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Towards a Replicable Innovative Tool for Adaptive Climate Monitoring and Weather Forecasting Using Traditional Indigenous and Local Indicators to Strengthen Agro-Weather Resilience at Scale

Joab J. L. Osumba[1*], Maren Radeny[1], John W. Recha[1], George W. Oroma[2], Oscar Nzoka[2], Joyce Mbingo[2], Enock Warinda[3], Simon Mwale[4]

[1] = CGIAR, International Livestock Research Institute (ILRI): J.Recha@cgiar.org; m.radeny@cgiar.org;
[2] = SNV Netherlands Development Organization: goroma@snv.org; onzoka@snv.org; jmbingo@snv.org;
[3] = Association for Strengthening Agricultural Research in Eastern and Central Africa (ASARECA): e.warinda@asareca.org
[4] = Centre for Coordination of Agricultural Research and Development for Southern Africa (CCARDESA): SMwale@ccardesa.org
**Correspondence: Joab Osumba J.Osumba@cgiar.org Telephone: +254722408387*

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Abstract
This paper presents lessons of a replicable innovative decision support tool to systematize traditional indigenous knowledge base for local climate monitoring and weather forecasting. The methodological tool, herein called the traditional indigenous and local knowledge tool (TILKIT), was conceptualized under two training-of-trainers initiatives on Climate-Smart Agriculture (CSA) in East Africa from March 2016 to December 2021. The aim was to build local momentum for consensus-based ethnographic weather monitoring, local weather forecasting and agro-weather advisory development for adoption by local stakeholders to improve agro-climatic extension service delivery. The objective was to strengthen local capacity of smallholder farmer leaders, agribusiness value chain partners, and field extension agents on the practical applications of indigenous climatology. Most of this indigenous traditional knowledge or local technical knowledge (ITK or LTK) is now getting lost due to climate change and loss of institutional memory but little effort is being made to identify and systematize the use of emerging ITK or LTK. It is against this background that these initiatives conceptualised and developed an innovative approach to bridge the gaps in order to address the challenges of salience, access, legitimacy, equity and integration of climate information to meet users' felt needs. The study adopted a transdisciplinary, participatory learning and action research (PLAR) model to identify and confirm emerging local weather indicators and what they mean for local rainfall forecasting, and to drive self-organization processes to bring indigenous climate knowledge into practical use in each community. The tool emphasizes a consensus-based co-production of local weather forecasts and agro-weather advisories to improve climate information services and extension service delivery. Testing and validation were conducted with 1,127 participants among various communities across Kenya, Tanzania and Uganda. Results comprise identified ethnographic weather prediction indicators per locality, and their implications for local weather forecasting, which for the first time is presented in probabilistic terms in a way local communities can associate with, and which can compare and contrast empirically with conventional weather forecast language. The tool also provides actionable agro-climate/ agro-weather advisories with appropriate lead times for local response, and a basis for strategic seasonal planning and operational risk management decision-making. Evidence from this work can be packaged for sensitization to influence policy reforms and decision-making at various levels among relevant stakeholders in the region.

Keywords: Rainfed, climate risk, folklore ITK, community-based, early warning, lead time, planting window

1. Introduction

1.1 Context and background infromation

Generating locality-specific and easily understandable local climate forecasts can enhance the capacity of smallholder crop growers, livestock producers, aquaculture practitioners, pastoralists and agro pastoralists (all herein henceforth referred to as "farmers") and other agricultural stakeholders to use climate forecasts to manage local climate risk [8]. This article describes an innovative community-based adaptation (CbA) decision support tool for indigenous, traditional and local climate monitoring and weather forecasting to strengthen climate risk management and resilience in agricultural production, agricultural value chains and agribusinesses. The tool, applying indigenous, traditional and local technical knowledge (ITK, LTK), rides on the back of transdisciplinary co-production and downscaling, monitoring, forecasting, dissemination and communication of locality-specific weather forecasts and agro-weather advisories (early warnings, alerts and suggestions) using consensus-based ethnographic weather indicators to overcome the challenges of salience, access, legitimacy, equity, and integration of climate information services into extension service delivery. Local community ownership of co-generated weather forecasts simultaneously addresses these challenges to meet end users' "felt needs" [9]. This study tested the hypothesis that identifying, monitoring, analysing and tallying several traditional indigenous and local indicators (TILI) of weather leads to determination of a local weather forecast to enhance local adaptive capacity of smallholder farmers and pastoralists in Eastern Africa. A second test was that authentic traditional/indigenous/local knowledge methods of weather forecasting using authentic (non-mystical) experiences validated by local community members is more sustainable than the mystical, ritualistic "rainmaker" model or the "elderlies-only" model.

Indigenous weather information (using agreed indicators) was observed, recorded, analysed, tallied and reported to determine local weather forecast probabilities. The objective was to draw upon common knowledge among local communities and not to rely only on the preserve of a few privileged members of the community, viz the mystical, magical, elderly male "rainmakers" [10]. ICPAC and national meteorological agencies have done pilot studies on forecast co-production and integration but the pilots are heavily inclined towards mystical dimensions which is not replicable or testable beyond the local community [10]–[12]. Currently there are weak mechanisms for collecting information on climate risks to help tailor the subsequent content for proper integration. What often happens in such pilots is merely to ask subjective questions about whether traditional weather predictions correlate with conventional forecasts, without any corresponding empirical comparison [15]. The tool presented here provides opportunity for empirical comparison. Indigenous or traditional methods of weather forecasting using authentic (non-mystical) experiences validated by local community members will be more sustainable than the mystical, ritualistic rainmaker model.

Despite the availability of relatively more reliable forecasts from conventional meteorological services, farmers seldom use their climate and weather information for farm level decision-making because they are not adapted to the locality and it is difficult for farmers to access the information on time and in a format that they can easily understand, so its uptake by small-scale farmers has been limited. Farmers and pastoralists seldom use the coarse macro-weather forecasts for local level decision-making because either they are not adapted to the locality or it is difficult for them to access the information on time or in a format they can easily understand. It is against this background that this study was set to explore options for applying community-based local indicators of indigenous and traditional weather forecasting to support the needs of stallholder farmers and pastoralists, and communication gaps in forecast information availability and usability to enhance local adaptive capacity of smallholder farmers in East Africa [10], [16]. Several community workshops were held in the region to test a new decision-support tool for forecast information generation, communication and usability to enhance local adaptive capacity of local communities. The study tested a new tool for local weather forecasting and advisory development, communication and usability to enhance local adaptive capacity of smallholder farmers in

the region. Through this improvement farmers and pastoralists will be able to take advantage of good seasons and minimize risks in bad seasons.
At present, farmer and pastoralist access to seasonal forecasts is limited, and the ability of farmers and pastoralists to interpret probabilistic climate information is inadequate. Local climate information needs to be considered in strategic agricultural planning and tactical, operational decision-making [17], or even in emergency response. Based on the weather information generated, the indicator assessment facilitates the determination of local lead times for scalable strategic, tactical, operational and emergency decisions in local agro-weather risk management, additional to conventional weather forecast, which often comes late. Although ITK-LTK-based weather prediction is inbuilt and established among many local communities in East Africa, systematic monitoring, observation and tallying of ITK-LTK for local weather forecasting has never been attempted. This article systematizes in an ITK-LTK methodology and tool for weather forecasting in East Africa using community-based studies from Kenya, Tanzania, and Uganda.

