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Research

Bridging Epistemologies: A University-Led Co-Designed Framework Integrating Indigenous Knowledge and Atmospheric Science for Environmental Sustainability in Nigeria

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Highlights

- A capacity-building initiative at AFUED bridged Indigenous Knowledge (IK) and atmospheric science through curricula and community engagement.
- Students' ability to design interdisciplinary solutions rose by 43.6%; faculty confidence in IK integration increased by 94%.
- Environmental impact included an 18.7% drop in $PM_{2.5}$ and 23% reduced deforestation in project areas.
- Findings influenced Nigeria's 2027 Climate Policy and protected 48 Indigenous practices via Traditional Knowledge Labels.

Abstract

Environmental sustainability initiatives in Nigeria are limited by an epistemological divide between Indigenous Knowledge (IK) systems and Atmospheric Science. This study developed, implemented, and validated a university-based capacity-building framework—encompassing curricular and community engagement elements—at Adeyemi Federal University of Education (AFUED) to bridge this gap. Using a 12-month transformative mixed-methods approach, the project engaged 48 IK holders, 32 faculty, 217 students, and 12 policy stakeholders. Key interventions included co-creating five interdisciplinary courses embedding cultural frameworks (e.g., Yoruba awọsanma cloud classification) into science curricula and community projects integrating traditional practices with modern technologies. Results demonstrated transformative outcomes: Educational impact included a 43.6% increase ($p<0.001$) in students' capacity to design interdisciplinary environmental solutions and a 94% rise in faculty confidence in IK integration. Environmental efficacy was demonstrated through two key outcomes: an 18.7% $PM_{2.5}$ reduction ($p<0.01$) in Ikare-Akoko—achieved by aligning traditional burning bans with atmospheric inversion periods—and a 23% decrease in deforestation rates within agroforestry corridors, which preserved 29% more endemic species than conventional reserves. IK validation showed strong statistical correlations with instrumental data (e.g., $\rho=0.85$ between ant colony behavior and rainfall predictability). Policy impacts included integrating evidence into Nigeria's 2027 National Climate Change Policy, mandating IK inclusion in adaptation planning. Traditional Knowledge Labels preserved cultural sovereignty over 48 practices. The study establishes that deliberate IK-science integration enhances pedagogy, generates ecological co-benefits, and advances epistemic justice. The framework provides a replicable model for achieving SDGs 4 (Education), 13 (Climate Action), and 15 (Life on Land) in the Global South.

Keywords: Indigenous Knowledge, Atmospheric Science, Environmental Sustainability, Decolonial Pedagogy, Policy Integration, Nigeria, SDGs.

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1.0 Introduction

Environmental sustainability represents an urgent global imperative, with developing nations like Nigeria facing disproportionate impacts from escalating ecological crises. The country experiences a 3.5% annual deforestation rate (FAO, 2023), while urban centres such as Lagos and Onitsha record $PM_{2.5}$ concentrations reaching 30 μg/m³—six times the WHO safety threshold (5 μg/m³ annual mean**) (**WHO, 2023). Climate vulnerability is particularly acute given that 65% of Nigeria's population depends on climate-sensitive agriculture (World Bank, 2022). Despite this pressing context, environmental management strategies remain critically constrained by the systematic exclusion of Indigenous Knowledge (IK) systems from scientific and educational frameworks. This epistemic marginalization persists despite robust evidence demonstrating that IK integration significantly enhances environmental outcomes. For instance, Hausa farmers' *duba* (cloud observation) techniques predict rainfall onset with 82% accuracy compared to 68% for conventional regional models alone (Adejuwon et al., 2021), while Yoruba sacred groves (*igbo imale*) harbor 30% greater endemic species richness than government-protected reserves (Ogunnowo et al., 2022). Further empirical validation comes from documented 22% reductions in respiratory hospitalizations in Bauchi communities following the implementation of IK-guided burning schedules (National Climate Change Council [NCCC], 2023).

Within Nigerian higher education, a 2022 audit of 17 universities revealed profound institutional gaps: 89% of Atmospheric Science courses lack IK modules (Ogunyemi et al., 2022), fewer than 5% of environmental studies co-design research with IK holders (Balogun, 2023), and top-down sustainability interventions achieve only 34% community compliance compared to 89% for IK-co-developed initiatives (Nigerian Environmental Study Team [NEST], 2022). This pedagogical and research disconnect perpetuates intellectual land dispossession (Simpson, 2021), directly undermining progress toward critical Sustainable Development Goals. Excluding IK creates demonstrable gaps across sectors: climate models underestimate West African monsoon variability by 40% (IPCC, 2022); satellite monitoring misses 29% of small-scale deforestation detected by IK systems (Akinsanola et al., 2023); and 78% of graduates cannot articulate IK's scientific relevance (UNESCO, 2023). These failures highlight an urgent need for knowledge systems integration to achieve SDG 4 (Quality Education), SDG 13 (Climate Action), and SDG 15 (Life on Land).

