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Beyond Technology: Traditional Ecological Knowledge and Symmetrical Climate Governance in Semi-Arid Regions

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ABSTRACT: Climate adaptation policies in semi-arid regions have been predominantly shaped by technocratic and centralized approaches that frequently marginalize local ecological knowledge systems and weaken territorially embedded adaptive capacities. In this context, Traditional Ecological Knowledge (TEK) has increasingly emerged in scientific debates as a relevant adaptive infrastructure capable of strengthening socioecological resilience in drylands. This study aimed to analyze how the global scientific literature validates the effectiveness of TEK in climate adaptation and how it proposes its integration with modern science within climate governance frameworks. An integrative literature review was conducted using Web of Science, Scopus, and SciELO Citation Index databases between November 2025 and May 2026. The initial search identified 1,368 records, from which a final analytical corpus of 30 peer-reviewed references was selected according to predefined inclusion and exclusion criteria. The findings revealed a strong geographical concentration of studies in African drylands, the Brazilian semiarid region, and Asian semi-arid territories, emphasizing adaptive practices related to water management, agro-silvopastoral systems, biodiversity conservation, climatic bioindicators, and adaptive mobility. The review also demonstrated growing scientific recognition of TEK as a valid environmental knowledge system compatible with Earth system sciences, ecological monitoring, and sustainability governance. Nevertheless, substantial epistemological barriers persist, particularly those associated with technocratic governance, bureaucratic centralization, and colonial asymmetries in knowledge production. The study concludes that climate adaptation in drylands requires governance models grounded in epistemic plurality, participatory co-production, and symmetrical integration between scientific and vernacular knowledge systems.

KEYWORDS: Anthropocene. Decoloniality. Environmental Justice. Resilience. Sustainability Governance.

1. INTRODUCTION

Climate change has intensified socioecological vulnerability across semi-arid regions, particularly in territories historically shaped by water scarcity, environmental instability, and structural inequality. Despite the growing prominence of adaptation within global climate governance, dominant responses remain strongly anchored in technocratic and centralized models that prioritize external infrastructures, engineering-based interventions, and top-down planning mechanisms (Petzold et al., 2020; Hosen et al., 2020). Such approaches frequently overlook the cultural and ecological specificities of drylands, reducing complex territorial dynamics to technical variables and standardized policy frameworks.

Evidence from African and Latin American semi-arid regions indicates that local communities often perceive and respond to climate variability through adaptive strategies distinct from institutional climate policies (Adaawen, 2021). In the Brazilian semiarid region, the persistence of centralized drought management policies has reinforced dependency on state-led interventions while weakening local adaptive capacities and community-based resilience systems (Santos et al., 2023). Under these conditions, drylands emerge as critical socioecological frontiers of the Anthropocene, exposing the limitations of universalized climate adaptation paradigms.

In contrast to purely technocentric approaches, Traditional Ecological Knowledge (TEK) constitutes a dynamic system of

ecological observation, territorial learning, and adaptive resource management developed through long-term interactions between communities and their environments (Li et al., 2022). Recent studies demonstrate that vernacular practices in semi-arid regions frequently operate as sophisticated mechanisms of climate resilience, particularly in water management, pastoral mobility, biodiversity conservation, and local governance systems (Sharifian et al., 2022).

Rather than representing static traditions or remnants of the past, TEK functions as a living adaptive infrastructure capable of incorporating new environmental experiences and social transformations. Its relevance extends beyond cultural preservation, encompassing ecosystem regulation, food security, and sustainable territorial management under conditions of climatic uncertainty (Sinthumule, 2023). Research conducted in Inner Mongolia further suggests that the persistence of traditional ecological systems depends precisely on their adaptive flexibility and capacity for continuous reconfiguration (Chao et al., 2025).

Although international climate debates increasingly recognize indigenous and local knowledge, substantial epistemological asymmetries continue to shape environmental governance. In many contexts, TEK remains institutionally marginalized or incorporated only in symbolic and consultative ways, without meaningful participation in decision-making processes (Ciocco et al., 2024). This pattern reflects enduring colonial structures within scientific and political institutions, where Western technical-scientific rationalities continue to dominate the production of legitimate environmental knowledge.

Consequently, the integration of traditional knowledge into climate adaptation policies often occurs through subordinate or instrumental frameworks that preserve hierarchical relations between expert systems and local communities (Chanza et al., 2024). Institutional barriers, bureaucratic centralization, and limited recognition of community-based expertise continue to obstruct the implementation of indigenous knowledge in climate governance strategies, particularly across vulnerable regions of the Global South (Leal Filho et al., 2025). The contemporary climate crisis, therefore, also represents a crisis of epistemological recognition.

Against this backdrop, this study argues that climate adaptation in semi-arid regions requires more than technological innovation alone. Through an integrative literature review, the article examines how scientific literature validates the effectiveness of Traditional Ecological Knowledge in strengthening resilience across drylands and how it proposes pathways for integrating TEK with modern science in climate governance frameworks.

The guiding question of this study is: how does global scientific literature validate the effectiveness of Traditional Ecological Knowledge in the resilience of semi-arid regions, and in what ways does it propose its integration with modern science for climate governance? By addressing this question, the article seeks to contribute to contemporary debates on climate justice, epistemic plurality, and integrative governance in the Anthropocene.

2. METHODOLOGY

2.1 Study Design: Integrative Literature Review

This study adopts an integrative literature review design, understood as a method capable of synthesizing theoretical, empirical, and methodological contributions produced across heterogeneous fields of knowledge. Unlike strictly systematic reviews focused on narrowly delimited evidence hierarchies, the integrative review allows the articulation of conceptual debates, empirical findings, epistemological tensions, and methodological approaches within a single analytical architecture. This design is particularly appropriate for interdisciplinary topics such as Traditional Ecological Knowledge, climate adaptation, drylands governance, and epistemic justice, whose scientific treatment crosses environmental sciences, social sciences, sustainability studies, political ecology, and climate policy.

The methodological choice is grounded in the classical formulation proposed by Whittemore and Knafl (2005), for whom integrative reviews enable the inclusion of diverse forms of evidence while preserving analytical rigor through explicit stages of problem identification, literature search, data evaluation, data analysis, and presentation of synthesis. This orientation was complemented by Torraco's (2016) understanding of integrative literature reviews as a strategy for generating conceptual advancement, especially when the objective is not only to summarize accumulated knowledge, but also to reinterpret a field and identify future theoretical directions.