Improving agri-food systems and food security needs appropriate climate and weather risk management strategies, including the use of climate and weather information to guide local level planning and decision-making in the agriculture sector. Agricultural and agro pastoral production (crops, livestock and fish) are critical to food security and are largely climate-dependent yet, in many localities, climate and weather information services that effectively address the needs of farmers, fisherfolk and pastoralists are very limited. Improving food security needs appropriate weather and climate-oriented risk management strategies, including the use of weather and climate information to guide local level decision-making. Access to timely, reliable, context-specific and user-friendly local seasonal weather and climate information is critical to the resilience of agricultural producers and pastoralists, especially under conditions of increased climate variability and unpredictable rainfall regimes occasioned by climate change [20]. The high level of climate variability associated with climate change requires a new methodology and tool to forecast and predict seasonal weather for strategic, tactical and emergency decision-making by agricultural sector stakeholders, especially farmers [1]–[5], [5]–[7]. However, despite significant progress in modern climate science scientific in Kenya, most of the seasonal weather forecasts are not yet locality-specific, not yet accessible, not yet timely, and often not yet locally relevant nor locally useable.

Indigenous Traditional Knowledge and Technologies (ITKT) variables and indicators have been used widely by local communities in the past to assess and predict local weather conditions as an adaptation measure for weather forecasting, climate prediction and water management to improve resilience in agricultural production. Improving weather and climate forecasting through the integration of modern science and ITK/ LTK is an area of growing interest and is an area in which indigenous peoples and local communities, especially local communities' women who mostly manage local natural resources, have much to contribute [21]. For instance, the Maasai still predominantly use traditional methods based on ITK/ LTK to manage livestock feeding (85.8%), livestock diseases (89.9%), livestock breeding (74.2%) and livestock protection against predators and other incidental accidents [22]. More so, indigenous peoples and local communities' women are at the forefront of helping their communities manage these challenges, through their key roles in identifying, applying, transmitting, and preserving the traditional knowledge that builds and sustains the resilience of local communities in the face of shifting seasonal weather patterns. The purpose and objective of this paper is to explore how climate information can be made more accessible and relevant to rural people whose livelihoods depend on it.

1.2 Purpose and objectives

The purpose was to develop a decision support tool for local climate monitoring and weather forecasting. The objectives of the study were: 1) to explore traditional, indigenous and local weather prediction indicators, 2) to draw upon what is common knowledge among local communities and not just what is a preserve of only a few privileged (often mystical, magical rainmakers, elderly, male) rainmaker members of the community, and 3) to interpret what the observation means for the season.

1.2 The gap – Literature Review

1.2.3 Challenges, gaps in and barriers to local climate monitoring and weather forecasting

Achieving forecast credibility with local communities using modern climate science among is a well-documented common problem faced by producers of scientific forecasts [23]. Currently there are weak mechanisms for collecting information on climate risks to help tailor the subsequent content for proper integration. For that reason, weather information as currently available in East Africa is mostly inadequate, imprecise, incomprehensible and mostly unreliable, and rainfall information is mostly provided in probabilities while farmers want the information in amounts. Some communities get climate information, mostly through the media, but most do not know how to act on the information received as it is often either too general, full of jargon or does not just represent the situation prevailing in their area. In the absence of reliable conventional weather information, many farmers and pastoralists resort to indigenous climate knowledge to fill the gaps. In traditional societies weather predictors helped villagers plan their agriculture activities based on how they sensed the forthcoming weather (human body sensing) and what they observed in the surrounding nature (plants, animals, birds, insects, heavenly objects, etc.) – Table 1.

Table 1: Indicators of indigenous, traditional and local rainfall prediction

Item/object:	Source documentation
Observations of…. • **The Sun**	[24],[25]
• **The Moon**	[24],[25]
• **The Stars**	
• **The Clouds**	[25]
• **The Wind**	[24]
• **Dew**	[25]
• **Etc.**	
Behaviour of • **Lightning/Thunder**	[25]
• **certain Flora/Plants/ Trees**	[26]
• **Termites**	
• **certain Insects**	[26]
• **certain Reptiles**	
• **certain of Birds**	[26]
• **certain Fauna/Animals**	[26],[25]
• **Etc.**	
Feelings/ sensations/ reactions in the Human Body (e.g., ambient temperature, humidity, etc.)	[25]
Etc.	

Majority of users trust traditional knowledge weather information more than conventional weather forecasts. However, climate change is impacting previously reliable local indicators[1] of weather prediction through disappearance or altering the attributes the indicators due to climate variability and human induced activities, making traditional weather forecasting less dependable as currently designed [27]. Further, the mystical or ritualistic "rainmaker" model of ITK/ LTK relied on by most of the local communities is too secretive hence unsustainable, and the use of elderly members of the community for that purpose is also not sustainable because individuals in this "elderly" generation are phasing out due to natural attrition.

The role of indigenous and traditional knowledge in sustaining the livelihoods of Kenya's indigenous and local communities has often been neglected in the climate and weather sector. Whereas the science of long-term macroclimate forecasts is well advanced, short-term local implications of weather and seasonal variations remain the least well addressed. Although progress has been made in providing climate services in Kenya, there are significant gaps with regard to locality-specific forecasts, as well as generating timely, reliable and user-friendly weather information. It is often argued that the problem with scaling ITK/ LTK of weather and climate is because it is context-specific and is not often documented, mainly sustained from one generation to another through oral history and local expertise or skills, and that the elders who are the custodians of this knowledge, skills and experience are exiting the scene, creating a wide inter-generational gap between the elders and the current generation. It is also often argued that these challenges are likely to worsen with climate change, mainly due to the changing behaviour and/or progressive disappearance of traditional indicators of local weather monitoring to determine a forecast, a situation which, it is argued, threatens the ability of crop producers and pastoral livestock keepers to cope with and adapt to climate change [28]. Often there is pressure on practitioners, researchers and stakeholders to collect, preserve, validate and adopt these ITK/ LTK indicators. However, the initiatives introduced so far to address this problem have been largely project-based, ad hoc and academic, with no clear decision-support tool to move the conversation to a practical and sustainable model, always fizzling out as soon as the project closes.

What is basically needed in the changing circumstances is not necessarily the uniformity of indicators or the presence historical experts or mystical/ritualistic rainmakers but a robust, easy to administer decision-support tool that can be owned by local communities and be applicable across different ethnographic and socio-cultural contexts. Instead of looking back to mystical or ritualistic rainmakers (all male) who are often secretive and not sustainable, or elders (all male) who are increasingly losing their grip on the traditional knowledge due to climate change and/or leaving the scene by natural attrition, making it irreplicable, unscalable and impossible to institutionalize [11], [29]–[31], it is possible to build a new set of knowledge using a new tool by opening the conversation with the whole community (both male and female, youthful and elderly) to identify emerging indicators and experiences [32]. This approach can support empowerment of women and youth through recognizing and valuing their knowledge and roles as change agents in using ITK/ LTK and can help to ensure that valuable ITK/ LTK held by local communities' women is not missed out in efforts to integrate scientific knowledge and ITK/ LTK of climate solutions. Through the new tool, local indicators that have become increasingly less reliable can be recalibrated and validated.

