Role of Indigenous and local knowledge in seasonal forecasts and climate risk preparedness: a case study of smallholder farmers in Chiredzi, Zimbabwe

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Research Article

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Role of Indigenous and local knowledge in seasonal forecasts and climate risk preparedness: a case study of smallholder farmers in Chiredzi, Zimbabwe

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Abstract

Accessible, reliable and diverse sources of climate information are needed to inform anticipatory responses to climate change at all levels of society, particularly for vulnerable sectors such as smallholder farming. Globally, many communities use Indigenous knowledge (IK) and local knowledge (LK) to provide contextually calibrated and trusted forecasting information to guide livelihood choices, including on-farm decisions by smallholder farmers. Here, we examined the role of IK and LK in seasonal forecasting, preparedness, and broader climate adaptation decision-making of smallholder farmers in Chiredzi, Zimbabwe. Data was collected from 100 smallholder farmers through face-to-face semi-structured interviews in the month before the rainy season onset when preparatory decisions about planting were being made. Seventy-three percent (73%) of the interviewed farmers are using IK and LK-based climate forecasts, and 32% (of 73%) farmers rely on IK and LK only for climate risk preparedness decision-making. Binary logistic regression found the use of IK and LK climate forecasts by farmers was strongly predicted by farmers' age and farm size with $p = 0.009$ and 0.017 respectively at $p<0.05$ significance level. Farmers using IK and LK forecasts are implementing, on average triple, the number of adaptation measures compared to farmers not using IK and LK. These findings emphasise the accessibility and reliability of IK and LK for seasonal forecasts and demonstrate the close link between use of IK and LK and the implementation of adaptation actions. Recognition, inclusion and preservation of IK and LK are important to ensure its potential role in informed responses to climate change.

Keywords: Smallholder farmers, Indigenous knowledge and local knowledge, Weather and seasonal climate forecasting, Climate decision-making, Climate risk preparedness and adaptation.

1. Introduction

Globally, there is increasing recognition of the potential value of Indigenous knowledge (IK) and local knowledge (LK) for climate change adaptation (IPCC, 2019). For example, case studies from Brazil have highlighted causal and mechanistic explanations provided by IK and LK for perceived local environmental changes can prove accurate and more nuanced than 'scientific' and academic explanations (El-Hani et al., 2022). Recognising epistemic differences between knowledge systems and triangulating their value for local decision-making is key to extending climate services and informed climate change adaptation to currently under-serviced smallholder farmers across Africa. This is especially crucial in most of Africa where climate and weather recording and forecasting infrastructure is lacking (Africa Adaptation Initiative, 2018; Singh et al., 2018; Hansen et al., 2019). Further, recognising the epistemic freedom of IK and LK and the broader roles it plays, for example in customary resource governance, can play an important role in decolonising science and highlighting the biocultural heritage of indigenous communities which is threatened by current megatrends of development including climate change (Breunlin, 2020; Liboiron, 2021; Simpson et al., 2022)

Communities in Africa across multiple sectors, geographies and scales are responding to climate change (Graham et al., 2021; Turek-Hankins et al., 2021; Williams et al., 2021; Leal Filho et al., 2022). How individuals and societies anticipate and respond to climate change risk is important as inappropriate responses can increase vulnerability and lead to maladaptation (Schipper, 2020), and thus can be a potential driver of increased climate change risk (Simpson et al., 2021b). Current evidence shows that adaptation is generally in nascent stages of implementation with little evidence of risk reduction under recent climate change conditions, particularly for rainfed smallholder farmers (Berrang-Ford et al., 2021; Thomas et al., 2021; Leal Filho et al., 2022). This demonstrates the importance of easily accessible and reliable climate information to smallholder farmers for climate adaptation decision-making which the smallholder farmers in Africa are acquiring through indigenous and local knowledge of interpreting the environment, surroundings, personal and shared experiences.

In Africa, the majority of farmers are smallholder entities employed in household agricultural production (FAO, 2018), consisting of mainly rainfed and subsistence agriculture. African farmers are already facing crop losses due to climate change, including yield reduction and lower productivity of staple crops (a reduction of maize yield by 5% in Southern Africa, 10-20% yield loss for millet and 5-15% for sorghum in West Africa) (Ray et al., 2019; Sultan et al., 2019; Ortiz-Bobea et al., 2021), plantain yield declined by 43% in Central Africa (Fuller et al., 2018) and livestock pasture losses (Sloat et al., 2018; Stanimirova et al., 2019). Further to the existing, current climate risk, the projected climate risk to food systems will likely have cascading effects across Africa with increased global warming tipped to decrease yields of maize, rice, wheat and soybean in the African tropics and Sub-Saharan Africa more generally, especially if the level of global warming exceeds 2 °C above pre-industrial levels (Rosenzweig et al., 2014; Moore et al., 2017; Franke et al., 2020). African smallholder farmers are also generally more vulnerable to climate risks due to a lack of capacity to adapt, through limited access to production and adaptation resources, including financial, land, technological and climate services (Pauline et al., 2017; Sonwa et al., 2017; Krell et al., 2021; Leal Filho et al., 2022).

