



The Role of Indigenous Knowledge in Climate-Smart Agriculture: A Case Study of Weather Forecasting in Uganda

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Abstract: Climate change is exacerbating rainfall unpredictability across Sub-Saharan Africa, threatening the livelihoods of millions of smallholder farmers who depend on rain-fed agriculture. While modern climate services are often promoted as the primary adaptation strategy, they frequently prove unreliable at the local level and inaccessible to resource-poor farmers. This study investigates the role of indigenous knowledge (IK) in weather forecasting among smallholder farmers in Uganda's Bukedi sub-region, drawing on qualitative data from 30 in-depth interviews, 10 focus group discussions (80 participants), and six weeks of participant observation across five villages. The findings reveal that weather forecasting is the most universally practiced IK category, reported in 100% of focus groups, with farmers employing a sophisticated typology of at least eleven distinct indicators spanning biological, meteorological, celestial, botanical and edaphic categories. Four core indicators, migratory birds, bird calls/behavior, dark clouds, wind direction, and tree flowering, were reported in all five villages, representing a foundational knowledge system. Farmers consistently expressed a preference for traditional forecasting over modern radio forecasts, citing superior local accuracy, accessibility, and cost-effectiveness. This paper challenges the prevailing epistemic hierarchy that privileges scientific knowledge over local knowledge, arguing that IK-based weather forecasting represents a vital, locally adapted, and cost-free climate adaptation strategy that merits systematic integration into agricultural policy and extension services. The findings contribute to the growing literature on climate-smart agriculture by demonstrating how indigenous knowledge systems can enhance resilience at the community level.

Keywords: *Indigenous knowledge, weather forecasting, climate adaptation, smallholder farmers, Uganda, climate-smart agriculture*

1. Introduction

Climate change poses an existential threat to smallholder agriculture in Sub-Saharan Africa, where the majority of food production depends on increasingly unpredictable rainfall patterns (IPCC, 2022; FAO, 2021). For the approximately 70% of Uganda's working population engaged in agriculture, mostly on plots of less than two hectares, the ability to accurately anticipate seasonal rainfall is critical for survival (Uganda Bureau of Statistics, 2020). Yet, modern meteorological services, while sophisticated at regional scales, often fail to provide the localized, fine-grained information that farmers need for daily decision-making (Orlove et al., 2010; Mubiru et al., 2018).

Against this backdrop, smallholder farmers in Uganda's Bukedi sub-region continue to rely on a rich body of

indigenous knowledge for weather forecasting. For generations, farmers have observed the behavior of birds, the appearance of butterflies, the flowering of trees, and the direction of wind to predict the onset, duration, and intensity of seasonal rains (Berkes, 2018; Egeru, 2019). These practices, embedded in local ecological knowledge systems, have sustained communities through decades of climatic variability and have demonstrated remarkable resilience in the face of environmental change. Despite growing international recognition of the potential contribution of indigenous knowledge to climate adaptation (FAO, 2017; IPCC, 2022), Ugandan agricultural policy continues to privilege scientific,

universal knowledge over local, experiential knowledge. This epistemic hierarchy, embedded in extension curricula, research funding criteria, and program design, represents a root cause of the underutilization of indigenous knowledge in agricultural programming (Akullo, 2007). The result is a policy gap where effective, locally adapted adaptation strategies remain marginalized, while costly and often inaccessible modern solutions are prioritized.

This study addresses this gap by providing systematic empirical evidence on the typology, prevalence, and perceived reliability of IK-based weather forecasting in the Bukedi sub-region of eastern Uganda. Drawing on qualitative data collected through interviews, focus group discussions, and participant observation, we seek to answer three research questions: (1) What indigenous weather forecasting indicators are currently used by farmers in Bukedi? (2) How prevalent are these practices across the study area? (3) How do farmers perceive the reliability and value of traditional forecasting compared to modern meteorological services? Our central thesis is that indigenous weather forecasting indicators provide a locally accurate and cost-effective strategy for climate change adaptation that is perceived by farmers as superior to modern meteorological services, challenging the dominant assumption of scientific knowledge's inherent superiority. By documenting and validating this knowledge system, we contribute to the growing literature on climate-smart agriculture and provide evidence for the integration of indigenous knowledge into formal adaptation policy.