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[1] Such indicators may include biological (behaviour of plants, animals), ecological (behaviour of ecosystems, etc.), physical (behaviour of objects and materials, position and motion of objects, water-related features e.g., dew, etc.), celestial or astrological features (behaviour of whirlwinds, moon, etc.), behaviour of the human body (sensations), etc., all of which are validated through observation and monitoring

1.3 Decision-support tool for local climate monitoring, weather forecasting and advisory development

This paper systematizes an innovative decision-support tool, the traditional indigenous and local knowledge tool (TILKIT), for local climate monitoring and weather forecasting in East Africa using Climate-Smart Agriculture (CSA) training and capacity building activities in Kenya, Tanzania, and Uganda. This is an early-warning and decision-support TILKIT tool for weather forecasting, tested and validated in various local level training sessions with 1,127 participants among various communities across East Africa from March 2016 to December 2019. It is a versatile Community-based Adaptation (CbA) decision-support tool for local climate monitoring and weather forecasting developed for effective validation and scaling of traditional climate monitoring and weather forecasting in various localities. The tool emphasizes transdisciplinary monitoring, dissemination and communication of local climate and weather forecasts and agro-weather advisories using consensus-based ethnographic indicators to overcome the challenges of salience, access, legitimacy, equity, and integration of climate information into extension services to satisfy users' felt needs. It adopts a participatory learning and action research (PLAR) model to drive self-organization processes and to bring ITK/ LTK of climate into the common knowledge pool in each community. It is meant to build local capacity for local weather forecasts and agro-weather advisories using consensus-based ethnographic weather indicators to improve climate extension service delivery.

The accompanying methodology focuses on local climate risk management as the main basis for devising adaptation strategies at local level. Identified local climate and weather indicators are observed, recorded, analysed and reported. The approach is to 1) identify and confirm (i.e., groupworks propose and plenary concurs) known local indicators that signal rain issues, 2) describe what that indicator means in terms rainfall forecasting in the locality, 3) determine whether or not the indicator has been observed in the season, 4) where it has been observed (if already observed), and 5) interpret what the observation means for the coming season – whether based on the indicator the rains can be normal, above normal or below normal, where normal is defined as local historical expectation. Depending on the number of TILI indicators the community identifies and the number of signs each indicator exhibits, it is possible to tally the observations and estimate percentages of the normal, above or below normal rainfall predictions in the community, and then derive locally appropriate advisories for the season. Results comprise identified ethnographic weather prediction indicators per locality, both celestial and environmental-biophysical, and their implications for local weather forecasting.

2. Materials and Methods

2.1 Study area and target population

The study covers the three East African countries of Kenya, Tanzania and Uganda, targeting smallholder farmer group leaders, agricultural extension agents, agricultural researchers and agro meteorologists, action researchers, climate extension and input service providers, farmer organizations, private sector, the media and other value chain actors.

2.2. Study design, approach & methodology

The study adopted a transdisciplinary, participatory learning and action research (PLAR) model to bring indigenous, traditional and local climate knowledge into the common knowledge pool and to drive self-organization processes in each community, including feedback loops necessary for knowledge integration, for a concurrent validation of methods and results, verified with scientific and technical knowledge [34]. Terminologies were defined and translated into local language before further discussion.

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The testing was conducted from 2017 to 2021. Fieldwork conducted at different times within the period. The scope of interventions covered:

1. Train agro-climate extension and input service providers, farmer organizations, private sector and other value chain actors, in the use of ethnographic methods for local climate information service delivery and feedback processes, and in the use and implementation of climate-informed agronomic options at scale, through sustainable delivery channels and platforms
2. Support communities to co-generate and disseminate local ethnographic weather forecasts using indigenous, traditional, natural, non-mystical indicators of community weather prediction to enhance preventive climate risk management
3. Refine the tool

2.3. Conceptual framework for traditional indigenous and local weather forecasting

The concept of traditional weather forecasting among indigenous and local communities is premised on the understanding that most elements of nature, lifeforms and weather correlate positively or negatively. There are lifeforms and natural objects that behave in a way that if monitored can be used to understand and predict weather events, thereby making forecasts from that understanding and prediction. The conceptual framework for the study (presented in Figure 1) stems from the broad understanding of the terminologies traditional, indigenous, cultural and ecological knowledge of local communities.