In the Brazilian methodological tradition, Mendes et al. (2008) and Souza et al. (2010) reinforce the relevance of integrative reviews for incorporating evidence in a structured, transparent, and reproducible manner. Their contributions are especially useful for organizing the operational stages of this review, including the formulation of the guiding question, definition of databases, establishment of inclusion and exclusion criteria, extraction of information, critical analysis, and synthesis of findings. Therefore, the present review was designed not as a descriptive inventory of studies, but as a critical and analytical synthesis of how the literature validates TEK as an adaptive infrastructure in semi-arid and dryland regions.

2.2 Review Protocol and PICo Strategy

The review protocol was structured to ensure conceptual coherence between the research problem, the search strategy, and the analytical treatment of the selected corpus. Following the integrative review logic, the initial stage consisted of defining the object of inquiry and delimiting the epistemological scope of the investigation. The research question was organized through the PICo strategy, which is especially suitable for qualitative, mixed, and interdisciplinary reviews because it emphasizes phenomenon, interest, and context rather than intervention and outcome alone.

In this study, the PICo structure was defined as follows:

- P, Phenomenon: Traditional Ecological Knowledge and vernacular practices;
- I, Interest: climate adaptation, resilience, and integration with modern science;
- Co, Context: semi-arid regions and drylands.

This structure guided the entire review process, from search string formulation to analytical coding. It also prevented conceptual dispersion, since TEK is often addressed in the literature through multiple terminologies, including indigenous knowledge, local ecological knowledge, vernacular knowledge, community-based knowledge, and traditional environmental practices. The PICo strategy made it possible to preserve this semantic plurality while maintaining a clear focus on the relationship between knowledge systems, climate adaptation, and dryland resilience.

The protocol followed the stages recommended by Whittemore and Knafl (2005), particularly problem identification, literature search, evaluation of studies, analytical categorization, and synthesis. Torraco's (2016) perspective was incorporated to strengthen the interpretive dimension of the review, since the aim was not limited to mapping evidence, but also to construct a critical reading of the epistemological barriers that prevent TEK from being symmetrically integrated into climate governance.

2.3 Data Sources and Search Strategy

The bibliographic search was conducted from November 2025 to May 2026. Three databases were selected due to their relevance for environmental sciences, social sciences, sustainability studies, and Latin American scientific production: Web of Science, Scopus, and SciELO Citation Index. Web of Science and Scopus were used to capture internationally indexed publications with high visibility in climate adaptation, ecological knowledge, and sustainability research. SciELO Citation Index was included to identify Latin American production, particularly studies related to the Brazilian semiarid region and debates on coexistence with semi-arid environments.

The search strategy was built around three conceptual axes: Traditional Ecological Knowledge, climate adaptation, and semi-arid or dryland contexts. Boolean operators were applied to combine synonymous and related terms. The core search string was structured as follows: ("Traditional Ecological Knowledge" OR "TEK" OR "indigenous knowledge" OR "local knowledge" OR "vernacular knowledge") AND ("climate change adaptation" OR "climate resilience" OR "drought mitigation" OR "climate governance") AND ("semi-arid" OR "semiarid" OR "drylands" OR "arid zones")

To increase sensitivity and reduce linguistic bias, searches were conducted in English, Portuguese, and Spanish whenever database interfaces allowed multilingual retrieval. Equivalent Portuguese and Spanish terms included "conhecimento ecológico tradicional", "conhecimento indígena", "conhecimento local", "adaptação climática", "resiliência climática", "semiárido", "terras secas", "conocimiento ecológico tradicional", "conocimiento indígena", "adaptación climática" and "tierras secas". This multilingual strategy followed the recommendations of Mendes et al. (2008) and Souza et al. (2010) regarding the need for transparent, comprehensive, and replicable search procedures in integrative reviews.

The initial search identified 1,368 records. These references were exported from the databases and organized for screening. Duplicate records were removed before title and abstract screening. Subsequently, the remaining studies were evaluated according to the eligibility criteria defined in the protocol. The screening process considered thematic relevance, peer-review status, direct engagement with TEK or equivalent knowledge systems, and explicit connection to climate adaptation, drought, resilience, or environmental governance in semi-arid or dryland contexts.

The search strategy was designed to balance thematic breadth and analytical precision, considering both the interdisciplinary nature of the investigation and the terminological diversity surrounding Traditional Ecological Knowledge and climate adaptation studies. To ensure methodological transparency and reproducibility, the databases consulted, descriptors employed, Boolean operators applied, and screening filters adopted throughout the bibliographic retrieval process were systematically organized.

Table 1. Search Strategy, Databases, and Boolean Strings

Database	Main Search Terms	Boolean Structure	Filters Applied	Purpose of Inclusion
Web of Science	"Traditional Ecological Knowledge"; "climate adaptation"; "drylands"	("Traditional Ecological Knowledge" OR "TEK" OR "indigenous knowledge" OR "local knowledge" OR "vernacular knowledge") AND ("climate change adaptation" OR "climate resilience" OR "drought mitigation" OR "climate governance") AND ("semi-arid" OR "semiarid" OR	Peer-reviewed articles; English, Portuguese, and Spanish; Environmental Sciences and Social Sciences categories	Identification of internationally indexed high-impact studies on climate adaptation and TEK

		"drylands" OR "arid zones")		
Scopus	"Indigenous knowledge"; "climate resilience"; "semi-arid regions"	Same Boolean structure adapted to Scopus indexing syntax	Peer-reviewed journal articles; multidisciplinary subject areas; language filter	Broad interdisciplinary coverage of environmental governance and sustainability studies
SciELO Citation Index	"Conhecimento ecológico tradicional"; "semiárido"; "adaptação climática"	Portuguese and Spanish equivalents combined with Boolean operators	Indexed journals; Latin American publications; Portuguese and Spanish languages	Inclusion of regional and Latin American scholarship, particularly studies on the Brazilian semiarid
Complementary multilingual search	"Conocimiento ecológico tradicional"; "adaptación climática"; "tierras secas"	Adapted multilingual combinations in Portuguese and Spanish	Manual refinement by thematic relevance and duplicate removal	Reduction of linguistic bias and expansion of Global South representation

Source: The authors themselves.

Adopting multilingual search procedures proved particularly important for reducing the overrepresentation of studies from the Global North and expanding the inclusion of research conducted in Latin American and African dryland contexts. Methodological studies on integrative reviews emphasize that linguistic restrictions may generate substantial biases in corpus composition, especially in research fields involving traditional knowledge systems and territorially embedded practices (Mendes et al., 2008; Souza et al., 2010).

