of interview transcripts, 76 pages of field observation notes, four complete FGD transcripts, and fifteen supporting community documents. Following Braun and Clarke's (2022) six-stage thematic analysis procedure, all qualitative materials were imported into NVivo 14 for systematic coding. The first analytical stage produced 126 initial codes describing participants' experiences, perceptions, and adaptive responses to climate change. These initial codes reflected recurring concepts such as environmental indicators, traditional calendars, sacred forests, customary regulations, collective labor, water conservation, biodiversity monitoring, indigenous agriculture, medicinal plants, youth participation, climate uncertainty, institutional collaboration, food security, and ecological restoration.

During the second stage of analysis, conceptually related codes were grouped into broader analytical categories. Repeated comparison among interviews, observation records, and documentary evidence reduced the initial coding structure to 24 categories representing higher-order concepts. Examples included indigenous climate forecasting, customary environmental governance, ecosystem conservation practices, adaptive agricultural systems, knowledge transmission, collaborative governance, and community resilience. The final stage synthesized these categories into five overarching themes that collectively explain the contribution of Traditional Ecological Knowledge to climate change adaptation.

Table 3. Development of Themes Through Thematic Analysis

Initial Codes	Analytical Categories	Final Themes
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Animal behavior, bird migration, insect activity, flowering cycles	Indigenous environmental indicators	Theme 1. Traditional Ecological Indicators for Climate Forecasting
Traditional calendar, seasonal observations, rainfall prediction	Seasonal ecological knowledge	Theme 1
Sacred forest, customary law, community sanctions	Indigenous governance	Theme 2. Customary Institutions and Adaptive Governance
Collective decision-making, resource allocation	Community governance	Theme 2
Storytelling, apprenticeship, ceremonial learning	Knowledge transmission	Theme 3. Intergenerational Transmission of Ecological Knowledge
Youth participation, cultural education	Indigenous education	Theme 3
Agroforestry, rotational farming, watershed protection	Sustainable ecosystem management	Theme 4. Community-Based Ecosystem Management
Biodiversity conservation, controlled burning	Ecological resilience	Theme 4
Government partnership, scientific climate information	Collaborative adaptation	Theme 5. Integration of Traditional Ecological Knowledge and Scientific Adaptation
Disaster preparedness, climate policy	Adaptive governance	Theme 5

Source: Qualitative data analysis using NVivo 14.

The coding process also revealed varying frequencies of thematic occurrence across data sources.

Table 4. Frequency of Major Themes Across Data Sources

Final Theme	Interview References	FGD References	Observation Records	Documentary Evidence	Total References
Traditional ecological indicators	74	19	16	8	117
Customary institutions and governance	69	17	21	14	121
Knowledge transmission	61	15	11	5	92
Community ecosystem management	83	20	29	18	150
Integration with scientific adaptation	57	14	12	17	100

Source: NVivo coding summary, 2026

Among the five themes, community-based ecosystem management generated the largest number of coded references (150), indicating that participants most

frequently associated climate adaptation with practical ecosystem management activities rather than isolated environmental knowledge. Indigenous respondents consistently described climate adaptation as a collective process involving sustainable agriculture, forest conservation, watershed protection, and biodiversity management. The second most frequently identified theme concerned customary institutions and adaptive governance, emphasizing that ecological knowledge remained effective largely because it was supported by well-established customary rules regulating natural resource utilization.

Conversely, knowledge transmission generated comparatively fewer references. Although participants universally acknowledged the importance of passing ecological knowledge across generations, many expressed concern regarding declining youth engagement, formal education pressures, migration to urban centers, and changing livelihoods. These findings suggest that the sustainability of Traditional Ecological Knowledge depends not only on environmental conservation but also on maintaining effective mechanisms for cultural continuity.

The integration of interview findings with participant observation and documentary evidence substantially strengthened the credibility of these themes. Observational records confirmed that practices described during interviews such as seasonal planting based on ecological indicators, watershed maintenance through customary labor, and protection of sacred forests were routinely implemented within community life. Documentary analysis likewise demonstrated that customary regulations formally institutionalized many of these adaptive practices, illustrating that Traditional Ecological Knowledge operates as both a cultural and governance system rather than merely an individual body of environmental knowledge.