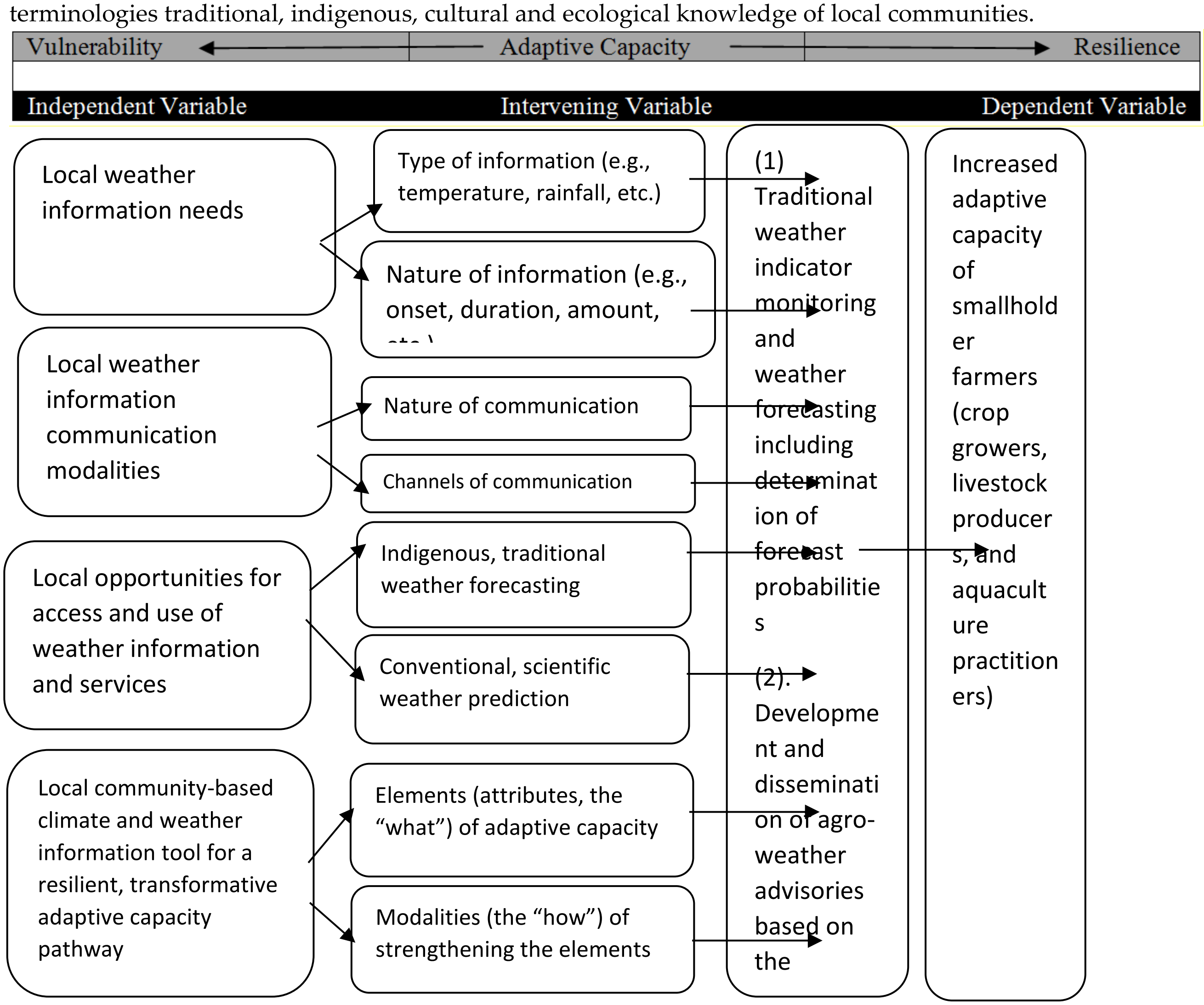

Figure 1: Conceptual Framework
It is becoming increasingly accepted that the concept of Indigenous knowledge goes beyond this narrow interpretation to include traditional and contextual knowledge of local communities, encompassing cultural knowledge in its broadest sense, including all of the social, political, economic and spiritual aspects of a local way of life [35]. The concept is based on the variables that feed into the innovative tool for indigenous weather forecasting described in Figure 2. The concept comprises four key elements, viz., knowledge of local climate risks and local vulnerabilities; monitoring of local weather using local indicators, analysis and forecasting of weather hazards based on indicator behaviour, dissemination and communication of advisories (warnings, alerts and suggestions) based on the forecasts; and local capabilities to respond to the warnings generated and/or received.

2.4 Approach to data collection and data analysis

The study began with a desktop synthesis of relevant information. Fieldwork was conducted at different times. FGD was conducted with community and group leaders and beneficiaries to explore climate events, trends and forecasts. The indigenous weather indicators session was facilitated both in groups and in plenary during the workshops and contributed by all participants to share their experiences, based on the principle that traditional practice of rainfall forecasting is embedded in community experience and socio-cultural beliefs. The facilitators deliberately omitted the common tendency of inviting known mystical, ritualistic rainmakers to present their skills to the audience and use the same to predict the forthcoming weather in the locality. Instead, the facilitators adopted a workshop plenary approach where all the participants had an equal chance of contributing what they know about local traditional forecasting of seasonal rainfall. The approach was to identify (=groups propose in groupwork) and confirm (=plenary agrees in discussion) known local indicators that signal rain issues, describe what that indicator means in terms rainfall forecasting in the locality, determine whether or not the indicator has been observed in the season, and where it has been observed (if already observed). The last step was to interpret what the observation means for the coming season – whether based on the indicator the rains can be normal, above normal or below normal, where normal is defined as local historical expectation. Depending on the number of indigenous indicators the community identifies and the number of signs each indicator exhibits, it is possible to tally the observations and estimate percentages of local rainfall predictions (the normal, above or below normal) in the community, with clear lead times, additional to conventional seasonal weather forecast, which is often released too late for effective farm level planning.

A briefing was done to set the stage for scenario building and development of advisories through groupwork. Facilitators first discussed several terminologies used in scenario development, using participatory modes to translate them into vernacular and explaining the meaning of each. Once the participants agreed they have understood the concepts, the facilitators divided them into discussion groups on scenario planning and advisory development. Using the indigenous forecast generated by the community participants and the conventional forecast presented by the meteorological service experts, the workshop came up with areas that needed action. Group discussion was explained to entail mapping of scenarios for the three weather/ rainfall conditions as it is likely to impact agricultural livelihoods. Advisories were developed based on the scenarios presented. The mode of grouping was based on commodity and locality, considering the target commodities and then nesting localities into the two groupings. Participants were divided into two groups on that crop basis. The mode of grouping was based administrative subunits forming the larger unit, considering the target commodity for the subunit in the meantime. The developed scenarios and advisories were presented in plenary, discussed to assess their validity and usefulness, and merged, integrated and packaged to reflect synergy and complementarity. This discussion was used as a forum to jump-start the process of communicating advisories. Data was analysed using both qualitative and quantitative methods.

2.5 Implementation

At each workshop, engagement and dialogue about local climate was always started with historical trends and impacts, before moving to the forecasts. Historical trend conversations revolved around hazards (meteorological/ biological/ physical), risks (agronomic/ ecological), impacts (economic/ social) and opportunities (e.g., resources available, actors who can be approached, etc.). This part was used as an icebreaking session to prepare the participants for the climate indicator identification and weather forecasting exercise.

3. Results

Synthesized results are presented in this article in narrative texts, tables and figures.

2.1 Participation

The testing and validation were conducted with a total of 1,127 participants across various communities in East Africa (Kenya, Tanzania, Uganda), from March 2016 to July 2021 (Table 2).

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Table 2: Participation results

Country	Cohort	Date	Total # of participants	Remarks
Kenya	Homa Bay and Migori	March 2016 and February 2017	129	STARCK+ Farmer representatives from one sub county in Migori and six sub counties in Homa Bay during CSA trainings
	Siaya	March 2016 and March 2017	150	STARCK+ Farmer representatives from five sub counties in Siaya during CSA trainings
	Kisumu	March 2017	67	STARCK+ Farmer representatives from six sub counties in Kisumu during CSA trainings
	Kisumu	March 2019	33	CRAFT and AICCRA – representing two farmer aggregators reviewing for CRAFT the work done by CCAFS from 2011 to 2018
	Kitui and Nakuru	August – September 2019	107	CRAFT and AICCRA – representing ten farmer aggregators and one local service provider
	Nakuru, Kisumu, Machakos, Narok, Embu,	June– July 2021	87	CRAFT and AICCRA – representing Farm to Market Alliance or FtMA [Cereal Growers Association (CGA) and Participatory Approaches for Integrated Development (PAFID)] and County Governments of Nakuru, Narok, Machakos and Embu, in a collaboration between CRAFT and the FtMA Initiative implemented in Kenya by World Food Programme (WFP)
Tanzania	Dodoma, Singida and other venues	September – December 2019	215	CRAFT – representing nine farmer aggregators
Uganda	Lira, Gulu and other venues	July – December 2019	339	CRAFT and AICCRA – representing 35 farmer aggregators
Total			1,127	Three countries; 6 years

3.2 Local seasonal weather forecast results

A screenshot image of the TILKIT tool is presented in Figure 2, using actual groupwork sample. Results of the discussion generally shows that different movements of certain insects, sounds of certain birds, nature/speed/direction of wind, behaviour of certain frogs, behaviour of certain plants/trees, ebbing of the lake tide, constellation of certain stars and specific feelings in the human body among other indicators help to determine weather forecasts.

igure 2: Example of actual groupwork output using the tool, Narok County, Kenya, July 2021

Groupwork: Traditional, indigenous and local community weather forecasting exercise:

In groups, share your experiences on traditional indigenous and local knowledge indicators (TILKI) of rainfall in your community

A1	B2	C3	D4	E5		
Traditional, indigenous and local indicator of weather in your area	**Local meaning for weather in the locality (in terms of whether there will be rain or drought, or whether the rains will be normal, more or less)**	**How long does it take for the prediction after witnessing the indicator**	**Have you already seen it this season? – meaning do we have a forecast based on this indicator**	**In view of, and based on, the information so far available from the weather indicator, by the rating of this locality:**		
				Is the rain for the season likely 0) no forecast yet 1) above normal or 2) normal, 3) below normal?	**When (dates range) is the rain likely to start or stop if it will happen?**	**What farming plans or actions, or strategies will you adopt based on this traditional weather forecast information available to you?**
Dew after long dry spell	Onset of rain	1 week	yes	2	Rains expected within days	Planting, planning for fertilizer application.
Clouds at 5am	Onset of rain	1 week	yes	2	Rains expected within a week	Planting, weed control
Lightning at the west	Onset of rain	1 week	no	0	Days after occurrence	Planting, weeding, fertilizer application.
Very Chilly morning	Beginning of dry spell	2 days	no	0	After a long time (not defined)	Water conservation, mulching,
When Moon disappears	Onset of 1 week-long rain	3 days	Yes	3	Days after occurrence	Planting, setting of farm structures.
Total tally for normal, above normal and below normal scores	**Summary of meanings for the indicators**	**Summary of lead times for indicator prediction**	**Tallies for Yes and No**	**Above normal = Y% Normal = X% Below normal = Z%**	**Summary of expected dates of onset**	**Summary of adaptation options suggested**

Source: author construct

A sample of identified TILKIT indicators for indigenous weather prediction are presented in Table 2, where the column for dates and advisories are omitted to save space for illustrating the forecast. From Table 2, it is shown that the shortest lead time in the forecast is one day. One-to-two-day or less than one week lead times lead times can be used for emergency decisions. TILKIs with long lead times can be used for strategic planning while those with short lead times can be used for tactical decision making [37], [38]. From Table 2, it is shown that the shortest lead time in the forecast is one day. One-to-two-day or less than one week lead times lead times can be used for emergency decisions on-farm. The longest lead time indicated is three months. A lead time of two-to-three months can be used for strategic planning by the community. Lead times of one week to one month can be used for tactical decisions in the community and on the farm. The longest lead time indicated is three months. A lead time of two-to-three months can be used for strategic seasonal planning by the community. Lead times of one week to one month can be used for tactical and operations decisions in the community.

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Table 2: Local traditional weather forecast – in plenary at the community workshops
Only a few indicators presented to save space. Each community can test their own indicators

Indicator category	A1	B2	C3	D4	E5
	Traditional indicator of indigenous weather prediction in the community/ locality/ area	Description: Local meaning for weather – Local meaning for weather in the locality (In terms of whether there will be rain or drought, or whether the rains will be normal, more or less)	How long does it take for the prediction, after witnessing the indicator?	Forecast (Y=Yes)	In view of, and based on, the information so far available from the weather indicator, by the rating of this locality: Is the rain for the season likely: 1) above normal or 2) normal, 3) below normal?
Celestial/ Astrological	Whirling wind from the lake	Depressed rain within a week	1-2 weeks	Y	Below Normal
	Whirlwind-to east	Rainfall	One week	Y	Above normal
	Whirlwind-West wards	Dry spell	One week	Y	Below normal
	When at Mwingi and the new moon faces Tanzania	Dry spell	3 months	Y	Below normal
	Full moon with halo (kivuuiyo)	Rain expected	1-2 weeks	Y	Above normal
Physical	Absence of dew on leaves in the morning	Rain on the same day	1 day	Y	Normal
	Morning Dew & fog	Dry spell	1-2 weeks	Y	Below Normal
	Lightning around Kisumu and Tinderet area	Rainfall	2/3 months	Y	Above normal
Biological	Regeneration of new leaves in acacia tree species/ Acacia starts to sprout	rains are approaching	1-2 weeks	Y	Normal to above normal
	Blooming of baobab trees.	Rains in few weeks	2-3 weeks	Y	Normal
	Shedding of leaves- Baobab	Dry spell	1-2 weeks	Y	Below Normal
	Frequent encounter of snakes, rodents and rabbits etc out of their habits	Dry spell	One month	Y	Below normal
	Touching down of dragon flies	Rain same day	1 day	Y	Normal to above normal (when they are many) Below normal (when they are few)
	Livestock restlessness	Dry spell	2 weeks	Y	Below normal
	Livestock oversleeping	More rain	2 weeks	Y	Above normal
	Croaking of frogs	Rain expected	1 to 2 weeks	Y	Normal
	Bee migration	Dry spell	1 to 2 weeks	Y	Below normal

	White butterflies	Rainfall	After-two weeks	Y	Above normal
	White birds/ chebiswet	Rainfall	One day	Y	Above normal
	Army worm	Dry spell	2 months	Y	Below normal
	Presence of red ants/ kumbe kumbe/ kongaek	Rain	One week	Y	Above normal
Human body behaviour (sensing)	High temperature (Yiungu)	Rain	1 to 2 weeks	Y	Above normal
	Soil smell- "pleasant"	Rain	1-2 weeks	Y	Normal
Forecast for the season: Total tally for normal, above normal and below normal scores; Summary of meanings for the indicators; Summary of lead times for indicator prediction		Above normal = 8 Normal to above normal = 6 Below normal = 10 Total = 24		Y	Above normal = 33% Normal to above normal = 25% Below normal = 42%

Note: Indicators with long lead times can be used for strategic planning while those with short lead times can be used for tactical and/or emergency decision making(Garcia et al. 2010; World Meteorological Organization, World Meteorological Organization, and Organisation Météorologique Mondiale 2011)(Garcia et al. 2010; World Meteorological Organization et al. 2011). In Table II the columns which covered questions on whether the meaning attached to the indicator has manifested, and based on that manifestation, when they expect the prediction of the manifestation to occur. Column for advisories based on that forecast is also omitted in this table. A screenshot image is presented in Figure 1 to illustrate the whole table. Note: The efficacy of the traditional forecast is premised on monitoring and observing as many local indicators as possible, tabulating the observations and their implications, and summing up their predictions to obtain forecast probabilities

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3.1 Weather forecasting and agro weather advisory development using the TILKIT tool

Agro-weather advisories were prepared based on the scenarios developed following the conclusion of the forecast in scenario outputs, providing options in line with the percentages of normal, above normal and below normal forecasts. Facilitators first discussed several terminologies used in scenario development, using participatory modes to translate them into vernacular and explaining the meaning of each. This briefing was done to set the stage for group work. Once the participants agreed they have understood the concept, the facilitator divided them into discussion groups on scenario planning and advisory development. Using the forecast presented by the participants, the workshops came up with areas that needed to action. Group discussion was explained to entail mapping of scenarios for the three weather/rainfall conditions as it is likely to impact agricultural livelihoods in general and sorghum/cassava in particular. The developed scenarios and advisories were presented in plenary, discussed to assess their validity and usefulness, and merged, integrated and packaged to reflect synergy and complementarity. This discussion was used as a forum to jump-start the process of communicating advisories.