Equally important was the need to reconcile broad bibliographic retrieval with rigorous thematic refinement. Research on Traditional Ecological Knowledge is characterized by significant conceptual dispersion, since multiple terminologies are often employed to describe closely related socioecological phenomena. Under these conditions, flexible Boolean structures become essential for minimizing the exclusion of potentially relevant studies while preserving the epistemological coherence of the final corpus. This methodological orientation contributed to maintaining alignment between the guiding question, eligibility criteria, and analytical objectives of the integrative review (Whittemore & Knafl, 2005; Torraco, 2016).

2.4 Inclusion and Exclusion Criteria

The eligibility criteria were defined before screening to ensure methodological consistency and reduce selection bias. In line with Whittemore and Knafl (2005), the criteria were designed to preserve both thematic relevance and analytical quality, while allowing the inclusion of empirical, theoretical, and review-based studies compatible with the integrative design.

The inclusion criteria were:

- Peer-reviewed articles published in indexed scientific journals;
- Empirical, theoretical, or review studies addressing TEK, indigenous knowledge, local ecological knowledge, vernacular knowledge, or equivalent knowledge systems;
- Studies explicitly related to climate adaptation, climate resilience, drought mitigation, climate governance, ecosystem management, or socioecological resilience;
- Research focused on semi-arid regions, drylands, arid zones, drought-prone territories, or comparable socioecological contexts;
- Articles written in English, Portuguese, or Spanish;
- Studies that discussed the interaction between local knowledge and modern scientific or institutional systems;
- Publications capable of contributing to the theoretical, empirical, or epistemological objectives of the review.

The exclusion criteria were:

- Editorials, opinion pieces, conference abstracts, book chapters, non-indexed reports, and grey literature;
- Studies without peer-review;
- Articles focused exclusively on engineering, infrastructure, or technological adaptation without interaction with local or traditional knowledge systems;
- Publications addressing indigenous or local knowledge without connection to climate adaptation, resilience, drought, environmental governance, or dryland management;
- Studies centered on urban climate adaptation with no relevance to semi-arid or dryland contexts;
- Duplicated records retrieved from more than one database;
- Articles with insufficient methodological or conceptual information for extraction and synthesis.

These criteria enabled the selection of studies aligned with the central objective of the review: to examine how the scientific literature validates TEK as a relevant adaptive system and how it discusses its integration with modern science in climate governance.

2.5 Data Extraction and Analytical Procedures

Data extraction was conducted through a structured analytical matrix designed to capture both descriptive and interpretive dimensions of each selected study. The extracted information included author and year, geographic region, type of knowledge system addressed, TEK-related practice, climate challenge examined, adaptation strategy, principal findings, methodological approach, and type of relationship proposed between TEK and scientific or institutional knowledge.

The analytical procedure combined thematic synthesis, comparative coding, and epistemological categorization. First, studies were read to identify recurrent themes related to water management, biodiversity conservation, agroecological practices, pastoral mobility, drought perception, local climate indicators, land-use change, and community-based governance. The second stage compared how different geographic contexts framed TEK as either empirical evidence, adaptive practice, cultural heritage, governance resource, or epistemological system. This comparative movement was essential to avoid treating TEK as a homogeneous category detached from territorial, political, and cultural conditions.

The third analytical stage focused on epistemological categorization. Studies were examined according to the way they positioned the relationship between TEK and modern science. Four interpretive categories were constructed: TEK as complementary data, TEK as locally validated adaptation practice, TEK as co-produced knowledge, and TEK as an autonomous epistemic system requiring symmetrical recognition. This classification allowed the review to move beyond descriptive mapping and identify the degree to which the literature challenges or reproduces hierarchical relations between scientific and vernacular knowledge.

Following Torraco (2016), the synthesis sought to generate conceptual advancement rather than merely aggregate findings. For this reason, the extracted evidence was organized into analytical axes capable of supporting the discussion section: scientific validation of TEK, epistemological barriers to integration, institutional limitations of technocratic adaptation, and pathways toward symmetrical climate governance. Whittemore and Knafl's (2005) methodological orientation informed the iterative process of data reduction, comparison, categorization, and synthesis, ensuring that the review remained systematic while retaining the interpretive depth required by the research problem.

To organize the analytical synthesis of the selected studies, a structured extraction matrix was developed to systematize the principal dimensions examined throughout the review. Beyond descriptive categorization, the matrix was designed to identify recurring adaptive patterns, epistemological approaches, and forms of interaction between Traditional Ecological Knowledge and scientific or institutional climate governance systems. This procedure enabled comparative interpretation across distinct geographical and socioecological contexts while preserving the thematic coherence of the review.

Table 2. Analytical Matrix of Included Studies

Author/Year	Geographic Context	TEK Practice or Knowledge System	Climate Challenge Addressed	Type of Integration with Science
Adaawen (2021)	West African savannah	Local drought perception and adaptive farming practices	Drought and climate variability	Community-based adaptation knowledge
Hosen et al. (2020)	Southeast Asia	Traditional ecological adaptation systems	Climate change impacts on rural livelihoods	Conceptual integration between TEK and adaptation science
Jellason et al. (2019)	Northwestern Nigerian drylands	Smallholder adaptation practices	Climate uncertainty and agricultural vulnerability	Local adaptation strategies linked to resilience debates
Mugi-Ngenga et al. (2021)	Semi-arid Kenya	Indigenous climate forecasting and farming practices	Rainfall variability and food insecurity	Hybrid indigenous-conventional climate knowledge
Li et al. (2022)	Global indigenous contexts	Traditional ecological adaptation systems	Climate adaptation and resilience	Recognition of TEK as adaptive governance
Sharifian et al. (2022)	Global pastoral systems	Pastoral ecological knowledge	Environmental instability and mobility pressures	Comparative synthesis of pastoral adaptation

Santos et al. (2023)	Brazilian semiarid region	Territorial coexistence strategies	Climate risk and socioecological vulnerability	Governance-oriented adaptation analysis
Emard et al. (2024)	Global ecological modeling contexts	Local ecological knowledge integration	Environmental modeling limitations	Integration between TEK and Earth system science
Chanza et al. (2024)	African contexts	Indigenous mitigation and adaptation practices	Climate governance asymmetries	Epistemological integration debates
Ciocco et al. (2024)	Climate adaptation planning systems	Indigenous participation in adaptation planning	Institutional exclusion	Participatory governance frameworks
Dorji et al. (2024)	Indigenous and rural territories	Traditional resilience practices	Climate vulnerability and adaptation	Scientific validation of indigenous knowledge
A, Siru et al. (2024)	Land-use change contexts	Traditional land management knowledge	Environmental degradation and land-use change	Integration with land-cover assessment systems
Chao et al. (2025)	Inner Mongolia, China	Adaptive persistence of TEK	Socioenvironmental transformation	Dynamic reinterpretation of TEK systems
Angelotti et al. (2025)	Brazilian semiarid region	Agricultural adaptation initiatives	Climate impacts on semiarid agriculture	Research-policy adaptation integration
Ngonyani et al. (2025)	Mara River Basin	Indigenous water management systems	Water scarcity and watershed management	Local governance and water resilience
Silva-Ávila et al. (2025)	Global adaptation governance	Knowledge alliances for adaptation	Global environmental change	Collaborative and integrative governance

Source: The authors themselves.

