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Climate Variability and Traditional Weather Forecasting Practices

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Abstract — As climate variability intensifies across the globe, rural and indigenous communities that depend directly on rainfall and seasonal patterns for their livelihoods face growing uncertainty in agricultural planning, resource management, and disaster preparedness. Long before the advent of instrumented meteorology, such communities developed elaborate systems of traditional or indigenous weather forecasting, drawing on the observed behaviour of plants, animals, insects, celestial bodies, and atmospheric phenomena to anticipate seasonal and short-term weather conditions. This paper examines the relationship between climate variability and traditional weather forecasting practices, drawing on documented case studies from East and Southern Africa and from India, to assess the empirical basis, contemporary relevance, and limitations of indigenous forecasting knowledge in an era of accelerating climatic change. The paper argues that while traditional weather forecasting cannot substitute for instrumented meteorological science, it retains significant value as a locally accessible, culturally embedded, and complementary source of climate information, particularly where formal forecasting infrastructure remains limited, and that the integration of traditional and scientific forecasting systems offers a promising pathway toward more resilient and locally relevant climate adaptation.

Keywords — climate variability, indigenous knowledge, traditional weather forecasting, climate adaptation, agrometeorology, bioindicators, farmers, resilience

Introduction

Weather and climate have shaped human settlement, agriculture, and social organisation since the earliest periods of human history, and communities dependent on rain-fed

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https://gjirp.org/

agriculture and pastoralism have long developed systems of observation and interpretation to anticipate the conditions on which their survival depends. These systems, variously termed indigenous knowledge, traditional ecological knowledge, ethnoscience, or indigenous technical knowledge in the scholarly literature, rely on the close, generationally transmitted observation of biological, meteorological, and astronomical indicators, ranging from the flowering patterns of specific plants and the behaviour of birds and insects to the alignment of stars and the character of cloud formations, to generate forecasts of rainfall onset, seasonal quality, and extreme weather events.

Fig. 1: Data-Driven Weather Forecasting and Climate Modeling from the Perspective of Development

Source: ***https://www.mdpi.com/2073-4433/15/6/689***

The growing intensity and unpredictability of climate variability in the twenty-first century has renewed scholarly and policy interest in these traditional forecasting systems, for two related reasons. First, in many rural and remote regions, particularly across sub-Saharan Africa and parts of South Asia, formal meteorological infrastructure remains limited in its geographical resolution, timeliness, and accessibility, leaving traditional forecasting as a continuing, and in some contexts primary, source of locally actionable climate information. Second, as climate variability increasingly disrupts the seasonal regularities on which traditional forecasting systems were originally calibrated, questions have arisen regarding the continued reliability of these systems and the extent to which they can be meaningfully integrated with, rather than superseded by, modern scientific forecasting. This paper examines both dimensions of this relationship, situating traditional weather forecasting practices within the broader scientific understanding of climate variability and assessing the documented evidence for their continued relevance to climate adaptation.

Objectives of the Study

This study seeks to achieve the following objectives:

To clarify the scientific distinction between climate variability and long-term climate change as a conceptual foundation for assessing traditional forecasting practices.

To document and synthesise the principal categories of indicators used in traditional weather forecasting systems, drawing on documented case studies from East Africa, Southern Africa, and India.

To examine the empirical literature on the perceived and assessed reliability of traditional forecasting knowledge among farming and pastoral communities.

To evaluate the role of traditional weather forecasting in supporting climate adaptation and resilience, particularly in regions with limited access to formal meteorological services.

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https://gjirp.org/

To assess ongoing efforts to integrate traditional and scientific forecasting systems, and the challenges such integration presents.

To identify the structural threats facing the continuity of traditional forecasting knowledge and to propose directions for its documentation, validation, and integration into climate services.