3.2 Dissemination and communication of the developed agro weather advisories at community Level

Various actors agreed to disseminate advisory information arising from the process. They also request conventional meteorological agencies to share targeted formal locality-specific climate weather forecast to targeted recipients for comparison and validation. Matters of who will do the dissemination, and what existing channels can be used, we discussed and agreed (Example in Figure 3. Short term updates (e.g., weekly, monthly) were requested, based both on community monitoring and conventional climate information services.

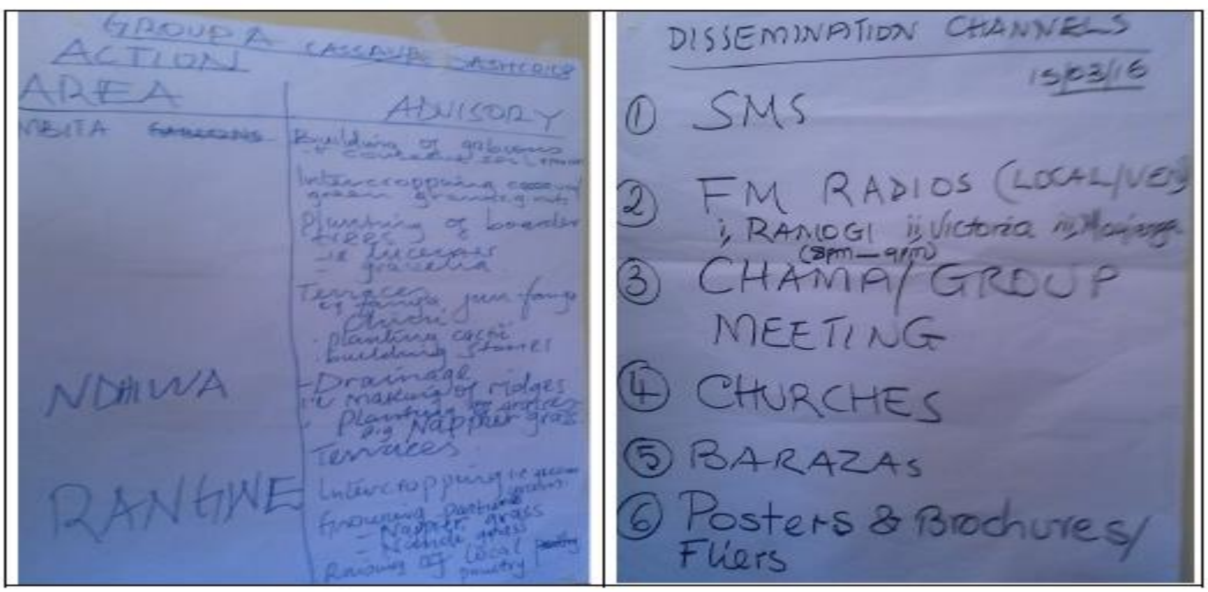

Figure 3: Group-A "Action Plan" and Agro-Weather Advisory "Dissemination Channels" for Homa Bay County, MAM 2016.

Agro Weather Information Dissemination Channels at Community Level were listed as

- Radio: vernacular FM stations
- Television
- Newspapers/bulletins/ brochures

- E-mail
- Phone: Bulk SMS, WhatsApp
- Internet: Websites, social media accounts
- Community based baraza meetings, field days, churches/ mosques, Funerals

Dissemination plan for implementation of advisories included

- Phone: Bulk SMS
- Advisories to be produced/printed and disseminated to all stakeholders, especially aggregators and technical partners

3.5 Potential for integrating the TILKIT tool in weather forecasting strategies, policies and programs

There are many ongoing efforts aimed at improving climate forecasting and its use. Traditional weather and climate forecasting is used by many indigenous communities globally as a guide in making vital decisions that enable them to cope and adapt to the effects of the climate change-induced extremes in weather variation [27]. The use of scientific and indigenous climate forecast information for farm level decision making has been reported in Kenya among other countries (Lucio 1999, Ngugi 1999). These initiatives support livelihood resilience and climate adaptation in the face of increased climate variability and extremes, some of which have integrated Local and Traditional Knowledge (LTK) into service development, improving the relevance, legitimacy, useability, and sustainability of the service. However, so far LTK has not been integrated systematically into the development of climate services alongside scientific knowledge [23]. However, the actual state of meaningful integration is limited and scientific knowledge is typically prioritized in forecast production and service development [23]. The Kenya Meteorological Department recognizes and works towards integrating and blending indigenous and traditional forecasts with science-based predictions to produce more useable weather and climate data at the local level [39]. In the process of developing the tool described in this paper, similarities and differences between traditional/community and scientific forecast were identified and described. Some of them are presented here. Similarities of indigenous and conventional forecasts were found to be as follows:

- ✓ Both are based on observation of nature
- ✓ Both have a scientific basis
- ✓ Both can forecast onset and the quality of the season to come
- ✓ Both are accompanied by warnings on likely risks and hazards
- ✓ Both use signs/indicators and patterns
- ✓ Both use observance of wind
- ✓ Both can forecast below normal rainfall or an impending dry spell

Differences between traditional/community and scientific forecast as discussed are presented in Table 4. Each of the two models of weather forecasting and climate information generation and dissemination has its strengths and weaknesses, but each also provide opportunities for synergy between them.

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Table 4: Similarities and differences between indigenous and conventional forecasts

Attribute	Indigenous traditional method	Conventional scientific method
1. Amount of rainfall	• Can only guess amounts, e.g., more, less, etc.	• Able to present amount (e.g., 500mm)
2. Scenarios (terminologies used)	• Much, Little, Moderate, Average	• Normal, Above Normal, Below Normal
3. Distribution (Space/locality, Time (days, months)	• May not be able to guess	• Poorly estimated but can be estimated (in time and space)
4. Presentation	• Mostly oral	• Mainly visual
5. Prediction	• Uses local historical trends to predict future projections	• Uses global historical trends to predict future projections
	• Can forecast from 1 day up to 2 months or 3 months after indicator is seen	• Can forecast up to and beyond 3 months
6. Onset	• Can make a guess of onset	• Can calculate an estimate of onset
7. Cessation	• Generally, not capable of guessing cessation but some indicators are emerging which can give hints in the middle of a season	• Can calculate an estimate of cessation
8. Duration of rain	• Can guess that the rains will be longer	• Can calculate start and end date
9. Length of season	• Can guess length of season (by intensity of frog croaking)	• Can calculate length of season
10. Off-season rains	• Difficult to deal with off-season rains	• Can give a clear indication of off-season rains
11. Nature of forecast	• Narrow in coverage and only momentary in relevance • Culture-based and may be interpreted differently for different areas • Not always documented in ways that farmers can understand • Does not apply weather instruments and probability • Cannot forecast amounts, distribution and end date • Process/ procedures are not documented • Emphasizing relationships between multiple parameters/ indicators • Easily available and accessible for use in agriculture by locals • Culture-based and interpreted differently for different areas • Easy to interpret and easy to make decisions based on the observations made • Relies mostly on holistic assessment of parameters/ indicators to inform decisions	• Has a wide spatial-temporal coverage/relevance • Not culture-based and is interpreted uniformly for different areas • Not always documented in ways that farmers can understand • Applies weather instruments and probability • Can forecast amounts, distribution and end date • Process/procedures well-documented • Focusing on individual parameters/ indicators of high predictive value • Not easily available and accessible for use in agriculture by locals • Not always documented in ways that farmers can understand • Difficult to interpret and not easy to make decisions based on the probabilistic information given • Relies mainly on individual mean values of parameters/ indicators to formulate advisories
12. Potential extent of extreme and/or severe weather events	• Not able to quantify the potential	• Able to quantify the potential