To address these gaps, this study develops and implements a transformative university-based framework that integrates Yoruba, Igbo, and Hausa IK systems with Atmospheric Science. The six primary objectives are to: (1) document and codify 48+ IK practices using Traditional Knowledge Labels to protect cultural intellectual property; (2) co-design an interdisciplinary curriculum fusing numerical weather prediction with Yoruba *awọsanma* cloud classification; (3) train faculty in *Two-Eyed Seeing* pedagogy through 12 participatory workshops; (4) implement community projects measuring $PM_{2.5}$ reductions via IK-calibrated sensor networks; (5) evaluate impacts on student competence, ecological resilience, and policy reform through mixed-methods assessment; and (6) advocate for IK inclusion in Nigeria's Climate Act (2027 Draft). The framework advances Kimmerer's (2020) 'braided knowledge' paradigm—integrating Indigenous and scientific ways of knowing—by empirically demonstrating synergies (e.g., 18.7% greater pollution reduction than science-only approaches) while institutionalizing justice through benefit-sharing mechanisms that allocate 20% of research funds to community-led sustainability initiatives. By directly informing Nigeria's revised climate policy—mandating IK integration across all 36 states—this initiative establishes a replicable model for decolonizing environmental governance in the Global South.

2.0 Research Methodology

This study employed a transformative mixed-methods paradigm (Mertens, 2017), integrating participatory action research (PAR) with quasi-experimental components to bridge Indigenous Knowledge (IK) systems and Atmospheric Science. Grounded in decolonial theory (Smith, 2012), the 6-month intervention (January 2025– June 2025) prioritized epistemic justice by positioning IK holders as co-researchers. The sequential design unfolded across three phases: an initial exploratory phase (Months 1–2) focused on qualitative IK documentation; an intervention phase (Months 3–4) for curriculum co-development and community projects; and an impact assessment phase (Months 5–6) evaluating environmental and educational outcomes.

2.1 Study Site and Participants

The research was anchored at Adeyemi Federal University of Education (AFUED) in Ondo State, Nigeria (7°15′N, 5°12′E), extending to six agrarian communities (*Ikare-Akoko, Owo, Ondo City, Akure, Idanre, Ore*). Participants were strategically sampled across four stakeholder groups (Table 1)**:**

Table 1: Participant Sampling Framework

Group	**Sampling Method**	**Size**	**Justification**
IK Holders	Purposive + Snowball	48	Elders/farmers with ≥30 years local expertise
Faculty	Stratified random	32	Representatives from Environmental Science, Atmospheric Physics, and Social Sciences
Students	Cluster sampling	217	Enrolled in Environmental Science courses
Policy Stakeholders	Expert sampling	12	National Climate Change Council (NCCC) Staff

2.2 Data Collection Procedures

The study employed triangulated methodologies to capture multidimensional data across Indigenous Knowledge (IK) systems, Atmospheric Science, and educational impacts, ensuring both epistemological diversity and empirical rigor. Indigenous knowledge documentation utilized four complementary approaches to honor the oral, experiential, and contextual nature of traditional wisdom. Semi-structured interviews formed the cornerstone, with 45 sessions (60–90 minutes each) conducted with elders and farmers using culturally responsive prompts such as *"Walk me through how your community validates drought predictions from animal behavior signs."* These were augmented by 15 Focus Group Discussions (FGDs) with 6–8 participants per session, facilitating intergenerational knowledge exchange on environmental stewardship. To capture non-codified practices, 120 hours of participant observation documented rituals like the *Oro festival* rainmaking ceremonies, noting subtle cues in material use, timing, and ecological interactions. Finally, seasonal calendars and resource mapping exercises (Bernard, 2017) translated temporal and spatial IK into visual frameworks, enabling comparative analysis with scientific data.

Atmospheric Science monitoring deployed precision instruments to quantify environmental variables, with specifications calibrated for Nigeria's tropical conditions (Table 2):

Table 2: Atmospheric Data Collection Specifications

Parameter	Instrument	Specifications	Frequency
$PM_{2.5}/PM_{10}$	Atmotube PRO sensors	0.3–10 µm detection; IoT-enabled	15-min intervals
NO_x, SO_2, CO_2	Aeroqual Series 500 monitors	±5% accuracy; GPS-tagged	Hourly
Meteorological Data	Davis Vantage Pro2 stations	Wind, temp, humidity, rain	5-min intervals
Land Use Change	Sentinel-2 satellite imagery	10m spatial resolution	Bi-monthly

Sensors were strategically placed across 8 community sites to capture microclimatic variations, with real-time data streams validated against IK observations (e.g., correlating Harmattan dust events with Yoruba *èfúùfù* predictions).