When adapting to climate risks, smallholder farmers in Sub-Saharan Africa have been relying on available knowledge sources they trust for on-farm decision-making, including IK and LK both for weather forecasting and implementation of adaptation measures (Ajani et al., 2013; Zuma-Netshiukhwi et al., 2013; Nkomwa et al., 2014; Grey, 2019; Mekonnen et al., 2021). Case studies of how smallholder farmers use various IK and LK systems to forecast weather and adapt to the climate risk have increased in Zimbabwe (Mavhura et al., 2013; Jiri et al., 2015; Gwenzi et al., 2016; Mugambiwa, 2018). For example, Indigenous knowledge is relied upon by smallholder farmers in Chiredzi (the study site in south-eastern Zimbabwe) for both short-term and seasonal rainfall predictions (Jiri et al., 2015). However, both at national and continental levels, less is known about the instrumental connection between IK and LK forecasts and local climate decision-making for climate risk reduction.

In smallholder farming, climate decision-making occurs mainly at household level and is affected by several factors including climate information quality and its availability to decision makers (Waldman et al., 2021). Further, there are limitations to the impact of climate information as perceptions of climate risk do not necessarily translate into actions (Waldman et al., 2019; Simpson et al., 2021a). Among smallholder farmers in Africa there is high variability of quality and accessibility of scientific climate information at appropriate scales for farm-level decision-making (Singh et al., 2018; Antwi-Agyei et al., 2021). This has led to increasing recognition of the potential value of IK and LK to inform climate relevant decisions and actions, particularly for rainfed smallholder farmers (Alemayehu and Bewket, 2017; Nyadzi et al., 2021).

Therefore, this study focuses on the climate decisions based on IK and LK climate forecasting systems. We assess the role of IK and LK on smallholder farmers' climate risk preparedness, decision-making and adaption to the anticipated seasonal variability in Chiredzi, Zimbabwe. The study also examines the factors that determine smallholder farmers' use of IK and LK to forecast weather and climate and its role in the implementation of responses to anticipated climate variability. The findings broaden our understanding of how IK and LK systems shape household level decision-making for smallholder farmers. The discussion and conclusion highlights the value of IK and LK in Africa that is at risk from climate change, and the utility of a blended approach to climate information services which draws on the strengths of IK and LK to enhance implementation for adaptation to climate change.

2. Methods

2.1 Study area

The study was conducted in the southeast lowveld of Zimbabwe in the Chiredzi district. The Chiredzi district is located in the semi-arid Natural Region V, which is the driest of Zimbabwe's Agro-Ecological Zones with highly variable rainfall patterns (Chikodzi and Mutowo, 2012; Mugandani et al., 2012). The Chiredzi district is among the regions that are most vulnerable to climate variability and change (Unganai and Murwira, 2010). Smallholder farming is the main economic activity in many rural wards in Chiredzi. Due to lack of access to reliable scientific weather forecast information, farmers in the region use indigenous methods to predict season quality (Jiri et al., 2015), however, there are three weather stations in Chiredzi district (see Figure 1). Five wards out of the total 32 wards in Chiredzi rural district were strategically selected for data collection (see Figure 1). The five wards were: 1, 3, 25, 27 and 32.