Research Methodology

This paper adopts a descriptive-analytical research methodology based on secondary sources, synthesising peer-reviewed academic literature published in journals including *Climatic Change*, *Pastoralism*, the *South African Journal of Libraries and Information Science*, and *Climate and Development*, alongside working papers published by international agricultural research organisations and reports from the Intergovernmental Panel on Climate Change. The study draws primarily on documented empirical case studies employing household surveys, focus group discussions, and key informant interviews with farmers, pastoralists, and traditional forecasters across multiple regions, particularly East Africa (Ethiopia, Tanzania, Uganda), Southern Africa (South Africa, Zimbabwe), and India (Northeastern states, Rajasthan, Tamil Nadu, Karnataka). The study does not involve new primary data collection; it synthesises existing empirical findings to construct a comparative, evidence-based account of traditional weather forecasting practices and their relationship to climate variability.

Literature Review

The scholarly literature on traditional weather forecasting and climate variability can be organised around several converging themes: the documentation of indicator systems across diverse geographical and cultural contexts, farmer and pastoralist perceptions of the reliability of traditional forecasting relative to formal meteorological services, and emerging efforts to integrate traditional and scientific knowledge systems for climate adaptation.

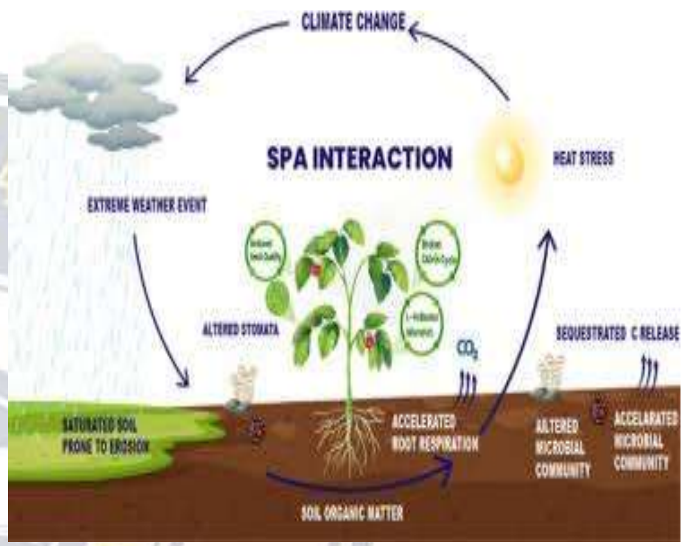

Fig. 2: SPA Interaction

Source: ***https://www.sciencedirect.com/science/article/pii/S2949919425000032***

A substantial body of empirical research has documented indigenous weather forecasting systems among pastoral communities in East Africa. Balehegn and colleagues, in a study published in the journal *Pastoralism* examining Afar pastoralists in northeastern Ethiopia, found that these communities traditionally predict weather and climate variation through the systematic observation of a diverse range of biophysical entities, including livestock behaviour, insects, birds, trees, and wildlife, information gathered through individual interviews and focus group discussions and

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Volume-2 Issue-3 || Jul – Sep 2026 || PP. 30 – 39
https://gjirp.org/

documented with the explicit aim of exploring synergies between indigenous knowledge and modern weather forecasting systems. This finding is substantially corroborated and extended in a comparative study published in *Climatic Change*, which documented and synthesised indigenous forecasting knowledge across case studies in Ethiopia, Tanzania, and Uganda, finding that farmers and pastoralists across East Africa employ a combination of meteorological, biological, and astrological indicators to forecast seasonal weather conditions and to inform crop and livestock production decisions. The same study found that astrological indicators, involving the observation of star positions and movements, were particularly pronounced among Borana pastoralists in Ethiopia, where traditional astrologists used such indicators to plan livestock mobility and resource-sharing arrangements among relatives and friends specifically to minimise losses during drought, and that both the Borana pastoralists and Tanzanian farmers in the Lushoto district considered indigenous forecasting a reliable source of climate information.