Educational impact assessment combined psychometric and performance-based measures:

- Pre/post-intervention surveys employed validated 5-point Likert scales (Cronbach's α = 0.89) to quantify shifts in students' ability to synthesize satellite rainfall data with Igbo cloud proverbs*."*
- Scenario-based skill evaluations tested applied competence through simulations like *"Design an erosion control plan using GIS and Hausa terrace-farming knowledge."*

This integrated approach enabled cross-validation between knowledge systems—e.g., comparing FGD narratives on smoke dispersion with CALPUFF aerosol models—while centering ethical rigor through IK holder-led data interpretation sessions.

2.3 Intervention Framework

The intervention was structured around two synergistic pillars designed to operationalize knowledge integration at both institutional and community levels. The curriculum co-development pillar initiated with a rigorous gap analysis of 17 existing environmental science courses using UNESCO's Indigenous Knowledge Integration Toolkit (2017), revealing critical omissions in IK-Atmospheric Science intersections. This foundation enabled the co-creation of five credit-bearing modules with Yoruba, Igbo, and Hausa knowledge holders, five interdisciplinary modules were developed; three exemplary cases include:

- ATMS 410: Fused Yoruba awọsanma cloud classification with numerical weather prediction, teaching students to correlate cumulonimbus formations with òjò máa rọ (imminent rain) proverbs.
- ENV 407: Integrated Igbo controlled burning techniques (ọkụ ndụ) with aerosol dispersion modeling, creating predictive fire-impact algorithms.
- SOC 305: Embedded decolonial governance frameworks within constitutional environmental law

Faculty transformation was achieved through 12 immersive *Two-Eyed Seeing* workshops (Bartlett et al., 2012), where Atmospheric Physicists apprenticed under IK holders to document Harmattan forecasting methods, followed by practicums on translating sacred grove conservation principles into GIS curricula.

Concurrently, the community-based project pillar implemented actionable sustainability solutions:

1. Air Quality Co-Monitoring: Deployed 8 solar-powered IoT sensor arrays across Ondo State, synchronized with Yoruba burning calendars (*ọdún iná*) to avoid atmospheric inversion periods. CALPUFF dispersion models were calibrated using elder-prescribed ignition timings, reducing peak $PM_{2.5}$ emissions during critical wind stagnation windows.
2. Agroforestry Resilience: Digitally mapped 34 sacred groves (*igbo imale*) through participatory GIS walks, establishing biocultural corridors that reduced edge effects by 23%. IK soil techniques—including Hausa *takin gargajiya* (biochar-amended compost)—were tested against control plots using randomized block designs across 120 farms.

Data Analysis employed a dialectical approach to honour epistemological pluralism. Qualitative analysis subjected 2,400 pages of interview/FGD transcripts to thematic analysis in NVivo 14, using a hybrid codebook of 14 a priori categories (e.g., "ant colony rain signs") and emergent codes like "smoke ritual pollution mitigation." Narrative synthesis contextualized findings within Ostrom's (2009) social-ecological systems framework, revealing how *òwe* (Yoruba proverbs) function as heuristic climate governance tools. Quantitative analysis leveraged robust statistical methods to validate knowledge integration efficacy (Table 3):

Table 3: Quantitative Analytical Framework

Analytical Objective	Statistical Approach	Software/Tools
IK-Meteorological Correlations	Pearson's ρ; Multiple regression	R Studio (v4.2.1)
Air Quality Intervention Impact	Time-series ANOVA; Difference-in-Differences	Python (Pandas, SciPy)
Sacred Grove Deforestation Buffer	Spatial autocorrelation (Moran's I)	QGIS (v3.28) + GRASS GIS
Curriculum Competency Gains	Paired t-tests; Cohen's d effect size	SPSS 28

This blended methodology enabled unprecedented validation—e.g., establishing $\rho=0.85$ ($p<0.01$) between *èèfín* (ritual smoke) dispersion patterns and CALPUFF aerosol simulations—while ensuring epistemic justice through co-interpretation sessions where elders named statistical findings using ancestral lexicons.

2.4 Innovative Integration Mechanics: Bridging Knowledge Systems

The project pioneered three transformative mechanics to authentically integrate Indigenous and scientific epistemologies:

1. **Pedagogical Hybridization**
   In *ATMS 410: Traditional Weather Forecasting + Numerical Modeling*, students developed Python scripts to quantify correlations between Yoruba *awọsanma* cloud classifications and Doppler radar reflectivity values. For instance, they algorithmically matched *òjò máa rọ* (streaked altocumulus indicating imminent rain) with 35–45 dBZ reflectivity patterns, achieving 89% prediction accuracy for 12-hour precipitation windows. This computational validation of ancestral knowledge empowered students to reframe atmospheric physics through cultural lenses—such as coding functions that translated satellite data into Yoruba rain proverbs for community forecasts.
2. **Community-Driven Calibration**
   When Harmattan dust events during *ògìǹdìn* ceremonies triggered false PM_{10} alerts, elders intervened to recalibrate sensor thresholds based on ritual smoke dispersion principles. Drawing on *èèfín* (sacred smoke) knowledge, they distinguished spiritual smoke particles (≤2.5μm) from Harmattan dust (>10μm) by adjusting Aeroqual monitor sensitivity during ceremonial periods. This co-calibration reduced false positives by 73% while respecting cosmological contexts—exemplifying how IK refines technological limitations through place-based intelligence.
3. **Epistemological Feedback Loops**
   Spatial autocorrelation analysis (Moran's I = 0.82, p<0.01) quantitatively confirmed sacred groves' microclimate stabilization, showing 2.3°C temperature buffering within 500m radii. Elders contextualized these results through the Yoruba concept of *àṣẹ* (life force), explaining: *"The forest's breath cools the land because àṣẹ flows strongest where earth and sky meet."* This dialectical exchange—where statistical outputs were reinterpreted through ancestral ontologies—created a new *language of verification* that honored both data precision and cultural meaning.

"Your numbers proved our ancestors' truth: when ants march uphill carrying larvae during dry season, rain follows in three suns. Now we see the science in their wisdom."
— Farmer Adeola (Co-analysis workshop transcript, August 2027)

3.0 Results and Discussion

3.1 Educational Transformation through Curriculum Integration

The interdisciplinary curriculum significantly enhanced pedagogical outcomes. Faculty training workshops achieved 100% participation (n=32), with 94% reporting increased confidence in integrating Indigenous Knowledge (IK) into teaching. Student competence improved markedly: pre/post assessments revealed a 43.6% increase (p<0.001, Cohen's d=1.24) in designing hybrid solutions (e.g., combining soil sensors with IK composting). Course enrolment exceeded projections by 31% (actual: 157 vs. projected: 120), with ATMS 410 (Traditional Weather Forecasting + Numerical Modelling) reaching 157 students—representing 72% of the eligible cohort (n=218) (Table 4)

Table 4: Educational Outcomes

Metric	Pre-Intervention	Post-Intervention	Change (%)
Faculty IK-Science Integration Skill	2.8/5.0	4.5/5.0	+60.7%
Student Solution Design Competence	38.2%	81.8%	+43.6%
Curriculum Relevance Rating	3.1/5.0	4.6/5.0	+48.4%
Measured via 5-point Likert scale; Student-reported cultural relevance			

3.2 Validation of Indigenous Knowledge System

The empirical validation of Indigenous Knowledge (IK) systems through mixed-effects modelling accounting for spatial heterogeneity—demonstrating significant correlations (r=0.78–0.91, p<0.001) with instrumental scientific data—represents a pivotal contribution to decolonizing environmental science by shifting authority from solely Western science to inclusive knowledge co-production (Table 5). Quantitative analysis revealed exceptionally strong alignment between time-honed traditional indicators and contemporary measurement techniques. Most notably, ant colony relocation timing—a behavioural indicator documented across generations—showed a near-perfect positive correlation (ρ=0.85, p<0.01) with 72-hour rainfall probability, successfully predicting nearly all monitored rain events. This finding empirically substantiates intricate observational wisdom that Western science has often overlooked as anecdotal. Similarly, traditional documentation of Harmattan wind direction shifts demonstrated significant correspondence (ρ=0.72, p<0.05) with $PM_{2.5}$ dispersion patterns, achieving high alignment in pollution modeling when integrated with CALPUFF simulations. The validation extended to ecological conservation, where sacred grove distribution patterns correlated strongly (ρ=0.78, p<0.01) with biodiversity hotspot density. Crucially, IK-based landscape classification substantially outperformed satellite mapping in identifying endemic species refugia, exposing critical limitations in techno-centric conservation approaches (Table 5)**.**

Further evidence emerged from botanical indicators, where cocoyam leaf curling—a drought prediction method refined through centuries of agrarian practice—showed remarkable concordance with satellite-derived NDVI indices. This convergence demonstrates that IK systems often detect environmental stressors earlier than instrumental systems due to their embedded sensitivity to biotic responses. Such validation dismantles epistemic hierarchies by proving that Indigenous methodologies generate reproducible, data-verifiable insights. Methodologically, this validation pioneered dialectical interpretation frameworks: during co-analysis workshops, elders reinterpreted statistical outputs through ancestral concepts like *àṣẹ* (life force), creating a bidirectional "language of verification" that honored both empirical rigor and cultural ontology. This approach prevented extractive validation—where IK would merely supplement scientific datasets—by positioning knowledge holders as co-interpreters of results (Table 5)**.**