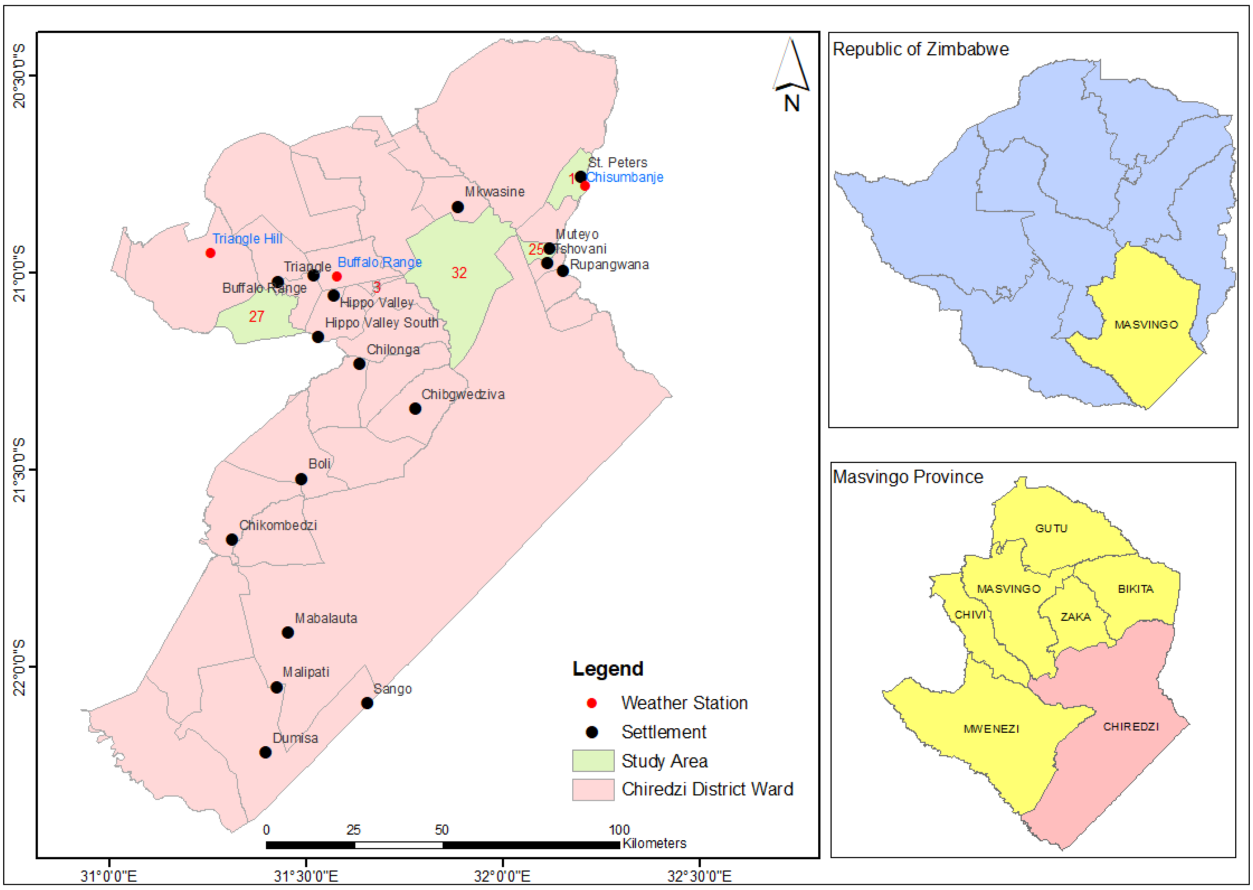


Figure 1: Map showing the five wards in Chiredzi considered for this assessment including key weather infrastructure.

2.2 Data collection

A random sample of 100 farmers were surveyed through face-to-face, in-depth, semi-structured interviews in the five wards. The wards were selected from two clusters: three wards (1, 3 and 25) from communal and two wards (32 and 27) from resettled farming areas. Wards from communal areas consisted of farmers that have been staying in the area all of their lives, whilst resettled wards consisted of farmers that were resettled between 2000 and 2005 under Zimbabwe's land reform programme (Chaumba et al., 2003; Ndhlovu, 2018). While the IK and LK of farmers in the communal areas was anticipated to be multigenerational and endemic, IK and LK for the resettled areas was anticipated to be younger and syncretic of exogenous knowledge systems, including knowledge which has been brought with the resettled farmers and potentially adapted with local IK and LK over the past 15-20 years to the local context.

Data collection was performed in October 2021. The month of October was strategically selected for interviews because the growing season usually starts around mid-November to early December. October is therefore a critical month where climate-relevant farming decisions are top-of-mind for respondents, as smallholder farmers are preparing for the upcoming planting and growing season. During that time of the year, farmers use various indigenous and local indicators, observing how flora and fauna behave, and applying the information to forecast the expected weather/climate of the incoming season, amongst them, onset rain dates, season quality, length, cessation dates and the possibility of a drought (Jiri et al., 2015; Soropa et al., 2015). The forecasts are used to make household decisions on when to perform key farm operations such as dry planting, considering options between drought resistant crops such as cotton, sorghum and millet crops, as well as selection and allocation of crops per cultivation area (Soropa et al., 2015). In addition to gathering key socio-demographic characteristics of the respondents, the interviews were structured to explore four main areas: i) how smallholder farmers use IK and LK to perform seasonal climate forecasting, ii) farmer's confidence in the reliability of IK and LK forecasts, iii) the influence of IK and LK forecasts on season preparedness and potential climate risks, and iv) the subsequent broader climate adaptation measures implemented by smallholder farmers linked to IK and LK.