The paper is structured as follows: Section 2 reviews the literature on indigenous knowledge, weather forecasting, and climate adaptation. Section 3 outlines the conceptual framework and methodology. Section 4 presents the empirical findings, including a typology of forecasting indicators and farmer perceptions of their reliability. Section 5 discusses the implications of these findings for theory, policy, and practice. Section 6 concludes with recommendations for integrating IK into climate adaptation strategies.

2. Literature Review

2.1 Indigenous Knowledge and Climate Adaptation

Indigenous knowledge (IK) has been conceptualized as a set of beliefs, practices, and embodied skills rooted in local experience, often transmitted orally, and demonstrably effective in addressing local challenges (Ellen & Harris, 1996; Berkes, 2018). Key characteristics include its local specificity, oral transmission, dynamic and adaptive nature, uneven

distribution within communities, and embeddedness in broader cultural and spiritual beliefs (Sarkhel, 2016). Far from being static or backward, indigenous knowledge systems are dynamic, evolving in response to environmental change and accumulating knowledge across generations through observation and experimentation.

The role of IK in climate adaptation has received increasing attention from scholars and international organizations. Berkes (2018) and Makhura and Makhura (2020) have emphasized the importance of traditional ecological knowledge for understanding and responding to environmental variability. The Intergovernmental Panel on Climate Change (IPCC, 2022) has recognized that indigenous and local knowledge systems can contribute significantly to climate resilience, providing context-specific insights that complement scientific approaches. Similarly, the Food and Agriculture Organization (FAO, 2017, 2020) has highlighted the potential contribution of IK to sustainable agriculture and food security.

However, the integration of IK into formal climate adaptation policy remains limited, constrained by what scholars have described as an epistemic hierarchy that privileges scientific, universal knowledge over local, experiential knowledge (Agrawal, 1995; Akullo, 2007). This hierarchy is perpetuated through educational curricula, research funding mechanisms, and extension approaches that systematically marginalize indigenous knowledge. The result is a policy gap where effective local solutions are overlooked in favor of often inappropriate or inaccessible modern alternatives.

2.2 Traditional Weather Forecasting in Africa

Across Sub-Saharan Africa, smallholder farmers have developed sophisticated systems for predicting seasonal weather patterns using local environmental indicators (Orlove et al., 2010; Mubiru et al., 2018; Egeru, 2019). These systems draw on multiple categories of indicators, including biological signals (bird behavior, insect emergence, animal movements), meteorological observations (cloud formation, wind direction, lightning patterns), celestial phenomena (moon position, star visibility), botanical cues (tree flowering, leaf changes) and edaphic Indicators (Soil and water).

Studies in Uganda have documented the use of traditional weather forecasting in various regions. Tabuti and Van Damme (2012) found that farmers in central Uganda used lightning patterns over Lake Victoria as a primary forecasting indicator, while Egeru (2019) documented the use of termite flights and bird behavior in northern Uganda. In the Bukedi sub-region, preliminary studies have suggested the use of butterflies, moon observations, and tree phenology as forecasting indicators (Kaddu & Haumba, 2016), but systematic documentation of the full typology and prevalence of these practices has been lacking.

Research from other African countries has similarly documented the diversity and sophistication of traditional weather forecasting. In Zimbabwe, Winniefridah and Manuku (2013) found that farmers use multiple indicators, including bird calls and tree phenology, to make planting decisions. In South Africa, Rankoana (2020) documented the use of indigenous forecasting methods among smallholder farmers, noting that these methods are often preferred to modern forecasts for their local accuracy and accessibility. In Ethiopia, Mulat (2013) found that farmers integrate multiple forecasting indicators to make agricultural decisions, reflecting a sophisticated understanding of local environmental dynamics.