Organizing the studies through a comparative analytical matrix made it possible to identify recurring thematic convergences despite the geographical and methodological heterogeneity of the corpus. Water management, adaptive agriculture, biodiversity conservation, pastoral mobility, and local climate forecasting emerged as the most recurrent dimensions of Traditional Ecological Knowledge across semi-arid and dryland regions. Such recurrence suggests that TEK operates not as an isolated cultural phenomenon, but as a systematic form of environmental regulation and socioecological adaptation embedded within territorial practices and collective memory (Li et al., 2022; Sharifian et al., 2022).

Another important pattern concerns the growing movement toward epistemological integration between vernacular knowledge systems and scientific climate governance frameworks. While some studies still position TEK as complementary empirical information, more recent contributions increasingly recognize its analytical, predictive, and adaptive capacities within broader resilience debates (Emard et al., 2024; Silva-Ávila et al., 2025).

Simultaneously, the matrix also reveals persistent institutional asymmetries, since several studies emphasize that indigenous and local knowledge continues to face barriers related to bureaucratic centralization, technocratic planning, and unequal recognition within formal climate adaptation policies (Ciocco et al., 2024; Chanza et al., 2024).

3. RESULTS

3.1 Global Distribution of TEK and Climate Adaptation Studies

The selected literature reveals a marked geographical concentration of studies in regions historically exposed to climatic instability, prolonged droughts, and resource scarcity. African drylands emerged as the most recurrent spatial focus within the corpus, particularly the Sahel, West African savannahs, semi-arid Kenya, and Nigerian drylands. This predominance reflects both the acute socioecological vulnerability of these territories and the growing scientific interest in community-based adaptation systems capable of responding to intensifying climate stress. Jellason et al. (2022), in a systematic review of Sub-Saharan African drylands, identified a substantial expansion of research on smallholder adaptation after 2015, particularly studies examining indigenous farming practices, local climate forecasting, and knowledge integration mechanisms.

A similar pattern appears in studies conducted across semi-arid regions of Latin America, especially in the Brazilian semiarid region. Although quantitatively less represented than African drylands, Brazilian studies display a stronger emphasis on coexistence paradigms, territorial governance, and sustainable agricultural adaptation. Research developed by Angelotti et al. (2025) highlights the consolidation of climate-oriented agricultural initiatives in the Brazilian semiarid, especially those focused on drought-resilient production systems, water management technologies, and locally adapted farming practices. Rather than

framing drought exclusively as a climatic disaster, several Brazilian studies reinterpret semi-aridity as a permanent ecological condition requiring adaptive territorial strategies.

Asian drylands also occupy a relevant position within the corpus, particularly studies centered on pastoral systems, adaptive mobility, and land-use transformations in Inner Mongolia and other environmentally fragile territories. Chao et al. (2025) demonstrate that TEK systems in Inner Mongolia persist not through static cultural preservation, but through continuous adaptation to environmental and socioeconomic transformations. According to the authors, "traditional ecological knowledge remains dynamic through continuous negotiation with changing ecological realities" (Chao et al., 2025, p. 39). This finding reinforces the argument that TEK operates as a flexible adaptive system rather than as a residual cultural artifact.

At the global level, the distribution of scientific production reveals important asymmetries. Petzold et al. (2020), in their global evidence map, identified a growing concentration of publications addressing indigenous knowledge and climate adaptation during the last decade, although substantial geographical gaps persist across several dryland regions. The authors emphasize that "indigenous knowledge is increasingly recognized as an important source of adaptation strategies" (Petzold et al., 2020, p. 5). Nevertheless, the literature also demonstrates that recognition remains unevenly distributed within international climate governance structures, where scientific legitimacy continues to be disproportionately associated with Western technical frameworks.

3.2 Traditional Ecological Practices Identified in Drylands

Water Harvesting Systems

Water management emerged as one of the most recurrent dimensions of Traditional Ecological Knowledge across the reviewed studies. Community-based water harvesting systems, local watershed management practices, seasonal storage mechanisms, and traditional irrigation strategies were repeatedly identified as critical adaptive responses to climatic variability. Research conducted in the Mara River Basin demonstrated that indigenous water governance systems play an important role in maintaining ecological balance and regulating water access during periods of scarcity (Ngonyani et al., 2025). In many contexts, these practices combine ecological observation, collective regulation, and intergenerational transmission of environmental knowledge.

Traditional water management systems also challenge dominant assumptions that technological modernization necessarily produces superior adaptive outcomes. Several studies revealed that decentralized community practices often operate with lower ecological costs and greater territorial adaptability than externally imposed infrastructures. Such findings complicate the widespread technocratic narrative that frames resilience primarily through engineering-intensive interventions.

Agro-Silvopastoral Management

Another recurrent adaptive strategy involves agro-silvopastoral systems developed through long-term interactions between human communities and dryland ecosystems. These practices integrate crop diversification, livestock mobility, vegetation management, and soil conservation techniques to reduce exposure to climatic instability. Okoronkwo et al. (2024) argue that many traditional agricultural systems in Sub-Saharan Africa already incorporate principles currently associated with climate-smart agriculture, despite rarely receiving equivalent institutional recognition.

Adaptive pastoralism appeared particularly relevant in regions characterized by rainfall unpredictability and ecological variability. Livestock mobility, rotational grazing, and flexible land-use arrangements were frequently described as mechanisms capable of minimizing environmental degradation while preserving productive resilience. Such strategies contrast sharply with rigid sedentary agricultural models often promoted through centralized adaptation policies.

Biodiversity Conservation

The literature also demonstrates strong connections between TEK and biodiversity conservation. Traditional ecological systems frequently operate through detailed environmental classifications, species-specific knowledge, and sustainable extraction practices capable of maintaining ecosystem functionality under conditions of climatic stress. Sinthumule (2023) argues that traditional ecological knowledge "plays a critical role in biodiversity conservation and sustainable natural resource management" (p. 4). This relationship becomes especially significant in semi-arid ecosystems, where biodiversity stability directly influences food security, water retention, and ecological resilience.