Source: author construct

3.4 Key lessons learnt

Based on the information generated, the ITK/ LTK indigenous indicator assessment facilitates the determination of local lead times for scalable strategic, tactical, operational and emergency decisions (see Table 3) in local agro-weather risk management, additional to conventional weather forecast, which often comes late. The tool can be applied earlier in the season before the conventional weather forecast is released, to serve as community preparedness mechanism for the season. ITK/ LTK indicators with long lead times can be used for strategic planning while those with short lead times can be used for tactical and operational decision making [37], [38].

Table 3: strategic, tactical, operational and emergency phases of planning and decision making

Response level Forecast level	**Strategic seasonal or inter-seasonal planning decisions to anchor the forecast in the plan for the season or for the year**	**Tactical intra-seasonal (on-farm) decisions to capitalize on the opportunities created by the forecasts**	**Operational intra-seasonal (on-farm) decisions to capitalize on the opportunities created by the forecasts**	**Emergency action decisions or contingency measures to avoid likelihood of negative impacts associated with extreme or severe weather events**
Seasonal and inter-annual forecast	Decisions on what to plan for and what to plan with, such as on crop varieties to plant, land preparation methods, etc.			
Monthly (extended range) forecast		Decisions on when to do what, such as on on-farm activities – weeding, pest and disease monitoring,		
Dekadal (medium range) forecast			Decisions such as on on-farm activities – weeding, pest, and disease monitoring,	
Weekly (short-range) forecast			Decisions such as on agrochemical application, fertilizer application, crop harvesting, crop air-drying time, etc.	
Daily (short-range) forecast				Decisions such as on agrochemical application, fertilizer application, crop harvesting, crop air-drying time, etc.

Source: author construct

4. Discussion

4.1 Opportunities for integrating locally-produced weather forecasts with conventional weather forecasts

The tool described here was developed using a Participatory Scenario Planning (PSP) approach piloted by CARE International in Kenya and now adopted by national meteorological agencies in the region, for example the Kenya Meteorological Department (KMD). In Kenya the PSP process is now called County Climate Outlook Forums (CCOF) for the co-production of the seasonal forecast. PSP is practiced at the county level but the initiative that produced this tool applied it at community level. The PSP approach, which provides a consensus-based platform for integrating ITK/ LTK forecast and scientific forecast information, has also been used by ICPAC and FAO in the ACREI (Agricultural Climate Resilience Enhancement Initiative) project in Kenya Uganda, and Ethiopia. Though the PSP approach encourages both the use of forecasts and ITK/ LTK, there is no proper integration of the two, because ITK/ LTK is often given lip service in those forums by conventional climate services experts and practitioners. However, therefore, there is room to establish relevant methodologies for proper integration of the tool, in line with WMO guidelines that promote objective forecasting.

Appropriate climate and weather information at certain lead times is generally established within the indigenous and traditional knowledge and observation of local communities, or accessible through conventional climate services. Greater understanding of indigenous, traditional and local indicators can complement the downscaling of seasonal forecasts and improve local relevance [23]. For the indigenous traditional methodology and decision-support tool to be successfully and effectively integrated with the conventional climate and weather forecast information, the conventional forecasting will need to be downscaled to the level of the traditional forecasting – the community level. This way when the conventional forecast (which always comes late) becomes ready, forecast comparisons can be made to validate each forecast, and a synthesis forecast developed for the locality, through integration of indigenous knowledge and scientific weather and climate forecasting for risk management. Further, there will be a need to strengthen understanding in the uptake and delivery process, of how to resolve cultural divides between science-based information and locally trusted Indigenous and traditional knowledge systems.

The next challenge is to find ways of integrating ITK/ LTK of weather forecasting using the decision-support tool with the scientific weather forecasting systems, as a module in the scientific weather information platforms. The proposal here is to test the hypothesis, using the tool, that identifying, monitoring and analysing traditional indigenous and local indicators (TILI) of local weather can and does actually lead to determination of a local weather forecast, just like the scientific methods of downscaled weather forecasting. Depending on the number of TILIs a community identifies and the number of signs each TILI exhibits, it is possible to tally the observations and estimate percentages of the more, less or normal rainfall predictions (normal, above or below normal) in the community. In Kenya this testing is proposed be undertaken in collaboration with the Community/Ward Level of the World Bank-supported Kenya Agricultural Observatory Platform (KAOP), at the Kenya Agricultural and Livestock Research Organization (KALRO), as an additional module for agro-weather advisories at scale through KAOP's Mobile App. The purpose of this proposed collaboration is to strengthen the existing extension service that is supported by the KAOP. KAOP has agro-weather ag-data hub, visualization tools and dissemination systems already running for the delivery of early warnings, climate services, and climate-informed digital agro-weather advisories to support agricultural decision-making. Based on the information generated, the indigenous indicator module can facilitate the determination of local lead times for scalable strategic planning and tactical/ operational decisions in local agro-weather risk management, additional to conventional weather forecast, which often comes late anyway.

5. Conclusions and Recommendations

5.1 Conclusions

The study describes an innovative tool for monitoring and exploring the emerging state of ethnographic, indigenous, traditional rainfall prediction indicators of local communities. The tool provides a good basis for strategic local seasonal planning and operational management decision-making. The user participation in this study was diverse and varied considerably in scope, ranging from individuals to user groups to communities. The transdisciplinary approach added value to users, practitioners and researchers for sustainability. Participatory engagement with end users in various formations increased the capacity of local communities to adapt to climate change. The context-specific nature of participatory processes influenced approaches but the core concept was maintained. The tool was found robust enough to be replicable, scalable and good for institutionalization of indigenous traditional weather forecasting under local contexts. For indigenous climate information to best be used to augment seasonal scientific weather forecasts in decision making at the local level the study, using the methodology for implementing the tool, identified where they are similar and looked for how the similarity can be used to support each other; and where they are different and looked for how the differences can be used to complement each other. Indigenous and traditional indicators with long lead times were used for strategic agricultural planning while those with short lead times were used for tactical farm level decision making. Evidence from this work has been used to influence policy reforms and sensitization for decision-making at various levels in the respective countries. Some of the disseminate channels include phone Bulk SMSs, and PSP workshops, brochures/bulletins/ banners, field days, community meetings, emails and any other channels as may be specified.