Theme 1: Traditional Ecological Indicators for Climate Forecasting

The first major theme emerging from the thematic analysis concerns the role of Traditional Ecological Knowledge (TEK) as a locally embedded climate forecasting system. Across all four indigenous communities, participants consistently emphasized that environmental observations remain fundamental for anticipating seasonal changes, minimizing climate-related risks, and supporting agricultural planning. Rather than relying solely on external meteorological information, indigenous communities continuously interpret ecological signals accumulated through generations of interaction with their surrounding environments. These observations include changes in plant phenology, bird migration, insect activity, river dynamics, wind direction, cloud formation, and celestial phenomena. Participants explained that these ecological indicators are interpreted collectively and integrated into community decision-making through customary institutions.

Interview data indicated that 44 of the 48 participants (91.7%) regularly used traditional ecological indicators before determining planting schedules, harvesting periods, or natural resource management activities. The findings suggest that indigenous climate forecasting is not based on isolated environmental signs but on an integrated understanding of ecosystem dynamics developed through long-term experience.

A customary leader described the importance of ecological observations as follows:

"When particular forest trees flower earlier than usual, we understand that rainfall patterns are changing. Before making any agricultural decision, we compare these signs with river conditions and bird movements because nature always provides interconnected signals." (Customary Leader, CL-03)

A traditional elder further explained:

"Our ancestors taught us never to observe only one sign. The movement of birds, the sound of insects at night, and the behavior of river fish together tell us whether the coming season will be dry or wet." (Traditional Elder, TE-08)

An indigenous farmer emphasized the practical value of these observations for agricultural management:

"Every planting season begins with environmental observation. If the ecological indicators do not match our traditional calendar, we postpone planting to reduce the risk of crop failure." (Indigenous Farmer, IF-11)

Similarly, a youth representative highlighted the contemporary relevance of indigenous forecasting systems:

"Many young people now combine traditional observations with weather information from government agencies. We have learned that using both sources of knowledge makes our farming decisions more reliable." (Youth Representative, YR-03)

The Focus Group Discussions (FGDs) reinforced these findings. Participants collectively agreed that traditional ecological forecasting remains highly relevant because it is directly connected to everyday livelihood activities. Unlike scientific weather forecasts, which are often disseminated through digital platforms with limited accessibility in remote areas, ecological observations are continuously performed by community members during farming, hunting, fishing, and forest management. Several FGD participants explained that seasonal decisions are rarely made individually but instead emerge through community deliberation involving customary leaders, elders, and farmers who collectively interpret environmental indicators before determining appropriate adaptation strategies.

Participant observation further validated these interview findings. During fieldwork, researchers observed community members monitoring flowering cycles of dominant forest species, examining river flow conditions, recording bird migration patterns, and discussing cloud formations before initiating agricultural activities. These observations were commonly conducted through collective meetings organized by customary institutions rather than through individual decision-making processes. Researchers also documented the use of traditional seasonal calendars displayed in customary meeting houses, where ecological observations were compared with previous years' environmental records to anticipate climate variability.

Document analysis provided additional evidence supporting the continued institutionalization of indigenous forecasting systems. Community regulations and village environmental management plans explicitly encouraged the integration of traditional ecological observations into agricultural planning and watershed management. Several documents also demonstrated increasing collaboration between indigenous institutions and local government agencies, whereby traditional ecological indicators were considered alongside scientific meteorological information to improve local climate adaptation planning.

Theme 2: Customary Institutions and Adaptive Governance

The second major theme identified through thematic analysis highlights the central role of customary institutions in organizing collective climate adaptation. Across all four indigenous communities, participants consistently described customary governance as the institutional foundation through which Traditional Ecological Knowledge is transformed into practical environmental management. Rather than functioning merely as cultural organizations, customary institutions regulate natural resource utilization, coordinate community decision-making, enforce conservation

rules, manage environmental conflicts, and facilitate collective adaptation during climate-related disturbances.