Interviews with smallholder farmers sought to acquire a deep understanding of how IK and LK systems influence decisions. Data collection focused on knowledge used to forecast the next season's weather and climate hazards: storms, heavy precipitation, rainy day; climate hazards (droughts, floods, heatwaves); season quality and length; rain onset and cessation dates. Special attention was given to farmer's perceived confidence in the reliability of IK and LK forecasts. Information on decision-making and the adaptation measures implemented by farmers based on the interpretations of IK and LK forecast was also collected for analysis. We analysed how smallholder farmers were reacting to IK and LK weather and climate forecasts. This was to establish the contribution of IK and LK to household and local level decision-making in climate adaptation.

2.3 Adoption and use of IK and LK climate forecasts

We used a binary logistic regression (BLR) model, elaborated in Van Huynh et al. (2020), to examine what influences smallholder farmers use of IK and LK climate forecasts in Chiredzi. The model contained thirteen independent variables (age of the farmer, education, farming type, gender, wealth level, access to irrigation, access to scientific weather information, perception of climate variability, livelihood diversification, access to extension services, farmland size, length of stay and family size) (see table 1 for detailed explanation of the predictor variables). We aimed to assess the impact of a number of factors on the likelihood that a farmer would report that they use IK and LK forecasts. We also analysed whether the farmer use of the IK and LK forecasts affect farming decisions and adaptation measures in response to perceived risks associated with anticipated climate variability. Lastly, we analysed whether access to scientific climate forecasts has an effect on the adoption and use of IK and LK forecasts and the overall adaptation measures implemented by farmers. The model assumes that if a farmer uses IK and LK in forecasting, they are likely to make decisions to prepare or adjust to the expected risks based on the forecasting. The BLR analysis was expressed as follows:

$$Ln\left[\frac{P}{1-P}\right] = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_4 x_4 \ldots\ldots\ldots + \beta_{13} x_{13} \qquad (1)$$

where $\left[\frac{P}{1-P}\right]$ = is the odds ratio.

P is the probability of a farmer in Chiredzi to forecast climate using IK and LK methods

$1 - P$ denotes the probability of not using IK and LK to forecast climate

β_0 is the intercept.

x_1, x_2, x_3..., and x_{13} are the independent variables

β_1, β_2, β_3..., and β_{13} are partial regression coefficients

Table 1: Description and justification of the predictor variables for a binary logistic regression model considered in this study

	Variable	**Variable code**	**Description and justification for the variable**	**Expected sign**
x_1	Age of the farmer	Continuous	Older farmers are more likely to use IK and LK weather forecasting compared to young farmers as they have better knowledge about weather information particularly the indigenous and local indicators of climate forecasting (Belay et al., 2017; Tunde and Ajadi, 2019).	+
x_2	Farmland size	Continuous	Farmers with large farm sizes are likely to adopt IK and LK forecasts and adapt because the larger the farm size the greater the proportion of land allocated to other crop varieties.	+