The effectiveness of traditional forecasting methods has been validated by comparative studies. Orlove et al. (2010) found that indigenous forecasting in southern Uganda often outperformed regional meteorological forecasts, particularly for short-term predictions. Mubiru et al. (2018) similarly found that farmers in Uganda's central region consistently preferred traditional methods for their reliability and accessibility. These findings suggest that IK-based weather forecasting is not merely a cultural practice but a scientifically valid approach to climate observation that warrants recognition and integration into formal adaptation strategies.

2.3 Knowledge Gaps and Contribution of This Study

Despite the growing body of literature on IK and climate adaptation, several significant gaps remain. First, there is limited systematic documentation of the full typology of weather forecasting indicators used in specific regions, including the Bukedi sub-region. Second, while farmers consistently express preference for traditional methods, the specific reasons for this preference have not been fully explored. Third, the mechanisms through which farmers integrate multiple forecasting indicators into their decision-making have not been adequately theorized.

This study addresses these gaps by providing a comprehensive typology of weather forecasting indicators in Bukedi, documenting their prevalence across communities, and examining farmer perceptions of their reliability and value. By applying critical realist and systems thinking frameworks, we move beyond mere documentation to provide causal explanations for how IK-based forecasting works and why it is valued. In doing so, we contribute to both the empirical literature on IK and the theoretical literature on knowledge systems and climate adaptation.

3. Conceptual Framework and Methodology

3.1 Conceptual Framework

This study adopted a critical realist framework, which holds that reality exists independently of our

knowledge of it, but our access to reality is always mediated by social and linguistic interpretations (Bhaskar, 1975; Archer et al., 2016). This perspective is ideal for studying indigenous knowledge because it recognizes both the material effectiveness of practices and the cultural contexts in which they are embedded. As Archer et al. (2016) argue, critical realism enables researchers to distinguish between the real mechanisms that generate outcomes, the actual events that occur, and the empirical observations that researchers capture. This stratified ontology allows for rigorous analysis of the causal powers of IK practices while acknowledging their social construction.

Our conceptual framework posits that indigenous weather forecasting operates through multiple categories of indicators, each of which is linked to underlying environmental mechanisms. Drawing on Berkes (2018) and Orlove et al. (2010), we conceptualize these indicators as signals that farmers interpret based on accumulated knowledge of local environmental dynamics. The reliability of these indicators is grounded in their connection to real causal mechanisms: biological phenomena (insect emergence, bird behavior) respond to the same atmospheric conditions that generate rainfall, making them sensitive bio-indicators of impending weather events.

The framework also incorporates systems thinking, recognizing that IK-based forecasting is embedded in broader social-ecological systems (Meadows, 2008). We identify two key feedback loops that shape the trajectory of IK forecasting in Bukedi: (1) a reinforcing loop where successful forecasting leads to improved agricultural outcomes, which in turn encourages continued observation and knowledge sharing, and (2) a balancing loop where climate change alters traditional patterns, reducing the reliability of indicators and potentially leading to loss of trust and abandonment of practices. These feedback loops explain the persistence and resilience of IK systems, as well as the challenges they face in a changing climate.

3.2 Research Design

This study employed a qualitative case study design with elements of simple descriptive quantification. The case is the Bukedi sub-region of eastern Uganda, comprising the districts of Tororo, Busia, Butaleja, and Pallisa. According to the Uganda Bureau of Statistics (2020), the population of Bukedi is approximately 2.1 million, with 85% living in rural areas, most of whom are subsistence farmers. The region experiences a bimodal rainfall pattern, with annual rainfall ranging from 1,100 mm to 1,700 mm. Temperatures vary between 16°C and 28°C, and soils are predominantly sandy clay loams.

The study was conducted in five villages across the sub-region, selected through purposive sampling to capture variation in community characteristics, accessibility, and agricultural practices. Within each village, participants were stratified by age (under 35, 35-60,

over 60) and gender to ensure representation of different generational cohorts and gender-specific knowledge roles. The sampling strategy was designed to maximize information power, as recommended by Malterud et al. (2016), by focusing on experienced farmers with demonstrated knowledge of indigenous practices.