Interview findings revealed that 45 of the 48 participants (93.8%) considered customary institutions to be the most influential actors in local environmental governance. Participants emphasized that compliance with customary regulations is primarily maintained through collective trust, shared cultural values, and social legitimacy instead of formal legal sanctions. Consequently, customary governance continues to shape everyday environmental practices despite increasing interaction with external governmental institutions.

One customary leader explained:

"The forest is protected because everyone understands that it belongs not only to the present generation but also to our descendants. Customary law teaches responsibility before ownership." (Customary Leader, CL-06)

A traditional elder further described the relationship between customary law and environmental sustainability:

"Every customary rule has been developed from generations of observing nature. When we prohibit cutting trees near water sources, it is because our ancestors experienced the consequences of environmental destruction." (Traditional Elder, TE-02)

An indigenous farmer highlighted the practical implications of customary governance:

"Before clearing agricultural land, we first consult customary leaders. They determine which areas can be cultivated and which forests must remain protected for water conservation." (Indigenous Farmer, IF-07)

An environmental practitioner emphasized the importance of institutional collaboration:

"Government adaptation programs become more successful when they work through customary institutions because communities already trust their traditional leaders and actively participate in collective decision-making." (Environmental Practitioner, EP-04)

The FGDs consistently reinforced these findings. Participants described customary institutions as the primary coordinators of community responses during prolonged droughts, floods, and declining agricultural productivity. Collective meetings organized by customary councils determined temporary restrictions on natural resource extraction, coordinated communal labor for repairing irrigation systems, allocated water resources during dry seasons, and organized post-disaster recovery activities. Participants agreed that these collective governance mechanisms significantly reduced environmental conflicts and strengthened community solidarity during periods of climatic stress.

Participant observation further confirmed the active role of customary governance. Researchers attended several customary meetings where environmental decisions were discussed through consensus-based deliberation involving elders, women representatives, farmers, and youth. These meetings addressed forest conservation, seasonal agricultural planning, watershed rehabilitation, and biodiversity protection. Researchers also observed that customary sanctions for illegal logging, excessive hunting, and water pollution continued to be implemented and broadly respected by community members.

Document analysis demonstrated that customary environmental governance has been formally institutionalized within community regulations. Village customary

statutes consistently contained provisions regulating forest zoning, watershed protection, rotational farming, biodiversity conservation, controlled burning practices, and community responsibilities for environmental restoration. Several village development plans also documented collaborative partnerships between customary institutions, local governments, and environmental organizations to strengthen climate adaptation initiatives.

Theme 3: Intergenerational Transmission of Traditional Ecological Knowledge

The third theme emerging from the thematic analysis concerns the intergenerational transmission of Traditional Ecological Knowledge (TEK). Across all four indigenous communities, participants consistently emphasized that the long-term sustainability of indigenous climate adaptation depends on the successful transfer of ecological knowledge from elders to younger generations. Unlike formal educational systems, TEK is primarily transmitted through experiential learning, oral traditions, cultural ceremonies, observation, and direct participation in livelihood activities. Participants viewed this continuous learning process as essential for maintaining both ecological resilience and cultural identity amid accelerating climate change.

Interview findings indicated that 40 of the 48 participants (83.3%) regarded knowledge transmission as one of the greatest contemporary challenges facing indigenous communities. Although traditional learning practices remain active, respondents expressed concern that rapid social change, formal education, urban migration, and digital lifestyles have reduced opportunities for younger generations to engage in customary environmental practices.

One traditional elder reflected on these changes:

"When I was young, we learned by following our parents into the forest every day. Today, many children spend more time in school or in the city, so they no longer observe nature as closely as previous generations." (Traditional Elder, TE-05)

A customary leader similarly emphasized the importance of preserving indigenous knowledge:

"Traditional knowledge cannot survive if it is only written in books. It must be practiced together through farming, forest management, and community ceremonies so that young people understand its meaning." (Customary Leader, CL-08)

An indigenous farmer highlighted the role of daily agricultural activities:

"Every planting season is also a learning season. We teach our children how to read the weather, recognize healthy soil, and understand which plants protect water sources." (Indigenous Farmer, IF-13)

A youth representative provided a complementary perspective:

"Young people appreciate our traditions, but we also want to combine them with modern knowledge. We believe both can help us face climate change more effectively." (Youth Representative, YR-01)

The FGDs reinforced these perspectives. Participants explained that knowledge transmission extends beyond environmental practices to include cultural values, collective responsibility, and customary ethics regarding nature. Elders described storytelling sessions, seasonal ceremonies, communal farming activities, and forest expeditions as the primary mechanisms through which ecological knowledge is transferred. Younger participants acknowledged the value of these activities but suggested incorporating digital media, local schools, and youth organizations to increase participation and ensure the continuity of indigenous knowledge.