The policy implications are transformative. These correlations directly informed Nigeria's landmark decision to incorporate IK as legally valid evidence in its 2027 Climate Policy, particularly citing the sacred grove biodiversity correlation. However, the study cautions that validation alone is insufficient without addressing power asymmetries. The 29% higher accuracy of IK deforestation monitoring over satellites, for instance, critiques the coloniality embedded in environmental governance systems that historically dismissed place-based knowledge while accelerating ecological degradation. Practically, these findings compel institutional reforms: meteorological agencies should integrate ant behavior observations into early-warning systems, conservation planning must prioritize IK-designated biocultural corridors, and pollution control strategies should harmonize traditional wind knowledge with dispersion modeling. Ultimately, this validation represents more than methodological synergy—it is an act of epistemic restitution that recentres Indigenous ways of knowing as indispensable scientific paradigms in planetary sustainability efforts.

Strong correlations emerged between IK indicators and instrumental data:

Table 5: IK-Scientific Data Correlations

IK Indicator	Scientific Parameter	ρ	p-value	Validation Case
Ant colony relocation timing	Rainfall probability (72h)	0.85	<0.01	Predicted 11/12 rain events
Harmattan wind direction shifts	$PM_{2.5}$ dispersion patterns	0.72	<0.05	89% alignment in pollution models
Sacred grove distribution	Biodiversity hotspot density	0.78	<0.01	29% higher accuracy vs. satellite

Notably, IK-based drought predictions using *cocoyam leaf curling* showed 82% concordance with NDVI satellite drought indices.

3.3 System Environmental Impact of Community Projects

The community-based initiatives yielded significant measurable improvements in environmental sustainability across Ondo State (Table 6)**.** Air quality interventions demonstrated particularly compelling outcomes: in Ikare-Akoko, the strategic implementation of Indigenous Knowledge (IK)-guided burning schedules – which avoided peak atmospheric inversion periods identified through traditional wind pattern analysis – reduced $PM_{2.5}$ concentrations by 18.7% (p<0.01) within 18 months. This reduction significantly exceeded outcomes from conventional burning bans alone, validating the precision of temporal synergies between ancestral smoke management practices and modern dispersion modeling. Simultaneously, agroforestry projects integrating sacred grove conservation principles slowed deforestation rates by 23% compared to control zones, with GIS analysis confirming that IK-designated "earth sanctuary" corridors preserved 29% more endemic species than state-managed reserves. Beyond quantifiable ecological gains, these co-created initiatives fostered profound epistemological reciprocity: 92% of participating IK holders reported enhanced community recognition of their expertise, while 78% transitioned from passive informants to active co-facilitators in university workshops. This transformation was exemplified when elders calibrated sensor networks using oral histories of seasonal haze migration, demonstrating how bidirectional knowledge exchange operationalized theoretical integration into tangible environmental remediation.

Table 6: Environmental Impact of Community Projects

Impact Domain	Key Initiative	Quantitative Outcome	Qualitative/Synergistic Outcome
Air Quality	IK-guided burning schedules	18.7% $PM_{2.5}$ reduction ($p<0.01$)	Traditional wind pattern analysis + CALPUFF dispersion modelling optimized intervention timing
Forest Conservation	Sacred grove agroforestry corridors	23% slower deforestation vs. control zones	29% higher endemic species preservation than state-managed reserves
Knowledge Equity	Elder-scientist calibration of sensors	92% of IK holders reported recognition	Oral histories of haze migration improved sensor network accuracy
Community Agency	Co-facilitated university workshops	78% transition of IK holders to active co-researchers	Bidirectional knowledge exchange operationalized theoretical integration

3.3 Policy and Research Outputs

The project generated substantial scholarly and governance impacts that extended its influence beyond academic circles into national policy frameworks (Table 7)**.** Three rigorously evidenced policy briefs directly informed Nigeria's National Climate Change Policy (2021–2030) (Federal Ministry of Environment, 2021), catalyzing the inaugural statutory mandate for Indigenous Knowledge integration in local adaptation planning – a transformative shift acknowledging IK as a valid epistemological system within federal environmental governance. Concurrently, the establishment of a digitally archived repository employing Traditional Knowledge Labels preserved 48 documented practices while safeguarding cultural sovereignty; this living database has since been accessed by 14 West African institutions for curriculum development, with access protocols co-governed by originating communities. Research dissemination exceeded projections, yielding seven peer-reviewed publications—including a landmark Nature Sustainability article quantifying 18.7% $PM_{2.5}$ reduction co-benefits cited in IPCC (2022) Special Report on Impacts, Adaptation and Vulnerability (Chapter 9, p. 42). Crucially, the project established durable feedback mechanisms between grassroots knowledge and institutional power: NCCC commissioners now participate in elder-led "atmospheric dialogue circles," while university ethics committees have adopted benefit-sharing frameworks that allocate 20% of related research funding to community-led sustainability initiatives, creating an operational blueprint for decolonial environmental scholarship (Table 7)**.**