A parallel strand of research examines farmer reliance on indigenous knowledge in the context of perceived unreliability of formal weather services. Elia, Mutula, and Stilwell, in a study published in the *South African Journal of Libraries and Information Science* examining semi-arid central Tanzania, found that farmers in the study villages perceived conventional meteorological information as unreliable and untimely, and consequently turned to indigenous knowledge, encompassing observation of birds, insects, plants, animals, wind direction, and astronomical indicators, to predict weather patterns and adjust their farming practices accordingly, with uncertainty about seasonal forecasts identified as a critical factor sustaining continued reliance on traditional methods. This pattern of farmers valuing traditional forecasting precisely where formal services are perceived as inadequate recurs across the broader literature, including a study published in *Climate and Development* on techniques and skills of indigenous weather and seasonal climate forecasting in northern Ghana, which situates indigenous knowledge within a wider vocabulary encompassing traditional ecological knowledge, ethnoscience, and folk knowledge, and notes the documented applicability of such knowledge systems across multiple African contexts, including prior work in Kenya's former Makueni district and Zimbabwe's Chimanimani district.

Research from South Africa adds further empirical texture to this literature. A study published in a special issue on environmental policy, examining farmers in the Levubu and Nwanedi sites, assessed both the relevance of indigenous knowledge indicators to actual weather outcomes and farmer perceptions regarding climate change, explicitly noting in its review of literature that "much of the literature has shown that western scientific knowledge has failed at rural level," while indigenous knowledge has, for over a century, assisted rural farming households in addressing climate stressors and enhancing adaptive decision-making, though the authors also called for improved assessment methodologies to properly credit and validate indigenous knowledge systems rather than treating them as inherently either superior or inferior to instrumented forecasting.

Indian scholarship on traditional weather forecasting presents a similarly rich and geographically diverse body of documented practice. A study focused on Mizoram in Northeastern India documented that indigenous communities employ traditional calendar systems incorporating animal symbolism to forecast seasonal and climatic conditions, contributing to community resilience and adaptive capacity, with the study additionally noting that, despite this traditional knowledge base, a majority

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https://gjirp.org/

of surveyed respondents relied on radio broadcasts as their predominant weather information source, with traditional forecasters used by a smaller but still significant proportion of the community, suggesting a pattern of coexistence rather than outright displacement between traditional and modern information sources. Complementary research among the Bodo tribe of Northeast India similarly documented indigenous weather forecasting knowledge as a continuing and culturally embedded practice. Research conducted in Tamil Nadu's Salem and Kanchipuram districts documented indigenous forecasting methods used by both farmers and fishermen, finding that biotic indicators, including the presence of visible halos around the sun and moon, cloud formations, and wind direction, are used holistically to help farming communities psychologically and practically prepare for the agricultural year ahead, with indigenous knowledge additionally informing forecasts of monsoon onset, drought, flood, and cyclone. A review published in the *Journal of Farm Sciences* similarly documents that Indian farmers combine plant, animal, insect, meteorological, and astrological indicators, including wind direction and strength, star-moon alignment, cloud type, temperature conditions, lightning and thunder patterns, and sky colouration, to forecast rainfall onset, cropping season duration, and expected rainfall distribution, characterising indigenous technical knowledge as the accumulated experiential knowledge developed by communities over generations to manage climate-related vagaries, transmitted primarily through oral tradition rather than written documentation. Further documented Indian evidence connects traditional rainfall prediction explicitly to the traditional Hindu lunisolar calendar, or panchang, with farmers in arid and semi-arid regions such as Rajasthan reported to base seasonal rainfall predictions in part on this traditional astronomical-calendrical framework in combination with direct observation of animal behaviour and pre-monsoon ecological cues.

A further significant theme in the literature concerns explicit efforts to integrate traditional and scientific forecasting systems rather than treating them as competing alternatives. A working paper produced under the CGIAR Research Program on Climate Change, Agriculture and Food Security, examining the integration of indigenous knowledge with scientific seasonal forecasts for climate risk management in Tanzania's Lushoto district, and summarised in subsequent CGIAR reporting on lessons for building climate resilience in East Africa, found that the provision of context-specific, user-friendly weather information, potentially incorporating both indigenous and scientific inputs, is a key determinant of farmer and pastoralist resilience to climate variability. More recent Indian engineering and applied-science literature, including a study published by the International Journal of Engineering Research and Technology on integrating traditional knowledge with meteorological parameters, has explored the potential predictive value added by mathematically synthesising traditional ecological indicators alongside conventional meteorological variables, proposing institutional mechanisms such as block-level "Traditional Knowledge Weather Centers" staffed by locally trained personnel to formalise this integration, and suggesting extension of similar hybrid approaches to related domains such as avalanche and forest fire prediction.