x_3	Number of years living in the area	Continuous	Farmers that have lived in an area for a long time are likely to understand indigenous and local environment and indicators better. They may be more likely to adopt IK and LK forecasting compared to farmers that lived in an area for a short period (Van Huynh et al., 2020).	+
x_4	Access to scientific weather forecasting information	Yes = 1 No = 0	Farmers with access to scientific weather forecasting are more likely to adapt using the forecasts (Bryan et al., 2013), therefore, less likely to use and rely to IK and LK systems of weather forecasting.	+/-
x_5	Level of Education	Tertiary = 3 Secondary = 2 Primary = 1 No education = 0	Level of education increases the probability of use of scientific forecasts and use the scientific practices to adapt based on their awareness to the potential benefits from proposed climate variability adaptation measures (Belay et al., 2017). On the other hand, farmers that are less educated are more likely to use IK for both forecasting and adapting as their choices	-
x_6	Gender	Male = 1 Female = 0	Male farmers are more likely to use IK and LK forecasts compared to female counterparts (Tunde and Ajadi, 2019). This is because in rural set-up men are involved at household decision-making and are more involved in activities that allow them to interact with the environmental features that are key for IK and LK forecasting.	+
x_7	Access to irrigation	Yes = 1 No = 0	Access to irrigation reduces reliance of a farmer to rainfed systems and gives the farmer a leverage to try various strategies like repeated sowing thereby not following the natural seasons (Varadan and Kumar, 2014). This implies that farmers with access to irrigation are less likely concerned with rainfed systems and the need for IK and LK climate forecasting	-
x_8	Perception of climate variability and change	Yes (if perceive climate variability) = 1 Not = 0	Farmers that perceive climate variability and change are more likely to use IK and LK forecasts to plan, prepare and adjust to the anticipated risks (Van Huynh et al., 2020).	+
x_9	Farming type	Communal = 1 for Resettled = 0	Resettled farmers are less likely than farmers in communal areas to use IK and LK due to their limited time and knowledge of the local environment although indigenous knowledge can be transferred from place to place through resettlement	-
x_{10}	Livelihood diversification (non-farm activities)	Yes = 1 No = 0	Farmers that diversify their livelihoods invest less in knowing how the season is going to be or when the rains are going to be received because they have other means of living away from family farming (Bryan et al., 2013)	-
x_{11}	Access to extension services	Yes = 1 No = 0	Access to extension advise has been shown to increases farmers' exposure to scientific forecasts and knowledge and may reduce reliance or trust in IK and LK where a blended approach is not adopted.	-
x_{12}	Family size	Continuous	Farmers with more big family size will have more family members that are fit to work in the fields, hence intensifying production. This will therefore, increase chances of using IK and LK forecasts to make strategic decisions to buffer their farming systems	+
x_{13}	Wealth level	Yes = 1 No = 0	As wealthy farmers in this study were farmers owning things like a television or radio where they can access scientific/meteorological climate updates hence are less likely to use IK and LK forecasts or they combine	+/-

			the two to make climate adaptation and farming decisions.	

*Wealth was measured on the presence of a house with asbestos roofing, own a tv or radio, number of houses owned by the farmer and number of livestock.

3. Results

About 97% of the households surveyed in Chiredzi rural district rely on rainfed subsistence farming as their source of livelihood. The main crops grown are sorghum, maize, millet, sesame, groundnuts, and Bambara nuts. Maize and sorghum are grown as staple crops, while cotton and sesame are grown as cash crops. Cowpeas, groundnuts, and Bambara nuts are also grown as edible crops.

Almost three quarters (73%) of the smallholder farmers are using IK and LK seasonal climate forecasts and 90% of those using IK and LK, are using a combination of both IK and LK and scientific forecasts to make farming decisions. 88% of the smallholder farmers in Chiredzi have either direct or indirect access to scientific weather forecasts and updates. Rain onset (86%), storms and rainy days (64%), season quality and length (29%) forecasts are the most common climate indices that use IK and LK (Figure 2).

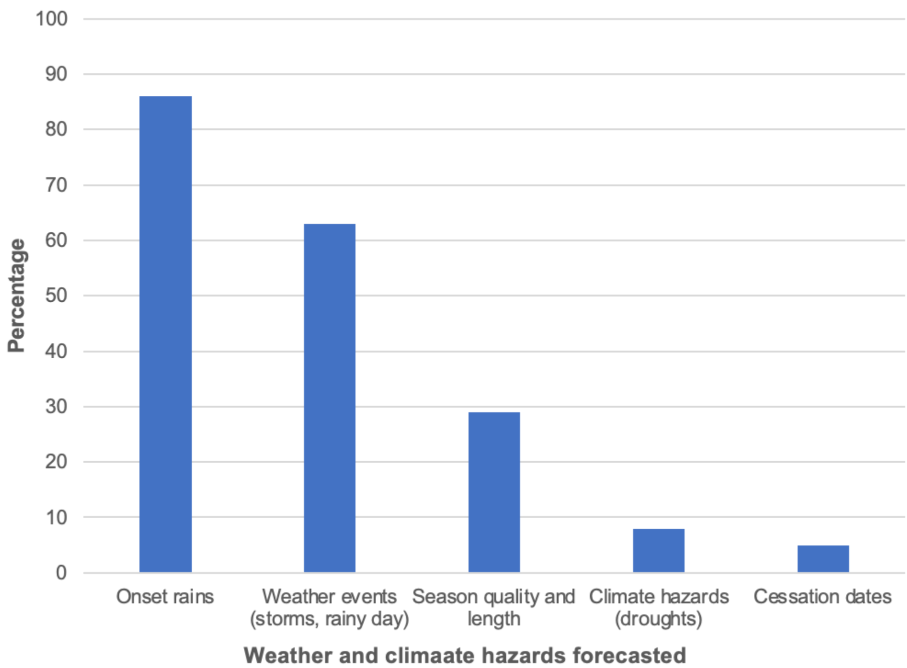


Fig 2. Weather events and climate hazards forecasted by smallholder farmers in Chiredzi using IK and LK systems