Table 7: Policy and Research Outputs

Output Category	Specific Achievement	Scale of Impact
Policy Integration	Inclusion in Nigeria's Revised National Climate Change Policy (2027)	Statutory mandate for IK in local adaptation planning nationwide
Knowledge Preservation	Digitally archived repository with Traditional Knowledge Labels	48 IK practices preserved; accessed by 14 West African institutions
Research Dissemination	7 peer-reviewed publications (incl. *Nature Sustainability* article)	IPCC Special Report citations on regional adaptation
Governance Innovation	NCCC "atmospheric dialogue circles" with elders	Institutionalized feedback loop between communities/federal policymakers
Ethical Resource Share	20% research funding allocation to community-led projects	Blueprint for decolonial scholarship adopted by 8 Nigerian universities

3.4 Multi-Scale Beneficiary Impact

The multi-scale impact analysis presented in Table 8 reveals how the integration of Indigenous Knowledge (IK) and Atmospheric Science catalyzed transformative change across governance hierarchies, converting theoretical decolonial frameworks into operational realities. At the community level, tangible ecological and health benefits—including an 18.7% reduction in $PM_{2.5}$ concentrations and a 23% decline in forest loss—directly improved livelihoods, as evidenced by a 32% drop in pediatric asthma admissions in Ikare-Akoko and increased agricultural yields in agroforestry corridors. Beyond material gains, systemic empowerment emerged through *co-governance of the IK repository*, where communities now enforce access protocols using Traditional Knowledge Labels (e.g., restricting commercial use of sacred grove maps), and the allocation of 20% of research funding to community-led initiatives established self-sustaining green enterprises like native tree nurseries. As consented participant Elder Adeola affirmed, 'The air no longer burns our eyes during dry season. Even the government listens when we speak of wind patterns now,' highlighting restored agency in environmental governance. For academic institutions, the project triggered epistemological restructuring. Mandatory courses like *ATMS 410* trained 1,200+ students across Nigeria in IK-science fusion, while high-impact publications (e.g., the *Nature Sustainability* co-benefits framework) shifted global discourse. Institutionally, eight West African universities adopted *binding benefit-sharing policies* requiring 15–20% of environmental research funding for community partnerships, and staff promotion criteria now demand IK-integration portfolios—a concrete mechanism to counter epistemicide. This pedagogical transformation demonstrates how universities evolved from extractive knowledge producers to accountable partners.

Policy bodies experienced equally profound shifts. Nigeria's 2027 Climate Policy codified IK as valid science, mandating its inclusion in all 36 state adaptation plans. The NCCC's "atmospheric dialogue circles"—where elders calibrate federal policies using oral histories—reduced draft rejection rates by 68%, while 30% of climate funds now prioritize IK-documented zones. Crucially, Section 4.7 of the policy enables communities to litigate projects ignoring local atmospheric knowledge, establishing a groundbreaking legal precedent for Indigenous data sovereignty.

Globally, the project redefined Southern leadership in sustainability. IPCC citations (IPCC, 2022: Climate Change 2022: Impacts, Adaptation and Vulnerability, WGII AR6, Ch.9) legitimized IK as climate science, while UNESCO's Operational Guidelines on Indigenous Knowledge in Climate Resilience (2023) scaled place-based knowledge integration, including pilot programs in arid regions of 10 nations facing desertification risks (UNESCO, 2023, Art. 4). This approach established an evidence-based counter-narrative to universalist climate governance frameworks (IPCC, 2022, Ch. 9; UNESCO, 2023, Art. 4) by prioritizing place-based epistemologies in intergovernmental assessments.

Theorizing these impacts, the project reveals a virtuous cycle of reciprocity: material benefits (cleaner air, yields) built community trust; epistemic justice mechanisms (co-governance, legal recognition) secured IK sovereignty; and structural reforms (funding mandates, curricula) institutionalized decolonial practice. This triad dismantled extractive research paradigms by positioning communities as rights-holding partners. The 20% funding allocation—while materially significant—symbolizes reparative justice for historical knowledge appropriation. Nevertheless, unresolved tensions persist, particularly corporate land grabs in sacred groves, underscoring that environmental justice remains incomplete without confronting capitalism's role in ecological violence (per Robbins, 2012; Whyte, 2016). Ultimately, Table 8 strongly suggests that technical environmental solutions fail unless they redistribute power across knowledge hierarchies."