Finally, the broader conceptual literature on climate variability itself provides essential grounding for interpreting these findings. The Intergovernmental Panel on Climate Change's glossary, developed for its Sixth Assessment Report, defines climate in the narrow sense as the statistical description of relevant quantities, most often surface variables such as temperature and precipitation, in terms of their mean and variability over periods conventionally spanning thirty years as defined by the World Meteorological Organization, while distinguishing this from climate change, defined as a statistically identifiable change in the mean or variability of climate properties that persists for an extended period, typically decades or longer. This distinction is significant for the literature on traditional forecasting, since traditional systems are calibrated primarily to interpret and anticipate climate variability, meaning fluctuations around an established seasonal baseline, and their reliability may be differentially affected as underlying long-term climate change gradually shifts that baseline itself.

Taken together, this literature demonstrates a broadly consistent pattern across geographically and culturally diverse contexts: traditional weather forecasting systems, grounded in intergenerationally transmitted observation of biological, meteorological, and astronomical indicators, continue to be actively used and, in many documented cases, actively trusted by farming and pastoral communities, particularly where formal meteorological services are perceived as inadequate, untimely, or insufficiently localised. At the same time, the literature increasingly points toward integration, rather than substitution, as the most promising direction for future climate services, combining the localised, culturally embedded strengths of traditional knowledge with the broader spatial and statistical reliability of instrumented meteorology.

Understanding Climate Variability

Climate variability refers to fluctuations in climate variables, particularly temperature and precipitation, around a long-term average, occurring across timescales ranging from intra-seasonal to multi-decadal periods, and encompassing phenomena such as El Niño-Southern Oscillation cycles, monsoon onset variation, and interannual rainfall fluctuation. This is conceptually distinct from long-term climate change, which the IPCC defines as a statistically identifiable shift in the mean or variability of climate properties persisting over decades or longer, whether driven by natural processes or anthropogenic forcing. This distinction matters directly for the study of traditional forecasting: such systems were developed and refined over generations to interpret and anticipate variability within a relatively stable long-term climatic envelope, and their continued predictive utility depends in part on the extent to which that underlying envelope itself remains stable, a condition increasingly challenged by anthropogenic climate change.

Categories of Traditional Forecasting Indicators

The documented literature identifies several recurring categories of indicators employed across traditional forecasting systems. Biological indicators encompass the observed behaviour, appearance, or timing of plants, animals, birds, and insects, including flowering patterns, migratory behaviour, and vocalisation, and are documented as the most variable category across regions, reflecting local ecological specificity. Meteorological indicators include direct observation of atmospheric phenomena such as cloud type and formation, wind direction and strength, temperature patterns, and the presence of solar or lunar halos. Astrological or astronomical indicators involve the observation of star positions, lunar phases, and, in the Indian context, the traditional lunisolar panchang calendar, used to anticipate seasonal transitions and rainfall onset. These indicator categories are frequently used in combination rather than isolation, with communities cross-referencing multiple signals to strengthen forecast confidence, a practice documented consistently across the East African, Southern African, and Indian case studies reviewed above.