Far from representing merely cultural heritage, biodiversity-related TEK functions as an operational environmental management system. In several studies, local ecological practices were associated with improved vegetation recovery, soil preservation, and ecosystem regulation, suggesting that traditional management systems may contribute directly to climate adaptation and sustainability objectives.

Climatic Bioindicators

Multiple studies identified the use of climatic bioindicators as a sophisticated mechanism of local environmental forecasting. Communities frequently interpret changes in animal behavior, vegetation cycles, wind patterns, cloud formation, and seasonal ecological signals to anticipate rainfall variability and climatic disturbances. Research in semi-arid Kenya demonstrated that indigenous forecasting systems continue to guide agricultural decision-making even in contexts where scientific meteorological services are available (Mugi-Ngenga et al., 2021).

Rather than operating in opposition to scientific forecasting, these local systems often coexist with formal climate information, generating hybrid adaptive strategies. This coexistence reveals the practical capacity of communities to combine distinct epistemological frameworks according to environmental uncertainty and territorial experience.

Mobility and Adaptive Livelihoods

Adaptive mobility emerged as another central dimension within dryland resilience systems. Tebboth et al. (2023) demonstrate that mobility practices in environmentally vulnerable territories cannot be reduced to simple migration responses, since they frequently represent historically consolidated livelihood strategies linked to climate adaptation and resource management. Seasonal displacement, diversified territorial occupation, and flexible livelihood arrangements function as mechanisms capable of redistributing environmental risk across landscapes characterized by ecological instability.

Importantly, several studies challenge the dominant policy tendency to interpret mobility primarily as evidence of vulnerability or developmental failure. In many dryland contexts, mobility constitutes an adaptive rationality embedded within traditional ecological systems and closely associated with resilience, social networks, and territorial governance.

3.3 Scientific Validation of TEK-Based Adaptation

One of the most significant findings emerging from the reviewed literature concerns the growing scientific validation of Traditional Ecological Knowledge as an effective adaptive system in semi-arid and dryland environments. Across multiple studies, TEK-based practices were associated with improved ecological resilience, efficient resource management, biodiversity conservation, and adaptive flexibility under conditions of climatic uncertainty.

Dorji et al. (2024) demonstrate that indigenous knowledge systems contribute substantially to climate adaptation through locally embedded strategies capable of responding to environmental variability in real time. Their findings indicate that communities using traditional adaptive practices frequently display higher resilience in relation to water scarcity, agricultural instability, and ecosystem degradation. Such evidence directly challenges narratives that portray local knowledge as technically inferior or environmentally obsolete.

Recent studies integrating ecological modeling and local knowledge systems further reinforce this validation process. Emard et al. (2024) argue that local ecological knowledge can substantially improve Earth system modeling by incorporating fine-scale environmental observations often absent from large-scale scientific datasets. According to the authors, “local ecological knowledge provides contextual information unavailable through conventional Earth system monitoring alone” (Emard et al., 2024, p. 43). This recognition represents an important epistemological shift, since TEK ceases to be treated merely as anecdotal information and becomes recognized as analytically relevant environmental knowledge.

Similarly, Rehman et al. (2025) demonstrated that combining remote sensing technologies with traditional ecological practices improves assessments of vegetation dynamics and land-use changes in semi-arid environments. Their results indicate that hybrid analytical frameworks produce more territorially accurate interpretations of ecological transformations than purely technocentric approaches. Parallel findings were reported by A, Siru et al. (2024), whose study showed that integrating traditional land management knowledge into land-use assessments improves the identification of localized environmental degradation patterns.

The ecological efficiency of TEK-based systems also appears strongly associated with ecosystem sustainability. Khosravi Mashizi (2025) found significant relationships between traditional ecological practices, ecosystem quality, and the maintenance of ecosystem services. Instead of maximizing short-term productivity through intensive environmental exploitation, many traditional systems prioritize ecological balance, adaptive continuity, and long-term territorial sustainability. Such dynamics become especially relevant under intensifying climate stress, where rigid production systems frequently exhibit lower adaptive flexibility.

3.4 Emerging Models of Knowledge Integration

The reviewed literature reveals an increasing movement toward models of climate governance based on knowledge integration rather than epistemological substitution. Instead of framing Traditional Ecological Knowledge and modern science as incompatible systems, several studies propose collaborative arrangements capable of combining territorial experience, scientific monitoring, institutional planning, and community participation.

Silva-Ávila et al. (2025) conceptualize these processes as “knowledge alliances” oriented toward global environmental adaptation. Their analysis suggests that sustainable adaptation strategies depend less on the unilateral transfer of scientific expertise and more on the construction of horizontal collaborative networks among communities, researchers, and institutions. Such approaches seek to replace extractive knowledge relations with participatory forms of co-production.

Participatory adaptation planning also emerged as a recurrent theme. Ciocco et al. (2024) demonstrate that climate adaptation policies become substantially more effective when indigenous and local communities participate directly in planning processes rather than being incorporated merely as consultative actors. This distinction is particularly important because many institutional adaptation frameworks continue to preserve centralized decision-making structures even while formally acknowledging community participation.

Research on public land management in the United States similarly indicates the growing institutional recognition of TEK within environmental governance systems. Souther et al. (2023) argue that integrating traditional ecological knowledge into public

management frameworks can improve ecological restoration, biodiversity conservation, and adaptive governance capacities. Nevertheless, the literature also emphasizes that meaningful integration remains constrained by bureaucratic rigidity, institutional asymmetries, and unequal epistemological recognition.

Although recent advances point toward more collaborative governance models, substantial tensions remain unresolved. Chanza et al. (2024) observe that many integration initiatives still operate through hierarchical scientific structures in which indigenous knowledge is selectively incorporated without challenging dominant epistemological frameworks. Consequently, the debate surrounding climate adaptation increasingly involves not only technical effectiveness, but also disputes over legitimacy, authority, and the politics of knowledge production within the Anthropocene.

4. DISCUSSION

4.1 Beyond Folklorization: TEK as Adaptive Climate Technology

A substantial portion of the reviewed literature challenges the persistent tendency to frame Traditional Ecological Knowledge as a static cultural remnant detached from contemporary climate governance. Such reductionist interpretations frequently confine TEK to symbolic heritage or localized empirical experience, preventing its recognition as a sophisticated adaptive system capable of generating environmental regulation, territorial resilience, and long-term socioecological learning. This epistemological reduction is particularly problematic in drylands, where climatic instability historically demanded flexible and cumulative adaptive mechanisms.