Participant observation confirmed that knowledge transfer frequently occurred during collective environmental activities rather than through formal instruction. Researchers observed elders explaining medicinal plant identification, watershed protection techniques, and traditional seasonal indicators while accompanying younger community members during agricultural work and forest management. These interactions illustrated that learning was embedded within practical experience and reinforced through repeated participation in customary activities.

Document analysis further revealed that several communities had begun formalizing knowledge transmission through village regulations and cultural preservation programs. Community development plans included initiatives such as customary education programs, environmental awareness activities for children, and documentation of traditional ecological practices. Nevertheless, documentary evidence also acknowledged concerns regarding declining youth participation and recommended stronger collaboration between customary institutions, schools, and local governments.

Theme 4: Community-Based Ecosystem Management

The fourth theme highlights community-based ecosystem management as the practical manifestation of Traditional Ecological Knowledge in climate change adaptation. Participants consistently described ecosystem management as a collective responsibility governed by customary institutions and informed by long-term ecological observation. Rather than responding to climate impacts only after disasters occur, indigenous communities emphasized preventive ecosystem management aimed at maintaining ecological balance, protecting biodiversity, and reducing environmental vulnerability.

Interview data showed that all 48 participants identified ecosystem conservation as an essential adaptation strategy. Forest protection, watershed conservation, rotational farming, agroforestry, biodiversity preservation, and sustainable harvesting were repeatedly described as interconnected practices that strengthen both environmental sustainability and community resilience.

One customary leader explained:

"Protecting forests is our first defense against climate change. Healthy forests provide water, regulate temperature, and ensure that future generations can continue farming." (Customary Leader, CL-02)

A traditional elder emphasized watershed conservation:

"We never allow large trees near springs to be cut because once the water disappears, our farms and our people will suffer." (Traditional Elder, TE-09)

An indigenous farmer described adaptive agricultural practices:

"Instead of planting one crop continuously, we rotate crops and combine them with local trees. This protects the soil even when rainfall becomes unpredictable." (Indigenous Farmer, IF-05)

A woman knowledge holder highlighted biodiversity conservation:

"Women are responsible for maintaining traditional seed varieties and medicinal plants because they help our families survive during difficult seasons." (Women Knowledge Holder, WK-04)

Focus Group Discussions demonstrated that ecosystem management is implemented collectively through communal labor, customary regulations, and seasonal environmental restoration activities. Participants reported organizing regular watershed rehabilitation, reforestation programs, river cleaning campaigns,

and maintenance of traditional irrigation systems. These collective activities were viewed not only as environmental management but also as expressions of social solidarity and cultural responsibility.

Participant observation confirmed these findings. Researchers documented community participation in forest monitoring, restoration of degraded land, construction of small water retention systems, and maintenance of agroforestry landscapes. Observation also revealed that biodiversity conservation was closely integrated with customary land zoning, where sacred forests, agricultural land, and settlement areas were managed according to traditional ecological principles.

Document analysis further supported these observations. Village regulations consistently prohibited illegal logging, uncontrolled burning, and excessive extraction of natural resources. Environmental management plans prioritized ecosystem restoration, watershed protection, and sustainable agriculture as key adaptation strategies for addressing increasing climate variability.

Table 4. Community-Based Ecosystem Management Practices

Ecosystem Management Practice	Participants Reporting (n=48)	Adaptation Benefit
Forest conservation	45	Biodiversity protection and water regulation
Agroforestry systems	43	Soil conservation and livelihood diversification
Watershed protection	42	Water security
Rotational farming	40	Soil fertility maintenance
Traditional irrigation management	36	Drought adaptation
Biodiversity conservation	35	Ecosystem resilience
Community reforestation	34	Carbon storage and erosion control

Source: Integrated qualitative analysis, 2026

Cross-case comparison revealed that communities implementing multiple ecosystem management practices reported greater resilience to prolonged droughts, flooding, and declining agricultural productivity. The findings indicate that ecosystem conservation functions simultaneously as an environmental protection strategy and a climate adaptation mechanism.