3.1 IK and LK weather and climate forecasting in Chiredzi

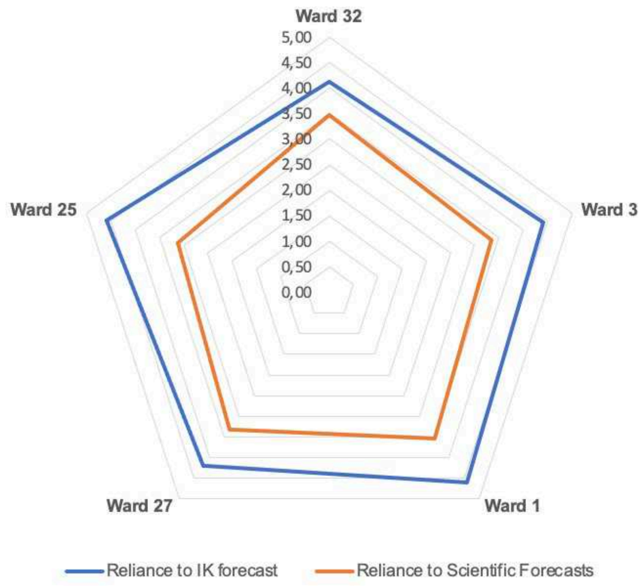
Eight (8) IK and LK indicator types are used by smallholder farmers to forecast weather and climate hazards (Table 2). Farmers rely more on IK and LK forecasts compared to scientific climate forecasts on a scale rating of 1(low reliance) to 5 (high reliance) on how they use and trust climate forecasts in climate decision-making (Figure 3a). Overall, farmers in communal wards (ward 1, 3 and 25) rely and trust IK and LK forecasts more compared to farmers in resettled wards (ward 27 and 32) (Figure 3a). According to climate indices and hazards, farmers from communal areas rely more on IK and LK forecasts in predicting storms and rainy days compared to wards in resettled areas (Wards 27 and 32) (Figure 3b). Summer temperatures, bird behaviour (e.g., cuckoo), cloud appearance and movement (e.g., nimbus clouds), tree flowering and fruiting and vegetation leaf-out of local and indigenous tree species mostly Mopane trees, are the common indicators used for seasonal climate forecasting in Chiredzi district.

Table 2: Common IK and LK indicators used by smallholder farmers in Chiredzi to forecast weather events and climate hazards

Climate variability or hazards	**Indicators**	**How perception of environmental variable is interpreted by IK and LK for season forecasting**	**Percentage of responses indicating use of the indicator (%)**	**Perceived reliability** (0-5)
Rain onset	Summer temperatures	Very hot summer days indicates the imminent coming of onset rains	26%	4.4
	Leaf-sprouting of Mopane trees (*Colophospermum mopane*); Rain tree (*Philenoptera violacea*), Baobab and other indigenous tree species	Shooting of brownish leaves indicates imminent rains	25%	4.1
	Clouds (Nimbus clouds)	Appearance of moving nimbus clouds indicates onset of good rains	23%	4.5
	Birds mostly Cuckoo (*Cuckoo Cuculiformes*)	Continuous call indicates imminent rains	22%	4.4
	Human body	Interpretation of human body pains; backpains, legs pains indicates imminent onset rains.	12%	4.3
	Wind direction	Wind constantly blowing from the east (from the Indian ocean via Mozambique) means onset rains are close	5%	4.5
	Christmas beetle (*Cicadas*)	Continuous call indicates imminent rains	4%	4.3
	Hibiscus vitifolius	Abundant flowering before rain season means delayed onset	2%	4.5
Weather events (storms, rainy day)	Clouds	Dark clouds indicates rainy day or very intense storm	25%	4.1
	Birds (southern ground hornbill)	Sounding means imminent storm	16%	4.7
	Wind temperature and direction	Warm wind and wind blowing from east to west indicates that a storm is close	8%	4.4
	Human body	Human body pains, sweating, aching (mostly elderly) means rainy days or storm is coming soon	5%	4.8
	Frogs	Continuous sounding indicates coming of a storm or rainy days	4%	5
	Outlook environment	Reddish sunsets indicates imminent storm	4%	4.7