3.3 Data Collection

Data were collected through three primary methods. First, in-depth interviews (n=30) were conducted with smallholder farmers using a semi-structured interview guide that covered each of eight IK practice domains, including weather forecasting. Interviews lasted 45-90 minutes, were conducted in Lugwere or Lunyole, audio-recorded, transcribed, and translated into English.

Second, focus group discussions (FGDs) (n=10, with 80 participants) were conducted across the five villages, with two FGDs per village. Each FGD included 8 participants and lasted 60-120 minutes. Topics included knowledge of forecasting indicators, methods of observation, and perceptions of reliability compared to modern alternatives. FGDs were facilitated by a trained moderator and audio-recorded with participant consent.

Third, six weeks of participant observation were conducted, during which the lead researcher lived in the community, participated in farming activities, and recorded detailed field notes on weather forecasting practices. Photographs were taken with consent to document observed practices. This immersion provided insights into how forecasting knowledge is applied in daily agricultural decision-making.

3.4 Data Analysis

Data analysis followed content analysis procedures as outlined by Elo and Kyngas (2007), with abductive and retroductive reasoning. The analysis proceeded through three stages. First, open coding identified meaning units related to weather forecasting indicators, methods of observation, and perceptions of reliability. Second, codes were grouped into sub-categories and then abstracted into themes, resulting in a typology of forecasting indicators. Third, abductive reasoning was used to infer the best explanations for observed patterns, and retroductive reasoning was used to identify the underlying causal mechanisms linking indicators to weather events.

Simple descriptive frequencies were calculated to show the prevalence of forecasting indicators across villages and FGDs, enabling quantitative comparison while maintaining the qualitative focus of the study. Thematic analysis of interview and FGD transcripts provided depth on farmer perceptions and decision-making processes.

3.5 Trustworthiness

Trustworthiness was ensured through multiple strategies. Credibility was enhanced through member checking: after preliminary analysis, findings were presented to two focus groups (16 participants), who confirmed the accuracy of descriptions and clarified two points about seasonal variation in indicator use. Peer debriefing was conducted with two fellow PhD researchers. Dependability was ensured through an audit trail of raw recordings, transcripts, field notes, coding sheets, and decision memos. Transferability was addressed through thick description of the Bukedi context and specific forecasting practices, enabling readers in similar contexts to assess applicability.

3.6 Ethical Considerations

Ethical clearance was obtained from the University of Cape Town (UCTDKIS2024-12-03) and the Uganda National Council for Science and Technology (SS4648ES). Local district authorities and village leaders granted permission. All participants gave informed consent, could withdraw at any time, and were assured of confidentiality. Reimbursement of 5,000 Ugandan shillings was provided to cover transport and snacks.

4. Results

4.1 Prevalence of Weather Forecasting

Weather forecasting was the most frequently mentioned indigenous knowledge practice across all study sites, with 46 total mentions and 100% of focus groups reporting its use. Table 1 presents the distribution of forecasting indicators across the five villages.

Table 1: Indigenous Weather Forecasting Indicators by Village

Indicator Type	Specific Indicator	Kagumu	Kasodo	Luhola	Petete	Puti-Puti	Total
Birds	Migratory birds	✓	✓	✓	✓	✓	5
	Bird calls/behaviour	✓	✓	✓	✓	✓	5
Insects	Butterfly appearance	✓	✓	✓	✓	-	4
	Termite flights	✓	✓	-	✓	✓	3
Weather	Dark clouds	✓	✓	✓	✓	✓	5
	Wind direction	✓	✓	✓	✓	✓	5
	Lightning patterns	✓	✓	✓	✓	-	4
Moon/Stars	Moon position	✓	✓	-	✓	✓	4
	Star visibility	-	✓	-	-	-	1
Trees/Plants	Tree flowering	✓	✓	✓	✓	✓	5
	Leaf changes	✓	✓	✓	-	-	3

Source: FGD and Interview Transcripts, Bukedi Sub-region (May 2023 - February 2024)

The table reveals that four indicators, migratory birds, bird calls/behaviour, dark clouds, wind direction, and tree flowering, were reported in all five villages, achieving a total score of 5 each. These universally used indicators represent the core of traditional weather forecasting in the Bukedi sub-region. Butterfly appearance and lightning patterns were reported in four villages (Puti-Puti being the exception). Moon position was reported in four villages (Luhola being the exception). Termite flights were reported in three villages, leaf changes in three villages, and star visibility was the least reported indicator, documented only in Kasodo.