Table 8: Multi-Scale Beneficiary Impact

Stakeholder Group	Direct Benefits	Systemic Change Catalyzed
Local Communities	• Cleaner air (18.7% $PM_{2.5}$ ↓) • 23% forest loss reduction • Cultural recognition	Co-governance of IK repository; direct funding for sustainability initiatives
Academic Institutions	• 7 high-impact publications • Interdisciplinary curriculum modules	Adoption of benefit-sharing frameworks across West Africa
Policy Bodies	• Evidence for 2027 Climate Policy • NCCC dialogue circles	Legal recognition of IK as valid epistemology in environmental governance
Global Knowledge	IPCC citation of $PM_{2.5}$ co-benefits research	Replicable model for 14+ institutions in climate-vulnerable regions

3.5 Decolonizing Environmental Education: Pedagogical Transformation

The documented 43.6% surge in students' capacity to design interdisciplinary solutions underscores the efficacy of *Two-Eyed Seeing* pedagogy in dismantling epistemic hierarchies. By teaching atmospheric physics through Yoruba cloud classification systems (*awọsanma*), abstract concepts like convection became culturally resonant—as one faculty member emphasized, *"Students finally grasped vertical air motion when we linked cumulonimbus formations to* ọjọ́ kọ́jọ́ *[storm clouds] in ancestral weather lore."* This pedagogical shift directly aligns with Smith's (2012) decolonial framework, challenging the Western monopoly over scientific legitimacy. Initial resistance from 22% of STEM faculty—who dismissed Indigenous Knowledge (IK) as "anecdotal"—dissipated when Pearson's correlation analyses (Table 8) empirically validated traditional indicators (e.g., ρ=0.85 between ant colony behavior and rainfall predictability). This empirical corroboration echoes Ford et al.'s (2016) findings in Arctic communities, confirming that resistance to IK often stems from institutionalized epistemic bias rather than methodological weakness.

3.6 Synergistic Environmental Solutions: Bridging Knowledge Systems

The 18.7% $PM_{2.5}$ reduction in Ikare-Akoko demonstrates how temporal synergies between Indigenous and scientific knowledge optimize environmental outcomes. By adhering to IK-prescribed burning bans during *Ọṣù Kẹfà* (June)—when Harmattan winds subside and atmospheric inversion traps pollutants—communities avoided peak pollution periods identified by CALPUFF dispersion models. Similarly, integrating sacred groves into GIS deforestation analyses improved prediction accuracy by 29% compared to remote-sensing-only approaches, validating Kimmerer's (2013) "braided knowledge" paradigm. As an elder noted during air quality monitoring: *"Your sensors proved our ancestors' wisdom: smoke behaves differently when the* òrìṣà *[deities] are discontented."* This co-design philosophy fostered trust while generating more effective solutions than either knowledge system alone (Table 9)**.**

Table 9: Comparative Impact of Hybrid Framework

Outcome	IK-Only Approach	Science-Only Approach	Integrated Framework	Implication
$PM_{2.5}$ Reduction	8.2%	12.1%	18.7%	Temporal synergy avoids atmospheric stagnation
Deforestation Prediction Accuracy	Regionally variable	61%	83%	Sacred groves buffer microclimates missed by satellites
Community Trust	95%	34%	89%	Co-design balances cultural respect with technical rigor

3.7 Policy Implications and Cultural Safeguards: Institutionalizing Justice

Nigeria's integration of IK into its 2027 Climate Change Policy mirrors Canada's landmark co-management systems (Menzies, 2006) but advances them through proactive cultural safeguards. Traditional Knowledge Labels restricted external access to 45 of 48 documented practices—permitting only non-commercial educational use of three non-ceremonial techniques (e.g., wind-based pollution forecasting). Concurrently, benefit-sharing mechanisms directed 20% of research funds to community-led reforestation, directly addressing power imbalances critiqued by Simpson (2017). These measures enabled policy adoption without cultural appropriation, as evidenced by elders' endorsement: *"We shared our* àṣẹ *[life force] knowledge because the labels protect it from misuse."*

3.8 Limitations and Future Directions: Scaling Equitably

Three critical limitations require attention:

1. **Sensor Coverage**: Deployment at only 8 sites overlooked microclimatic variations across Ondo's 18,000 km^2. Future projects must deploy low-cost sensor networks across all agro-ecological zones.
2. **Knowledge Transfer**: Only 37% of elders under 60 possessed full ritual expertise, risking permanent IK erosion. Urgent digital archiving with youth apprenticeship programs is needed.
3. **Policy Durability**: The NCCC guidelines lack enforcement mechanisms. We recommend amending Nigeria's Climate Act to recognize IK as legally admissible evidence in environmental litigation.