	Moon	Appearance of 1st and last quarter of the moon means rain days are close	3%	4
Growing season quality and length	Trees (*Acacia nigrescens)*	Abundant white flowering observed in September indicates good incoming rainy season and abundant red flowers indicates dry season	8%	4.5
	Dreams	Dreams on whether season is good or bad by individuals recognised to be ‘dreamers’	5%	5
	Trees (*Sclerocarya birrea*)	Profuse fruiting in Feb/March indicates bad incoming season and/ a drought	3%	4
	Trees (mahogany - *Afzelia qunzeisis*), mango tree	Abundant flowing and fruiting (observed prior to the start of the rainy season) indicates good incoming season	3%	4
	Stars	Big shining star in the western side indicates good season	3%	4.5
	Grasshoppers (*Schistocerca americana*)	Appearing in large numbers or swarms means abundance of food	3%	4
	Wind direction	Frequent winds from east to west indicates high rainfall	3%	5
	Whirlwind	Regular occurrence of strong whirlwind indicates high rainfall and perfect temporal distribution.	2%	5
Rain cessation	Cold temperatures	Decrease in summer temperatures.	4%	4.5
	Cold rainfall	Cold rainfall indicates the end of growing season marking the beginning of winter season	3%	4
	Clouds (cirrus)	Appearing of cirrus clouds means no more rain is coming	3%	4
	Mist	The occurrence of mist and light showers means the season is coming to an end	2%	4.5
Droughts	Stars	Big shining star in the eastern side forecast a drought	4%	4.5
	Marula tree (*Sclerocarya birrea*), bush fruits	Abundant fruiting indicates dry season/drought	4%	4.7
	Dreams	Dreamer in a village can foretell years of drought	3%	4.5

Average farmer perceived reliance was based on the ranking of each IK and LK forecast used by a farmer from a scale of 1 to 5 on how well they trust and rely to the forecasts in decision-making. 1 = “I use them but do not rely on them”, 2 = “Barely rely on the IK and LK predictions”, 3 = “Sometimes I rely on them”, 4 = “I rely on them”, 5 = “I strongly rely on them”. The reliability figures for each forecast indicator were averaged to give a representative reliance presented in last column.



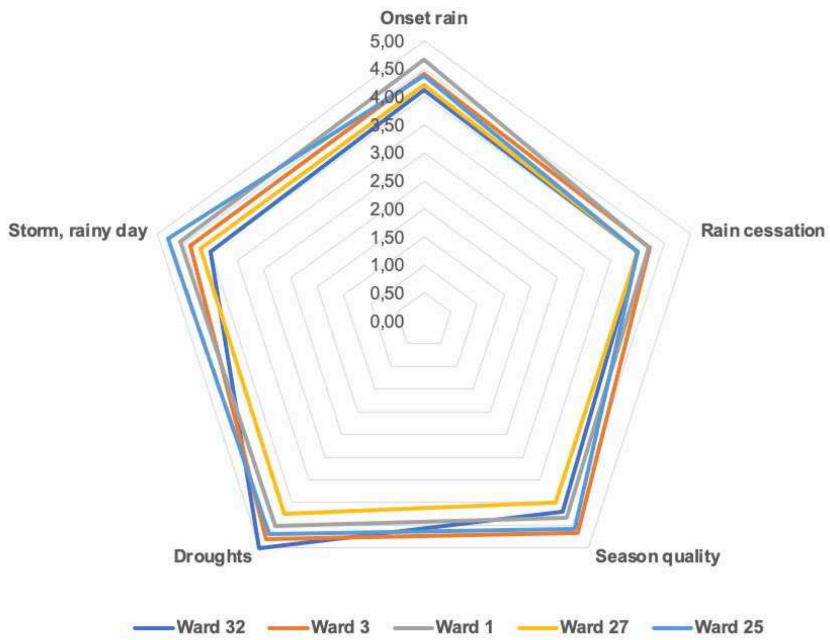


Figure 3: Farmer reliance to climate forecasts in Chiredzi: (a) overall ward level smallholder farmers' reliance to IK and LK and scientific weather forecasts in Chiredzi, (b) reliance to IK and LK forecast per forecasted climate indices. Reliance was based on the average ranking of forecast type used by a farmer from a scale of 1 to 5 reflecting how well they trust and rely to the forecasts in decision-making (see key for table 2 for the description of the reliability scale).