The TILKIT decision-support tool presented in this paper describes the emerging approach to monitoring ethnographic ITK/ LTK of rainfall prediction indicators and provides a good basis for strategic seasonal planning and operational decision-making based on local circumstances. The approach adopts a diverse user participation that varies considerably in scope, ranging from individuals to user groups to communities, as opposed to the usual deferment to mystical, ritualistic "rainmaker" model which is often gender-biased and socially exclusive. This study was set to explore options for forecast information availability and usability to enhance local adaptive capacity of smallholder farmers in East Africa to help farmers cope with risks and improve yields. The forecasts from local weather monitoring using the tool formed the basis of developing agro weather advisories for the localities. The study tested the idea that identifying, monitoring, analysing and tallying traditional indigenous and local indicators of weather can and does actually lead to determination of a local weather forecast, complementing scientific or conventional methods of downscaled weather forecasting. The study developed and validated an innovative tool for traditional weather forecasting, communication and usability to enhance local adaptive capacity of smallholder farmers. Through this innovative tool farmers and pastoralists will be able to take advantage of good seasons and minimize risks in bad seasons. Outputs of administering the tool with communities included community vulnerabilities to climate risks, current local traditional knowledge and coping strategies, and limiting factors that could restrict the adoption of effective/long-term adaptation mechanisms. It helped to identify adaptive measures that needed to be built on and strengthened, as well as innovative adaptation options that could add value to current climate coping strategies by addressing adaptation constraints experienced by communities. The results of this study are useful to smallholder farmers, pastoralists, agricultural extension agents, agricultural researchers and agro-meteorologists and climatologists.

5.2 Recommendations

The TILKIT tool is considered a living instrument that can be used to share traditional forecast information that are updated regularly as per local arrangements – e.g., onset of season, bi-monthly, monthly, weekly, daily. If adopted, the tool may need to be validated in each locality at the time of first application to test its robustness in different ethnographic circumstances. To apply the tool at scale, relevant policy reforms may be needed to mainstream and integrate it in extension services as part of regular extension messaging. The work of institutionalizing this tool will require strengthening information dissemination and communication processes in order to reach majority of the end-users with the innovation. A good example for this channeling can be the Kenya Agricultural Observatory Platform (KAOP), where discussion towards the same has begun. Special effort can be made to involve agricultural networks and community associations and the private sector – probably by involving targeted advertising with agribusiness content on dissemination portals such as KAOP where the information is channeled. Community radio stations and mobile phone companies can be enlisted to pick this information from the portals and broadcast it to the locality to boost their audience recruitment and retention. The portal can be used to monitor ITK climate information user perception to inform private sector interest in maintaining the service. This should lead to self-sustaining community climate information networks, with support from the authorities for the data networks, media and private sector.

5.3 Policy implications of the innovative TILKIT tool for local weather forecasting

The methodology accompanying the TILKIT tool identifies where the TILKIT approach and process is similar to the conventional weather forecasts, and looks for how the similarity can be used to support each other. Where they are different the methodology it looks for how the differences can be used to complement each other. TILKIT indicators with long lead times can be used for strategic seasonal agricultural planning while those with short lead times can be used for tactical or operational farm or pastoral level decision making. **Policy reforms** can be tailored to promote this integrated approach in a way that effectively embeds the TILKIT for decision-making at various levels for local climate risk management. However, for the TILKIT framework (both the tool and the methodology) to work well, the information dissemination process will need to be strengthened, and this will require **policy action**. Both the process and the tool should be institutionalized and be incorporated into the interpretation of climate information without prejudice. To operationalize the tool and the framework, **village community-based climate monitoring groups** of TILKIT weather forecasters can be formed and assigned specific areas of the locality to monitor, like has been piloted elsewhere [40]. The groups can meet monthly to discuss and document weather forecast observations and report the observations to a coordinating team, describing the indicators they observed for the forecasts. These monthly meetings for issuing new forecasts can also be used to review the previous forecasts. This could be achieved by integrating systems for disseminating climate information within the local communities, e.g., through the local schools, community-based organisations, churches in highly religious communities, partnership with NGOs and agricultural input dealers and service providers. A special effort can be made to involve the private sector, agricultural networks and community associations – probably by involving targeted advertising with agribusiness content on dissemination portals where the information is channeled.

A good example for this channeling can be national digital platforms such as the Kenya Agricultural Observatory Platform (**KAOP**), at the Kenya Agricultural and Livestock Research Organization

(KALRO), as an additional module for agro-weather advisories at scale through KAOP's Mobile App. That way it will be possible to establish a database of commonly, consistently and frequently used indicators across regions and communities, that can be incorporated in the national agro-weather observatory platforms (**NAWOPs**). The system can be used to share forecasting indicator information that are updated with each new forecast to provide three-month risk scenarios, available every two months or monthly. The system can display the forecast and also the associated risk for the coming season using a very simple color scale on an interactive map. The interactive GIS tool should represent spatial distribution of the indicators being monitored per locality, and the risk and vulnerability data for each locality, including layers of information that can be used to define levels of exposure to climate and levels of resilience based especially on social, economic, political and institutional parameters. The portal can be used to monitor ITK/ LTK climate information user perception to inform private sector interest in maintaining the service. This should lead to self-sustaining community climate information networks, with support from the authorities for the data networks, media and private sector.

The tool can be institutionalized within the general **extension system** to be used by communities for generating local climate and weather forecasts to complement conventional weather forecasts, accompanied with a local forecast information dissemination framework to provide the forecast information (alerts, warnings, advisories, etc.) to the wider community in all areas of the locality, using appropriate dissemination strategies and tools. Community radio stations and mobile phone companies can be enlisted to pick this information from the portals and broadcast it to the locality to boost their audience recruitment and retention. The following recommendations could promote integration, improving the development of relevant, legitimate, usable, and sustainable climate information services:

- Improved collection and documentation of ITK/ LTK of local climate indicators - this could be done through institutional mandates and/or the provision of specific funding for systematic data collection
- Integration of ITK/ LTK and scientific knowledge throughout the climate services value chain – by promoting meaningful and truly participatory forums for knowledge integration through all stages of service development. This includes forecast production, interpretation, communication, and feedback.
- Institutionalization of ITK/ LTK integration - enable sustainable integration by empowering national and sub-national institutions to adopt the transdisciplinary production of seasonal forecast information. The decentralization of meteorological services in Kenya is one example of a relatively good integration of ITK/ LTK and provides a positive regional model to build upon, but it hasn't gone far enough.
- Integration of communication channels - enable better access to diverse knowledge types by integrating the communication channels of both ITK/ LTK forecast information and scientific forecast information.
- Training of intermediaries - encourage the training of climate intermediaries across the climate services value chain to act as a bridge between ITK/ LTK and scientific knowledge.

6. Patents

- ✓ None

Supplementary Materials:

- ✓ None

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Conceptualization: J.J.L.O., G.W.O.; Methodology: J.J.L.O., G.W.O.; Validation: J.J.L.O., G.W.O., M.R., O.N., J.M.; Formal analysis: J.J.L.O.; Investigation: J.J.L.O., J.W.R.; Data curation: G.W.O., O.N., J.M.; Writing—original draft

preparation: J.J.L.O.; Writing—review and editing: M.R.; Visualization: J.J.L.O.; Supervision: J.R., M.R., E.W., S.M.; Project administration: J.W.R., G.W.O., O.N., J.M., E.W., S.M.,

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Conflicts of Interest:

The authors declare no conflict of interest.

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