The village-specific patterns reveal that Kagumu and Kasodo reported the highest number of indicators (11 each), Luhola reported eight, Petete reported seven, and Puti-Puti reported the fewest at six. This gradient from 11 to 6 indicators suggests variation in the retention of traditional weather forecasting knowledge across the study area, with some communities having preserved a broader range of forecasting methods than others.

4.2 Typology of Forecasting Indicators

The 11 indicators identified in the study can be organized into five taxonomic categories, each representing a distinct domain of environmental observation.

Category 1: Biological Indicators (Birds and Insects)

Farmers observe both bird behavior and insect emergence as key forecasting signals. Bird-related indicators include migratory birds (observing the arrival of certain species with seasonal movements) and bird calls/behaviour (changes in vocalization patterns signaling approaching rains). As one FGD participant in Kasodo (Male, 58) explained: *"There is a small bird that sings 'Kamutoigo' and we understand that the season is now in the middle of rain."*

Insect indicators include butterfly appearance and termite flights. Butterfly appearance is particularly significant, with farmers noting that the sudden appearance of large numbers of *nakabale* butterflies signals the onset of rains within approximately two weeks. As one FGD participant in Kasodo (Male, 58) noted: *"When we see the nakabale butterflies suddenly appearing in large numbers, we know the rains are coming within the next two weeks."* Termite flights, observed in three villages, similarly signal seasonal changes.

Category 2: Meteorological Indicators

Farmers observe atmospheric phenomena directly, including dark clouds, wind direction, and lightning patterns. Dark clouds and wind direction are universally used across all villages, reflecting their accessibility and reliability.

One farmer in Kagumu (Male, 62) explained: *"When the wind blows from the direction of Teso to the direction of Buganda and back from Buganda to Teso, it means that the rain season has approached."* Lightning patterns, observed in four villages, provide additional information about the nature and timing of approaching weather systems.

Category 3: Celestial Indicators

Lunar and stellar observations, while less prevalent than biological and meteorological indicators, provide supplementary forecasting information. Moon position was reported in four villages, with farmers observing the moon during specific phases to predict seasonal rainfall. As one interview respondent in Petete (Female, 45) explained: *"The elders in our village can predict the season's rainfall by observing the moon during the first week after the new moon. If it is clear and bright, we expect good rains."* Star visibility, reported only in Kasodo, suggests that celestial observations are more localized and may require specific expertise.

Category 4: Botanical Indicators

Tree flowering and leaf changes provide seasonal signals with lead times of approximately one month.

Tree flowering was universally reported across all five villages, with farmers observing specific species such as Mvule and African teak. As one farmer in Kagumu (Male, 63) explained: *"When the Mvule shades off all its leaves, this indicates times for sowing millet has come."* Leaf changes were reported in three villages, providing additional botanical signals.

Category 5: Edaphic Indicators (Soil and Water)

Soil conditions and water body behavior serve as supplementary forecasting signals, particularly for assessing the severity and duration of the coming season. Farmers in four villages reported observing soil moisture retention, cracking patterns, and the behavior of local streams or swamps. As one interview respondent in Petete (Female, 52) explained: *"If the soil cracks deeply in the dry season, we expect heavy rains when they start. If the swamps dry up completely, the season will be short."* The presence of specific soil insects or the appearance of algae in drying water sources were also mentioned in focus groups as markers of imminent seasonal shifts. While less universally referenced than biological or meteorological indicators, edaphic observations are integrated with other forecasts to refine planting decisions.