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https://gjirp.org/

Traditional Forecasting and Climate Adaptation

The documented literature consistently frames traditional weather forecasting as an active component of climate adaptation strategy among farming and pastoral communities, rather than a residual or purely cultural practice. In the Borana pastoralist context, traditional astrological forecasting directly informs livestock mobility planning and resource-sharing arrangements structured specifically to minimise drought-related losses, representing a direct, actionable link between traditional knowledge and adaptive behaviour. In Tanzania, farmer reliance on indigenous knowledge has been explicitly linked to the perceived unreliability of formal seasonal forecasts, positioning traditional knowledge as a functional substitute where scientific forecasting infrastructure underperforms. In India, the continued, if partial, reliance on traditional forecasters alongside modern information sources such as radio broadcasts, as documented in Mizoram, suggests a pattern of pluralistic information-seeking behaviour among farming communities, who draw on multiple, complementary sources rather than relying exclusively on either system.

Integration of Traditional and Scientific Knowledge Systems

A growing body of applied research has moved beyond documentation toward active integration of traditional and scientific forecasting systems. The CGIAR-affiliated work in Tanzania's Lushoto district represents an early and influential example of this integrative approach, seeking to combine indigenous seasonal forecasting with downscaled scientific climate information to improve climate risk management for smallholder farmers. More recent Indian engineering research has explored quantitative approaches to synthesising traditional ecological indicators alongside conventional meteorological variables, with proposed institutional mechanisms, such as localised knowledge centres integrating traditional observers with trained meteorological personnel, intended to formalise this integration at the community level. Such integrative approaches respond directly to a recurring finding across the literature: that traditional and scientific forecasting systems each possess distinct strengths, traditional knowledge offering hyper-local specificity and cultural embeddedness, and scientific forecasting offering broader spatial coverage and statistical rigour, suggesting that their combination, rather than the displacement of one by the other, offers the most promising path toward resilient climate services.

Discussion and Analysis

The literature reviewed in this paper reveals a nuanced and geographically consistent picture of the relationship between traditional weather forecasting and climate variability. Traditional forecasting systems remain actively practised and, in many documented contexts, actively trusted by the communities that rely on them, particularly where formal meteorological infrastructure is perceived as inadequate in its timeliness, spatial resolution, or local relevance. This persistence reflects not mere cultural inertia but a rational adaptive response: traditional systems offer immediate, locally accessible, and culturally interpretable information at a scale and cost that formal meteorological services often cannot match in remote or under-resourced regions.

At the same time, the accelerating pace of anthropogenic climate change poses a genuine challenge to the continued reliability of traditional forecasting systems, insofar as these systems were calibrated over generations to interpret variability within a relatively stable seasonal baseline. As that baseline shifts, whether through altered monsoon timing, increased

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Volume-2 Issue-3 || Jul – Sep 2026 || PP. 30 – 39 https://gjirp.org/

frequency of extreme events, or disrupted phenological cycles among the biological indicators traditional forecasters rely upon, the predictive accuracy of traditional systems calibrated to historical patterns may correspondingly diminish, an area the literature identifies as warranting further systematic, comparative validation against instrumented rainfall records. The emerging integrative approaches documented in this review, combining traditional indicators with scientific meteorological data, represent a constructive response to this challenge, seeking to preserve the accessibility and local specificity of traditional knowledge while supplementing it with the broader statistical grounding of modern climate science.

Conclusion

Traditional weather forecasting practices, grounded in the intergenerationally transmitted observation of biological, meteorological, and astronomical indicators, continue to play a significant and empirically documented role in the climate adaptation strategies of farming and pastoral communities across East Africa, Southern Africa, and India. Far from being displaced by the advance of instrumented meteorology, these systems persist precisely where formal forecasting infrastructure remains limited in reach, timeliness, or local specificity, and continue to inform real adaptive decisions ranging from pastoral livestock mobility to crop planting schedules. At the same time, the accelerating pace of climate change presents a genuine and still incompletely understood challenge to the continued reliability of forecasting systems calibrated to historical seasonal patterns. The most promising direction for future research and policy, as reflected across the reviewed literature, lies not in choosing between traditional and scientific forecasting systems, but in their thoughtful integration, documenting, validating, and combining traditional ecological indicators with modern meteorological data to build climate services that are simultaneously scientifically robust and locally accessible, trusted, and actionable for the communities most directly exposed to a variable and changing climate.

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