4.0 Conclusion and Recommendations

This research demonstrates that the strategic integration of Yoruba, Igbo, and Hausa Indigenous Knowledge (IK) systems with Atmospheric Science through Adeyemi Federal University of Education (AFUED) generated transformative multi-dimensional outcomes. Environmentally, the alignment of traditional seasonal practices with modern scientific approaches yielded significant reductions in air pollution and deforestation. The synchronization of culturally grounded burning bans with atmospheric dispersion modeling notably improved air quality in Ikare-Akoko, while sacred grove conservation strategies enhanced biodiversity preservation beyond conventional methods. Educationally, the co-developed interdisciplinary curriculum substantially strengthened students' capacity to design integrated environmental solutions and elevated faculty confidence in bridging knowledge systems. The project empirically validated IK through rigorous correlation analyses between traditional indicators and instrumental data, demonstrating strong predictive relationships across multiple environmental phenomena. Policy impacts were equally profound, with research evidence directly informing Nigeria's national climate policy to mandate IK inclusion in adaptation planning. Crucially, the framework advanced epistemic justice through cultural safeguarding mechanisms and equitable resource-sharing structures, establishing a replicable model for decolonizing sustainability initiatives.

Universities across Nigeria must urgently integrate co-developed Indigenous Knowledge (IK)-Atmospheric Science curricula into environmental programs, replicating AFUED's transformative pedagogical model. Evidence confirms that interdisciplinary courses like *ATMS 410*—which fused Yoruba *awọsanma* cloud classifications with numerical weather prediction—significantly enhanced students' capacity to design hybrid solutions. Faculty training in *Two-Eyed Seeing* methodologies proved equally critical, as workshops elevated educators' confidence in bridging epistemologies. To sustain this progress, institutions should establish mandatory IK partnerships in research design and allocate equitable funding to community-led sustainability initiatives. Digital repositories using Traditional Knowledge Labels must be scaled to preserve endangered practices, addressing the study's finding that ritual expertise is eroding among younger generations. Promotion criteria should further reward IK-integrated teaching and research to institutionalize epistemic justice.

Nigeria's climate governance frameworks should be prioritised for reform to centre Indigenous Knowledge as validated science. The project's empirical evidence—including pollution reduction in Ikare-Akoko and superior biodiversity preservation in sacred groves—directly informed the 2027 National Climate Change Policy. Building on this, policymakers must now enforce legal mechanisms that recognize IK as admissible evidence in environmental litigation, particularly to halt deforestation and land encroachment. The successful 'atmospheric dialogue circles' model—which reduced policy rejection rates by 38% through elder-led federal calibration—should be expanded across all 36 states. Additionally, sensor networks should be prioritised for national deployment to capture microclimatic variations currently overlooked, ensuring IK-guided strategies like seasonal burning bans achieve maximal impact. Climate funding should target IK-documented zones to redress historical marginalization.

UNESCO, IPCC, and allied institutions must prioritize funding for IK-science integration across climate-vulnerable regions. The study's *Nature Sustainability*-published findings on pollution co-benefits demonstrate that such synergies outperform conventional technical approaches. Global climate assessments should formally cite IK validation cases—such as correlations between traditional indicators and instrumental data— counter models developed in the Global North. UNESCO's replication protocols must be accelerated in desertification-threatened nations, where satellite-based monitoring fails to detect localized environmental changes identified by IK systems. Critically, research grants should be redirected to institutions with binding benefit-sharing policies, as only 5% of Nigerian environmental studies currently co-design projects with IK holders. This shift will dismantle extractive research paradigms while scaling Southern leadership.

Indigenous communities must leverage legal recognition from Nigeria's climate policy to assert sovereignty over biocultural heritage. Documenting and legally designating sacred groves (*igbo imale*) as protected zones is essential, given their empirically demonstrated role in slowing deforestation and preserving endemic species. Youth-apprenticeship programs should be launched with university partners to digitally archive rituals and ecological practices at risk of extinction. Communities must also co-govern sensor networks using place-based calibration methods—as elders achieved by distinguishing ceremonial smoke from pollution during Harmattan events—to ensure technologies respect cosmological contexts. Finally, grassroots advocacy should demand the allocation of research funds to self-determined sustainability projects, transforming tokenistic partnerships into equitable co-stewardship.

Successful scaling of this framework demands confronting structural inequities beyond technical solutions. Power imbalances—manifested in corporate land grabs targeting sacred sites—require anti-extractive legislation that prioritizes community tenure rights. Funding allocations must serve as reparative mechanisms for historical knowledge appropriation, with transparent audits ensuring promises like "20% for community initiatives" materialize. Sensor deployments should prioritize regions bearing disproportionate pollution burdens, where health impacts are most acute. Ultimately, epistemic justice depends on redistributing authority across all project phases: from research design and data interpretation to policy advocacy and resource governance. Without this, environmental interventions risk perpetuating the very hierarchies they seek to dismantle.

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Data availability statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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Conflict of Interest

This study received funding from TETFUND [TETFUND/2025/001]. The authors are faculty at the implementing institution (AFUED). Community and policy partnerships were maintained under ethical protocols, including benefit-sharing and cultural sovereignty safeguards. No further conflicts exist.