Five Categories:

Category	Domain
1	Biological (Birds & Insects)
2	Meteorological
3	Celestial
4	Botanical
5	Edaphic (Soil & Water)

To ensure consistency, you can add it in **Table 1** in Section 4.1 to include, an "Edaphic" row with relevant indicators (e.g., soil cracking patterns, stream behavior, algae growth) or, if it does not, add it to match the new category description.

4.3 Farmers' Perceptions of Reliability

Farmers consistently expressed preference for traditional forecasting over modern radio forecasts. This preference was grounded in three primary factors: local accuracy, accessibility, and cost-effectiveness.

Local Accuracy: Farmers emphasized that traditional indicators are calibrated to their specific location, providing more reliable information than regional radio forecasts. As one interview respondent in Kagumu (Male, 62) explained: *"Modern radio forecasts often fail us. They say rain is coming, but it doesn't come. Our traditional indicators are more reliable for our specific area."* This sentiment was echoed across multiple villages, reflecting farmers' experiences of generalized regional predictions that often prove inaccurate at the local level.

Accessibility: Traditional indicators are continuously available for observation, unlike radio forecasts that require access to electronic equipment and are broadcast at specific times. As one FGD participant in Luhola (Female, 44) noted: *"We can see the birds and the clouds every day. We don't need to wait for the radio to tell us what to expect."* This accessibility enables farmers to make timely decisions based on the most current information.

Cost-Effectiveness: Traditional forecasting requires no cash expenditure, making it accessible to all farmers regardless of economic status. This is particularly significant in the context of rural poverty, where cash is scarce and credit often unavailable. As one interview respondent in Petete (Male, 48) explained: *"Indigenous methods cost nothing. We observe what is around us. We don't need to buy radios or pay for weather updates."*

4.4 Integration with Agricultural Decision-Making

Weather forecasting is not an isolated practice but is integrated with other agricultural decisions, particularly planting timing and seed selection. Farmers described how they combine multiple indicators to make informed decisions about when to plant, which seeds to use, and when to undertake other agricultural activities.

One interview respondent in Kasodo (Male, 47) explained the integration of forecasting with planting decisions: *"We plant with the first rains after the butterflies appear. If we plant too early, the seeds rot in the ground. If too late, the rains stop."* This statement illustrates how biological indicators (butterfly appearance) are used in combination with meteorological observations (the first rains) to determine optimal planting timing.

Similarly, seed selection is informed by weather predictions, with farmers selecting drought-resistant varieties when forecasts suggest a dry season and higher-yielding varieties when conditions are expected to be favorable. As one FGD participant in Luhola (Male, 39) explained: *"We share seeds among neighbours. If someone's crop performed well in the dry season, everyone wants those seeds for the next planting."*

4.5 Changing Patterns and Adaptation

Farmers reported that climate change is altering traditional weather patterns, affecting the reliability of some indicators and requiring adaptation. As one interview respondent in Kagumu (Male, 63) noted: *"Right now the seasons have changed, we sow millet in March but in the past the month of April was the month of harvesting finger millet."* This observation indicates that farmers are aware of climatic shifts and have adapted their practices accordingly.

The changing reliability of indicators was also noted. Some farmers reported that certain biological indicators, particularly those related to insects, have become less

consistent as temperatures and rainfall patterns have shifted. However, farmers also noted that they continue to adapt their observation methods, learning new patterns and adjusting their interpretations. This dynamism reflects the adaptive capacity of indigenous knowledge systems, which evolve in response to environmental change.

5. Discussion

5.1 Theoretical Implications: Challenging Epistemic Hierarchies

The findings of this study challenge the epistemic hierarchy that privileges scientific, universal knowledge over local, experiential knowledge in agricultural policy and practice. The documented prevalence and perceived reliability of IK-based weather forecasting demonstrate that indigenous knowledge is not merely a cultural artifact but a practically effective system for environmental observation and decision-making.