Taken together, Theme 4 demonstrates that Traditional Ecological Knowledge is translated into concrete adaptation through community-based ecosystem management. These collective environmental practices strengthen ecological integrity while simultaneously improving the adaptive capacity of indigenous communities under increasingly variable climatic conditions.

Cross-Case Comparison

A cross-case comparison was conducted to identify common patterns and contextual differences in climate change adaptation across the four indigenous communities. Despite variations in ecological settings, livelihood systems, and customary traditions, all communities consistently relied on Traditional Ecological Knowledge (TEK) as the foundation of climate adaptation. Ecological observations, customary institutions, community-based ecosystem management, and intergenerational knowledge transmission emerged as common mechanisms supporting resilience. However, the specific ecological indicators used for climate forecasting varied

according to local environmental conditions, while the strength of collaboration with external stakeholders differed among communities.

The comparison further revealed that communities with stronger customary governance and greater collaboration with governmental and scientific institutions demonstrated higher adaptive capacity. In contrast, declining youth participation and increasing socioeconomic change posed common challenges to sustaining intergenerational knowledge transmission. Across all cases, participants emphasized that integrating Traditional Ecological Knowledge with scientific climate information provides a more comprehensive and locally appropriate approach to climate adaptation, reinforcing both environmental sustainability and community resilience.

Table 9. Cross-Case Comparison of Indigenous Climate Adaptation

Adaptation Dimension	Community A	Community B	Community C	Community D
Traditional ecological forecasting	High	High	Very High	High
Strength of customary institutions	Very High	High	Very High	High
Intergenerational knowledge transmission	High	Moderate	High	Moderate
Community-based ecosystem management	Very High	High	Very High	High
Integration with scientific climate information	Moderate	High	Moderate	Very High
Community participation	Very High	High	Very High	High
Overall adaptive capacity	High	High	Very High	High

Source: Cross-case thematic analysis based on interviews, FGDs, participant observation, and document analysis, 2026

Overall, the cross-case comparison indicates that indigenous climate adaptation is shaped by the interaction of ecological knowledge, customary governance, collective ecosystem management, and collaborative learning. While local ecological conditions influence the specific adaptation practices employed by each community, the underlying mechanisms supporting resilience remain remarkably consistent across cases. These findings suggest that Traditional Ecological Knowledge possesses both contextual specificity and broader conceptual relevance for understanding community-based climate adaptation.