Rather than functioning as a repository of immutable traditions, TEK operates through continuous interaction between environmental observation, collective memory, and adaptive experimentation. Hosen et al. (2020) argue that traditional ecological systems “hold the key” to climate adaptation precisely because they emerge from prolonged engagement with local ecological dynamics. Their findings indicate that adaptive effectiveness in vulnerable territories often depends less on technological complexity than on the capacity to interpret environmental variability through territorially embedded knowledge systems.

An equally relevant dimension concerns the role of TEK as ecological infrastructure. Unlike conventional infrastructures dependent on centralized investments and external maintenance, vernacular adaptive systems are distributed across social relations, territorial practices, and intergenerational learning processes.

Li et al. (2022) emphasize that indigenous communities rely on TEK not merely for cultural continuity, but for practical adaptation to changing climatic conditions. According to the authors, TEK “supports adaptation strategies deeply rooted in local ecological understanding” (Li et al., 2022, p. 31). This observation reinforces the argument that ecological resilience in semi-arid regions is inseparable from historically accumulated environmental knowledge.

Pastoral systems provide particularly illustrative examples of this adaptive complexity. Sharifian et al. (2022) demonstrate that pastoral ecological knowledge is characterized by high levels of flexibility, mobility, and environmental responsiveness, enabling communities to reorganize grazing practices according to climatic fluctuations. Such adaptive rationalities directly contrast with rigid territorial management models frequently promoted through technocratic climate policies. Consequently, resilience in drylands appears strongly associated with adaptive diversity rather than with standardized technological control.

Research conducted in Inner Mongolia further destabilizes linear narratives that portray modernization and traditional knowledge as mutually exclusive processes. Chao et al. (2025) found that TEK systems persist through constant reinterpretation and environmental negotiation. Instead of disappearing under conditions of socioeconomic transformation, local ecological knowledge frequently incorporates new information while preserving adaptive continuity. This dynamic character contradicts assumptions that traditional systems are inherently incompatible with scientific modernization.

Scientific evidence compiled by Dorji et al. (2024) also indicates that communities employing traditional adaptive practices often display greater resilience under climatic stress conditions. Their findings suggest that TEK contributes simultaneously to water management, biodiversity conservation, food security, and risk reduction. Such multidimensional functionality exposes the conceptual limitations of adaptation frameworks narrowly centered on technological interventions or infrastructure expansion.

4.2 Scientific Legitimacy and the Validation of Vernacular Systems

One of the most significant transformations identified in the literature concerns the growing scientific recognition of vernacular ecological systems as valid forms of environmental knowledge. Historically marginalized within dominant scientific institutions, TEK is increasingly being incorporated into climate adaptation research, ecological monitoring, and sustainability assessments. This movement signals not merely empirical acknowledgment, but a broader epistemological shift regarding the legitimacy of localized environmental intelligence.

Hydrological management constitutes one of the clearest examples of this validation process. Indigenous water governance systems documented in the Mara River Basin demonstrate high adaptive efficiency under conditions of recurrent water scarcity and environmental instability (Ngonyani et al., 2025). Local practices involving seasonal regulation, watershed observation, and community allocation mechanisms frequently operate with lower ecological degradation and greater territorial responsiveness than externally imposed hydraulic infrastructures. Such findings challenge the assumption that adaptive efficiency necessarily depends on large-scale technological modernization.

Parallel evidence emerges in studies examining land-use dynamics and ecosystem regulation. Rehman et al. (2025) demonstrated that combining remote sensing technologies with traditional ecological practices improves the interpretation of vegetation changes and ecological degradation patterns in semi-arid environments. Importantly, the study suggests that scientific monitoring systems become more territorially accurate when informed by local environmental observation. Similar conclusions were reported by A, Siru et al. (2024), who found that integrating traditional land management knowledge into land-use assessments enhances the identification of socioecological transformations frequently overlooked by standardized analytical models.

Environmental resilience also appears strongly associated with the ecological rationality embedded within traditional management systems. Khosravi Mashizi (2025) identified significant correlations between ecosystem quality and the presence of TEK-informed environmental practices. Rather than maximizing short-term extraction, many traditional systems prioritize ecological continuity, adaptive equilibrium, and long-term sustainability. Under intensifying climate stress, these characteristics become particularly relevant because rigid production systems often exhibit lower adaptive flexibility and higher ecological vulnerability.

Another critical dimension concerns the compatibility between TEK and Earth system sciences. Emard et al. (2024) argue that local ecological knowledge contributes fine-scale environmental information unavailable through conventional monitoring systems alone. As the authors observe, "local ecological knowledge can complement Earth system models with contextualized observations" (Emard et al., 2024, p. 43). This recognition destabilizes long-standing scientific hierarchies in which local knowledge was treated merely as anecdotal or supplementary information. Instead, TEK increasingly appears as a relevant epistemological partner in the production of climate knowledge.

Despite these advances, the literature also indicates that scientific validation often occurs within asymmetric institutional conditions. In many cases, vernacular knowledge becomes accepted only after being translated into technical-scientific categories recognized by dominant research institutions. Consequently, recognition remains partially conditioned by scientific authority itself, raising important questions about who defines epistemological legitimacy within climate governance systems.

4.3 Epistemological Barriers and the Coloniality of Climate Governance

Although international climate agendas increasingly acknowledge indigenous and local knowledge systems, substantial epistemological barriers continue to structure environmental governance. Far from representing isolated institutional failures, these barriers reflect enduring colonial dynamics within global climate governance, where scientific legitimacy remains concentrated in technocratic institutions and centralized policy frameworks.

Research conducted across African adaptation contexts demonstrates that indigenous knowledge frequently occupies peripheral positions within formal decision-making structures despite its demonstrated adaptive effectiveness (Leal Filho et al., 2025). Institutional obstacles identified in the literature include bureaucratic centralization, lack of participatory governance mechanisms, insufficient legal recognition, and persistent distrust toward community-based expertise. These asymmetries reveal that the exclusion of TEK is not primarily technical, but political and epistemological.

Environmental governance systems grounded in technocratic rationality tend to privilege standardized interventions, quantitative indicators, and externally generated expertise. Under such conditions, local ecological systems are frequently incorporated only as complementary data sources rather than recognized as autonomous knowledge frameworks. Ciocco et al. (2024) emphasize that indigenous participation in climate adaptation planning often remains symbolic, with limited influence over strategic decisions. Consequently, participatory discourse may coexist with deeply hierarchical governance arrangements.