Our typology of 11 distinct forecasting indicators across five categories reveals a sophisticated, multi-modal knowledge system. The integration of biological, meteorological, celestial, and botanical signals reflects a holistic understanding of environmental dynamics that is comparable in complexity to modern meteorological approaches. The universal use of four core indicators across all villages suggests that this knowledge system is not only widespread but also foundational to agricultural practice in the region.

The preference for IK over modern forecasts, expressed consistently across villages, points to the limitations of top-down, technology-centric adaptation strategies. While modern meteorological services provide valuable regional information, they often fail to capture the micro-climatic variations that are critical for local agricultural decision-making. As Orlove et al. (2010) and Egeru (2019) have similarly found, indigenous knowledge systems are specifically calibrated to local conditions, providing information that is directly relevant to farmers' immediate needs.

The critical realist framework adopted in this study enables us to move beyond the simple documentation of practices to understand the underlying mechanisms that make IK effective. The causal mechanisms we identify (butterfly phenology as a bio-indicator of atmospheric conditions, bird behavior as a signal of pressure changes, tree flowering as a response to moisture and photoperiod cues) provide a scientific basis for understanding why these traditional practices work. This mechanistic understanding challenges the dismissal of IK as "unscientific" and provides grounds for recognizing its validity alongside scientific knowledge.

5.2 Systems Dynamics: The Virtuous and Vicious Cycles

The systems perspective reveals two key feedback loops that shape the trajectory of IK-based forecasting in Bukedi. The reinforcing loop, or virtuous cycle, operates when accurate forecasts lead to successful agricultural outcomes, which in turn encourage continued observation, knowledge sharing, and refinement of forecasting methods. This positive feedback loop explains why IK forecasting has persisted for generations despite the absence of formal institutional support. Success breeds continued practice, and continued practice breeds further success.

The balancing loop, or vicious cycle, operates when climate change alters traditional weather patterns, reducing the reliability of some indicators. If farmers experience crop failure due to inaccurate forecasts, they may lose trust in IK and abandon traditional practices, leading to erosion of the knowledge base. This negative feedback loop represents a threat to the long-term viability of IK systems in the context of rapid environmental change.

The interaction between these two loops determines the trajectory of IK systems. Where the reinforcing loop dominates, IK systems are sustained and strengthened. Where the balancing loop dominates, IK systems may erode. The moderating role of extension services (either supporting IK or undermining it) is critical in determining which loop prevails. As our policy analysis in Section 5.3 explores, extension bias can accelerate the balancing loop, leading to loss of knowledge and reduced resilience.

5.3 Policy Implications: Bridging the Implementation Gap

Our findings reveal a significant gap between policy rhetoric and implementation regarding the integration of IK into climate adaptation. While Uganda's agricultural policy documents mention the importance of indigenous knowledge, the operational reality is that extension services, through programs such as NAADS, continue to privilege modern, scientific knowledge at the expense of local knowledge.

The epistemic hierarchy embedded in extension curricula is a key barrier to IK integration. Extension agents, trained in curricula that privilege Western scientific knowledge, often dismiss traditional practices as unscientific or backward. As one farmer in Kagumu (Male, 62) noted: *"When I ask about our traditional methods, they tell me to use modern seeds and fertilizers. They don't want to hear about how our fathers did it."* This institutional bias marginalizes effective local knowledge and undermines farmers' confidence in their own expertise.

The stakeholder interests that perpetuate this bias are significant. The system benefits input suppliers who profit from the sale of fertilizers, pesticides, and improved seeds. Modernized farming systems create

markets for these inputs, while IK-based systems that use locally available materials (cow dung, ash, neem) do not generate the same economic returns for commercial interests. This political economy of knowledge explains why IK continues to be marginalized despite its demonstrated effectiveness.