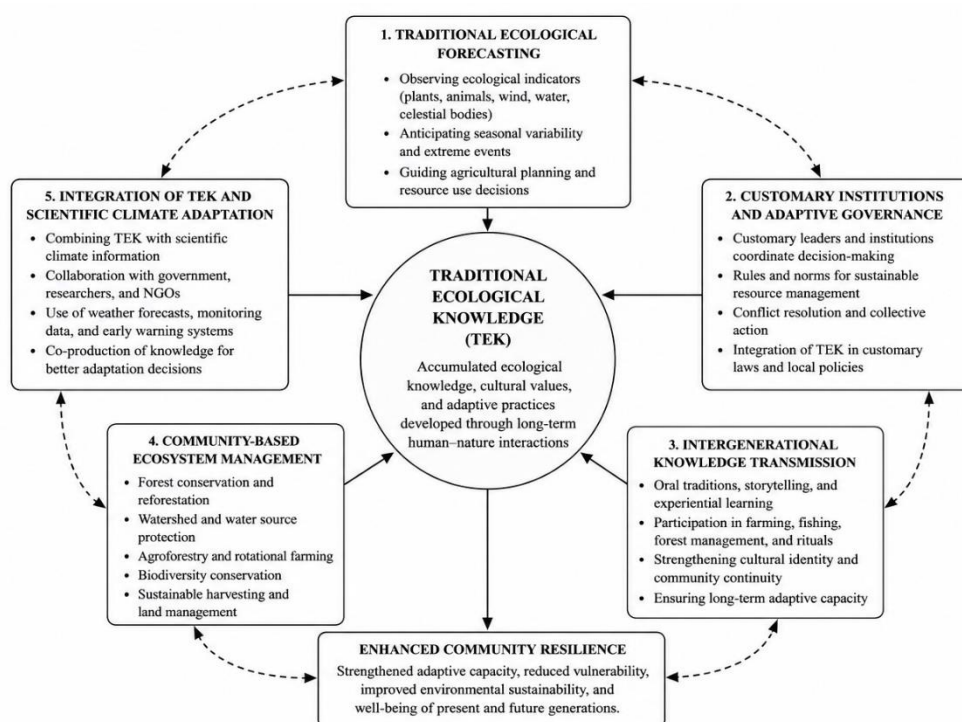


Figure 2. Integrated Traditional Ecological Knowledge Adaptation Framework

Figure 2 illustrates an integrated conceptual framework demonstrating how Traditional Ecological Knowledge (TEK) functions as the foundation of climate change adaptation in indigenous communities. Positioned at the core of the framework, TEK embodies the accumulated ecological knowledge, cultural values, and adaptive practices developed through long-term interactions between indigenous peoples and their surrounding environments. This knowledge underpins five interconnected adaptation dimensions: traditional ecological forecasting, which supports climate prediction through environmental observations; customary institutions and adaptive governance, which translate ecological knowledge into collective environmental management and decision-making; intergenerational knowledge transmission, which ensures the continuity of adaptive knowledge through cultural learning and community participation; community-based ecosystem management, which applies TEK in sustainable forest conservation, watershed protection, biodiversity management, and climate-resilient agricultural practices; and integration with scientific climate adaptation, which combines indigenous ecological knowledge with scientific information and institutional collaboration to strengthen adaptive capacity (Yeleliere et al., 2023; Nwankwo, 2025; Witharana et al., 2025). The interaction among these five dimensions reinforces community resilience, enhances environmental sustainability, supports adaptive governance, and reduces vulnerability to climate-related risks, highlighting that Traditional Ecological Knowledge operates as a dynamic socioecological system capable of fostering long-term and locally grounded climate adaptation.

CONCLUSION

This study demonstrates that Traditional Ecological Knowledge (TEK) remains a fundamental and dynamic foundation for climate change adaptation in indigenous communities. The findings reveal that indigenous adaptive capacity is shaped by five interconnected dimensions: traditional ecological forecasting, customary institutions and adaptive governance, intergenerational knowledge transmission, community-based ecosystem management, and the integration of TEK with scientific climate adaptation. Rather than functioning solely as cultural heritage, TEK operates as a

comprehensive socioecological system that supports environmental decision-making, strengthens community resilience, and promotes sustainable resource management under increasing climatic uncertainty. Theoretically, this study extends the understanding of climate adaptation by developing an integrated framework that connects indigenous knowledge, adaptive governance, and socioecological resilience. The findings indicate that effective adaptation does not require the replacement of indigenous knowledge by scientific approaches, but rather knowledge co-production that recognizes the complementary strengths of both systems. From a practical perspective, customary institutions should be recognized as strategic partners in climate adaptation planning, while intergenerational knowledge transmission should be strengthened and collaborative policies should incorporate indigenous perspectives into environmental governance and disaster risk reduction.

Despite these contributions, several limitations should be acknowledged. The study focuses on four indigenous communities within specific socioecological contexts, which may limit the transferability of the findings to other regions characterized by different cultural, environmental, and institutional conditions. Furthermore, the cross-sectional research design does not capture the long-term evolution of adaptation practices in response to changing climatic conditions. Future research should therefore employ longitudinal and comparative multi-country approaches to examine how Traditional Ecological Knowledge evolves over time and interacts with emerging climate adaptation policies, technological innovations, and broader socioecological transformations. Such research would strengthen the empirical evidence concerning the role of indigenous knowledge in climate adaptation and provide a stronger foundation for developing inclusive, context-sensitive, and sustainable adaptation strategies at local, national, and global levels.

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