An important contradiction emerges at this point. While climate adaptation policies increasingly advocate resilience and local participation, many institutional frameworks continue reproducing centralized models historically associated with developmentalist environmental management. Chanza et al. (2024) argue that climate governance frequently incorporates indigenous knowledge through subordinate integration mechanisms that preserve scientific dominance. According to the authors, meaningful integration requires confronting "power asymmetries embedded in knowledge production systems" (Chanza et al., 2024, p. 7).

Similar tensions are visible in rural drylands where communities often maintain adaptive systems developed through generations of environmental interaction, yet remain marginalized within formal adaptation policies. Evidence from West African savannah regions indicates that local perceptions of climatic risk frequently differ from institutional climate narratives, particularly regarding drought interpretation, environmental priorities, and adaptive responses (Adaawen, 2021). This divergence suggests that climate governance failures may derive not only from insufficient resources, but from epistemological disconnection between institutional planning and territorial experience.

The Brazilian semiarid offers another illustrative example of these asymmetries. Santos et al. (2023) demonstrate that climate risks in the region remain strongly associated with centralized drought-management paradigms that prioritize emergency interventions over structural coexistence strategies. Such approaches reinforce institutional dependency while neglecting historically consolidated community-based adaptive capacities. Within this context, environmental injustice becomes inseparable from epistemological injustice, since the invisibilization of local knowledge simultaneously weakens territorial resilience and

reproduces unequal power relations.

4.4 From Technological Solutionism to Epistemic Co-Creation

Growing dissatisfaction with technocentric adaptation models has stimulated the emergence of alternative frameworks centered on epistemic plurality, collaborative governance, and participatory adaptation. Instead of treating climate adaptation as a process exclusively dependent on technological transfer or centralized expertise, recent studies increasingly advocate forms of co-creation capable of integrating scientific systems and local ecological knowledge on more symmetrical terms.

Limitations of technological solutionism become particularly evident in semi-arid regions where environmental variability exceeds the predictive capacity of rigid planning models. Large-scale infrastructures and externally designed adaptation policies frequently fail to respond to localized ecological dynamics, especially when disconnected from territorial knowledge systems accumulated over generations.

Mbah et al. (2021), in their systematic review of indigenous knowledge deployment, observed that community-based adaptive practices often demonstrate greater contextual responsiveness than externally imposed interventions. The authors further emphasize that indigenous systems provide "locally grounded adaptive capacities" essential for long-term climate resilience (Mbah et al., 2021, p. 11).

Evidence from Sub-Saharan African drylands reinforces this argument. Jellason et al. (2022) identified that successful adaptation strategies among smallholder farmers depend strongly on enabling conditions for knowledge integration, including institutional flexibility, participatory governance, and recognition of local expertise. Adaptation effectiveness, therefore, appears closely related to the capacity of governance systems to accommodate epistemological diversity rather than impose singular technical frameworks.

Hybrid knowledge systems emerge in the literature as one of the most promising pathways for climate governance transformation. Research conducted in semi-arid Kenya demonstrates that farmers frequently combine indigenous forecasting systems with scientific meteorological information to guide agricultural decisions under conditions of climatic uncertainty (Mugi-Ngenga et al., 2021). Such coexistence does not imply epistemological homogenization. Instead, it reveals the practical possibility of adaptive complementarities between distinct knowledge systems.

Another important shift involves the transition from consultative participation toward co-governance arrangements. Silva-Ávila et al. (2025) conceptualize these processes as "knowledge alliances" capable of fostering collaborative adaptation strategies across scales and institutions. In this perspective, climate governance ceases to operate through unilateral dissemination of scientific expertise and becomes structured around reciprocal learning, shared authority, and distributed environmental intelligence.

Institutional experiences in public land management also indicate that collaborative governance frameworks may improve ecological restoration and adaptive planning capacities. Souther et al. (2023) found that integrating traditional ecological knowledge into public environmental management strengthens ecosystem monitoring, biodiversity conservation, and territorial legitimacy. Nevertheless, the literature repeatedly warns that genuine epistemic co-creation requires structural transformations within scientific institutions themselves. Without confronting institutional hierarchies and colonial patterns of expertise, knowledge integration risks remaining symbolic rather than transformative.

4.5 Toward an Integrative Climate Governance Framework

Findings from the reviewed literature suggest that contemporary climate adaptation challenges cannot be adequately addressed through technocratic governance alone. Increasing climatic instability, ecological uncertainty, and socioenvironmental inequality demand governance models capable of incorporating multiple forms of environmental intelligence, territorial experience, and adaptive rationality. Under these conditions, the literature points toward the need for a more integrative framework grounded in epistemic plurality and collaborative adaptation.

The proposed "Symmetrical Climate Governance Framework" emerges from this analytical synthesis. Rather than positioning Traditional Ecological Knowledge as subordinate to scientific expertise, the framework conceptualizes climate governance as a process of adaptive co-production involving scientific institutions, local communities, territorial organizations, and environmental governance systems. Its central premise lies in the recognition that resilience in drylands depends not only on technological innovation, but also on the capacity to mobilize cumulative ecological memory, participatory governance, and locally embedded adaptive systems.

Epistemic plurality constitutes the first dimension of the framework. Petzold et al. (2020) demonstrated that indigenous knowledge systems already contribute significantly to climate adaptation across multiple global contexts, although their institutional recognition remains uneven. Building on this evidence, the proposed framework argues that climate governance should move beyond extractive incorporation of local knowledge toward symmetrical recognition of distinct epistemological systems.

Community participation represents a second structural dimension. Evidence synthesized by Souther et al. (2023) and Silva-Ávila et al. (2025) indicates that participatory governance arrangements strengthen adaptive legitimacy, ecological monitoring,

and institutional responsiveness. Participation, however, cannot remain restricted to consultative mechanisms. Effective co-governance requires shared authority over planning, implementation, and environmental decision-making processes.

Ecological resilience and territorial governance form another central axis of the framework. Research integrating TEK with Earth system sciences demonstrates that local ecological observations provide critical fine-scale environmental information frequently absent from centralized monitoring systems (Emard et al., 2024). Simultaneously, territorial adaptive practices developed in drylands reveal high levels of environmental flexibility under climatic stress conditions. Combining these capacities may substantially improve adaptation planning across vulnerable regions.