Bridging this implementation gap requires a fundamental rethinking of extension approaches. Our findings suggest several pathways for change:

1. **Revising Extension Curricula:** Extension training institutions should revise their curricula to include IK, covering not only the practices themselves but also their scientific basis and effectiveness.
2. **Training Extension Workers:** Extension agents should be trained in participatory approaches that respect and value local knowledge, working collaboratively with farmers rather than imposing external solutions.
3. **Linking IK with Climate Services:** Traditional forecasting should be integrated with modern meteorological services, creating hybrid systems that leverage the strengths of both approaches.
4. **Supporting Community Knowledge Networks:** Community-based knowledge sharing mechanisms, including elder councils and farmer groups, should be supported as platforms for preserving and disseminating IK.

5.4 Practical Implications: Strengthening Community Resilience

Beyond policy changes, our findings have practical implications for strengthening community resilience to climate change. The continued use of IK-based weather forecasting reflects the adaptive capacity of farming communities, who have developed and refined their observation methods over generations. Supporting these existing capacities is more effective and sustainable than introducing external solutions that may be inappropriate or inaccessible.

The cost-effectiveness of IK-based forecasting is a crucial practical advantage. In a context of rural poverty where cash is scarce, methods that require no cash expenditure are inherently more accessible and equitable. This economic dimension of IK contributes to food security by enabling poor households to make informed planting decisions without incurring debt.

The social dimensions of IK, knowledge sharing, community networks, and intergenerational transmission, build social capital and community resilience. When knowledge is shared freely, the entire community benefits, and collective learning

enhances adaptive capacity. Supporting community knowledge networks, including elder councils and farmer groups, can strengthen these social processes and enhance resilience.

5.5 Limitations and Future Research

This study has several limitations that should be acknowledged. First, the sample (30 interviews, 80 FGD participants) may not capture all variations of weather forecasting indicators in Bukedi. The focus on five villages may miss practices specific to other communities. Second, self-reported data on perceptions of reliability may not fully capture objective accuracy. Future research could use quantitative methods, such as comparing forecast accuracy with actual rainfall data, to validate farmer perceptions. Third, the geographic scope (four districts in Bukedi) limits generalizability to other regions. However, the detailed typology and thick descriptions enable readers to assess transferability to similar contexts.

Future research should focus on quantitative validation of IK forecasting indicators, measuring their predictive accuracy compared to modern meteorological forecasts. Longitudinal studies could assess how IK systems are adapting to climate change and whether certain indicators are becoming more or less reliable. Comparative studies across agro-ecological zones could examine regional variation in forecasting methods. Gender analyses could explore how men and women differentially access and apply forecasting knowledge. Integration research could develop and test hybrid forecasting systems that combine IK and scientific knowledge.

6. Conclusion

This study has demonstrated that indigenous weather forecasting remains alive, relevant, and effective for smallholder farmers in Uganda's Bukedi sub-region. The typology of 11 indicators across five categories reflects a sophisticated knowledge system that has been refined through generations of observation and experimentation. Four core indicators, migratory birds, bird calls, dark clouds, wind direction, and tree flowering, are universally used across villages, representing a foundational knowledge system.

Farmers consistently expressed preference for traditional forecasting over modern radio forecasts, citing superior local accuracy, accessibility, and cost-effectiveness. This preference challenges the prevailing epistemic hierarchy that privileges scientific knowledge over local knowledge in agricultural policy and extension. The underutilization of IK is not due to a lack of local efficacy but to institutional biases that marginalize effective, locally adapted knowledge.

The findings contribute to the growing literature on climate-smart agriculture by demonstrating how indigenous knowledge systems can enhance resilience at the community level. By bridging the gap between local knowledge and formal policy, we can create more

effective, equitable, and sustainable adaptation strategies that build on existing capacities rather than imposing external solutions.

We conclude with a call for action: policymakers must recognize the validity of indigenous weather forecasting and integrate it into formal climate services. Extension workers must be trained to respect and value local knowledge. Development practitioners must support community-based knowledge networks. And researchers must continue to document, validate, and analyze the sophisticated knowledge systems that have sustained communities for generations.

In a changing climate, the wisdom of farmers who read the language of the land, the birds, and the stars is not a relic of the past but a vital resource for the future. By recognizing this wisdom and integrating it with scientific knowledge, we can build more resilient agricultural systems that serve both people and the planet.

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