A final dimension concerns adaptive co-production. Institutional barriers identified throughout the literature suggest that meaningful integration remains constrained by bureaucratic rigidity, scientific hierarchies, and colonial governance structures (Leal Filho et al., 2025). Consequently, the proposed framework emphasizes reciprocal learning processes rather than unilateral transfer of expertise. Climate adaptation, in this sense, becomes simultaneously a technical, political, ecological, and epistemological process.

To synthesize the analytical findings of this review, a conceptual framework termed the "Symmetrical Climate Governance Framework" was developed. The framework systematizes the principal dimensions identified throughout the literature regarding the integration of Traditional Ecological Knowledge and scientific climate governance systems. Rather than proposing a rigid institutional model, the framework seeks to organize the adaptive, epistemological, and governance principles recurrently associated with more resilient and territorially responsive climate adaptation strategies in drylands and semi-arid regions.

Table 3. Dimensions of the Symmetrical Climate Governance Framework

Governance Dimension	TEK Contribution	Scientific Contribution	Expected Adaptation Outcomes	Governance Implications
Epistemic Plurality	Local ecological observation, cumulative environmental memory, culturally embedded adaptation systems	Climate modeling, environmental monitoring, technical assessment tools	Broader adaptive intelligence and contextualized decision-making	Recognition of multiple knowledge systems within climate governance
Community Participation	Collective territorial management, intergenerational transmission of adaptive practices	Institutional planning support and participatory methodologies	Increased legitimacy and socially grounded adaptation policies	Shared decision-making and participatory governance mechanisms
Ecological Resilience	Biodiversity management, adaptive mobility, sustainable resource regulation	Ecosystem assessment, resilience indicators, environmental risk analysis	Enhanced ecosystem stability and adaptive flexibility under climate stress	Long-term sustainability-oriented governance
Territorial Governance	Place-based adaptation strategies and localized environmental regulation	Spatial analysis, land-use planning, integrated governance frameworks	Improved alignment between policy and territorial realities	Decentralized and context-sensitive climate governance
Adaptive Co-Production	Dynamic reinterpretation of traditional practices and local adaptive experimentation	Scientific innovation and interdisciplinary integration	Hybrid adaptation systems combining scientific and vernacular knowledge	Horizontal collaboration between institutions and communities

Source: The authors themselves.

A central contribution of this framework lies in shifting the analytical focus from technological adaptation alone toward the governance conditions that enable adaptive plurality. Findings from the reviewed literature consistently indicate that resilience in semi-arid regions emerges through the interaction between ecological knowledge, territorial experience, institutional flexibility, and collaborative decision-making rather than through isolated technological interventions. In this sense, adaptation capacity becomes inseparable from epistemological inclusion and political participation (Petzold et al., 2020; Silva-Ávila et al., 2025).

Equally important, the framework highlights that meaningful integration between TEK and scientific systems cannot be

reduced to the extraction of local empirical information for institutional use. Several studies emphasize that asymmetrical governance arrangements frequently reproduce colonial dynamics in which scientific institutions retain epistemological authority while community knowledge remains subordinated or selectively incorporated (Leal Filho et al., 2025; Souther et al., 2023).

By contrast, adaptive co-production implies reciprocal learning processes capable of transforming both governance institutions and climate adaptation paradigms themselves. Evidence from Earth system science integration studies further suggests that combining local ecological observations with scientific monitoring may improve adaptive planning accuracy, especially in environmentally unstable dryland contexts (Emard et al., 2024).

Taken together, the findings discussed throughout this review demonstrate that the climate crisis in semi-arid regions cannot be adequately understood as a merely technical or infrastructural challenge. What emerges from the literature is a broader dispute over epistemological legitimacy, adaptive authority, and the political organization of climate governance itself. Traditional Ecological Knowledge repeatedly appears not as a residual cultural element, but as a territorially embedded adaptive system capable of generating ecological regulation, resilience, and long-term environmental learning under conditions of climatic uncertainty.

Simultaneously, the persistence of technocratic and centralized adaptation models reveals how colonial patterns of governance continue to shape which forms of knowledge are considered scientifically valid and politically actionable. Under these conditions, the debate surrounding climate adaptation increasingly transcends questions of technological efficiency and enters the terrain of epistemic justice, participatory governance, and plural environmental rationalities.

The transition from extractive incorporation of local knowledge toward genuinely symmetrical co-production frameworks therefore represents not only an institutional adjustment, but a structural reconfiguration of how climate governance is conceived in the Anthropocene.

5. CONCLUSION

The evidence synthesized throughout this integrative review demonstrates that Traditional Ecological Knowledge constitutes far more than a cultural inheritance preserved within vulnerable territories. Across different dryland contexts, TEK emerged as a scientifically valid adaptive infrastructure capable of supporting ecological resilience, environmental regulation, resource management, and community-based responses to climatic uncertainty. Simultaneously, the literature consistently revealed the limitations of centralized and technocratic adaptation models that frequently marginalize territorially embedded forms of environmental intelligence. Under these conditions, climate adaptation in semi-arid regions increasingly depends on the recognition of epistemic plurality as a structural dimension of governance rather than as a symbolic or consultative addition.

Another important contribution of this study lies in reframing resilience beyond purely technological or infrastructural paradigms. The findings indicate that adaptive capacity in drylands is inseparable from collective memory, local ecological learning, participatory governance, and historically accumulated territorial practices. From this perspective, decolonial approaches to climate adaptation become essential not only for reasons of social justice, but also for improving the effectiveness, legitimacy, and sustainability of climate governance itself. Integrative governance frameworks capable of combining scientific systems and vernacular knowledge may therefore offer more context-sensitive responses to the escalating environmental uncertainties of the Anthropocene.

Policy implications emerging from the review point toward the necessity of incorporating Traditional Ecological Knowledge into climate planning through participatory and co-governance arrangements rather than extractive or subordinate integration mechanisms. Adaptation policies designed for drylands should prioritize community-centered resilience strategies, decentralized environmental governance, and institutional structures capable of recognizing local expertise as an active component of climate decision-making. Such transformations also carry implications for global climate institutions, particularly regarding the need to move beyond universalized adaptation frameworks toward more plural and territorially responsive governance models.

Despite its contributions, this study presents limitations inherent to integrative literature reviews, including dependence on indexed publications and the interpretive nature of thematic synthesis. In addition, important regional experiences may remain underrepresented due to linguistic, institutional, or publication asymmetries.

Future research would benefit from comparative empirical investigations examining how hybrid governance systems operate in practice across different semi-arid regions. Expanding the dialogue between climate science, political ecology, and plural epistemologies may also contribute to the development of more equitable and adaptive climate governance frameworks in an increasingly unstable planetary context.

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