3.2 Determinants of use of IK and LK climate forecasts in Chiredzi

3.2.1 Socio-demographic profile

The mean farmer age was 48.7±14.5 years with the majority being 50 years or older. The mean length of stay in an area, family size and farmland size were 29.1±17.9 years, 7.30±3, and 3.8±2.4 hectares respectively. The majority of the farmers (59%) were women and the highest proportion (48%) had primary education as the highest formal education qualification. The majority (54%) of the farmers were classified in the poor category of the wealth level. Just one-fifth (20%) use irrigation while a high percentage (88%) reported to have direct or indirect access to scientific weather information and updates. 96% of the farmers expressed perception of climate variability and change, 70% of them diversified their livelihood while 74% had access to extension service (see Table 3).

Table 3. Socio-demographic and other variables of the farmers (n = 100)

Variable	**Mean**	**SD**
Age (years)	48.73	14.45
Length of stay (years)	29.13	17.93
Family size	7.31	3.03
Farmland size (ha)	3.75	2.37
Variable	**Frequency**	**%**
Age category (years)		
20-29	11	11.0
30-39	19	19.0
40-49	24	24.0

≥ 50	46	46.0
Gender		
Female	59	59.0
Male	41	41.0
Education		
No Formal Education	18	18.0
Primary	48	48.0
Secondary	34	32.0
Tertiary	2	2.0
Farming type		
Resettled	40	40.0
Communal	60	60.0
Wealth Level		
Poor	54	54.0
Good	46	46.0
Use Irrigation		
No	80	80.0
Yes	20	20.0
Access to scientific weather information		
No	12	12.0
Yes	88	88.0
Perception of Climate variability and change		
No	4	4.0
Yes	96	96.0
Livelihood diversification		
No	30	30.0
Yes	70	70.0
Access to extension services		
No	26	26.0
Yes	74	74.0

3.2.2 Variable analysis

The BLR model as a whole explained between 19.7% (Cox and Snell R square) and 28.6% (Nagelkerke R^2) of the variance in use of IK and LK climate forecasts and correctly classified 79% of cases (table 4). This means that the 13 variable factors explained 28.6 percent of the probability that farmers would use IK and LK forecasts. For these 13 variables examined, age of the farmer and farmland size significantly predicted farmers' use of IK and LK forecasts with $p=0.009$ and $p=0.017$ respectively at significance level $p<0.05$. The other variables; education of the farmer, engagement of a farmer on irrigation, farming type (communal or resettled) and access to scientific weather forecasting information were found to be positively influencing farmer's use of IK and LK climate forecasts but were not statistically significant (Table 4). Family size, length of stay in an area, farmer perception of climate variability, access to extension services, wealth level, gender, and livelihood diversification were found to have no relationship with farmers' use of IK and LK forecasts at significance level $p<0.05$.

Table 4: Determinant factors influencing smallholder farmers use of IK and LK climate forecasting in Chiredzi

					95% CI		
Variables	β	**S.E.**	**Wald**	**OR**	**Lower**	**Upper**	p **- value**
Age (years)							
30-39	0.649	0.891	.531	1.914	0.334	10.969	0.466

40-49	**2.974**	**1.146**	**6.737**	**19.576**	**2.072**	**184.978**	**0.009***
50 and above	1.622	1.057	2.355	5.064	0.638	40.189	0.125
Education							
Primary	1.136	0.760	2.236	3.114	0.703	13.799	0.135
Secondary or higher	0.967	0.942	1.053	2.630	0.415	16.678	0.305
Farming Type	2.158	1.158	3.472	8.655	0.894	83.781	0.062
Gender	-0.139	0.590	.055	0.871	0.274	2.769	0.814
Wealth Level	-0.328	0.617	.283	0.720	0.215	2.413	0.595
Access to Irrigation	0.713	0.795	.804	2.040	0.430	9.680	0.370
Access to scientific weather information	1.091	0.839	1.690	2.977	0.575	15.413	0.194
Perception	-0.991	1.669	.352	0.371	0.014	9.785	0.553
Livelihood diversification	-0.594	0.755	.618	0.552	0.126	2.427	0.432
Access to extension services	-0.030	0.664	.002	0.971	0.264	3.568	0.964
Farmland Size	**.513**	**.214**	**5.727**	**1.671**	**1.097**	**2.543**	**0.017***
Length of stay	-.009	.024	.152	0.991	.946	1.038	0.697
Family Size	-.026	.103	.066	0.974	.796	1.192	0.797
Constant	-3.346	2.090	2.562	0.035			0.109
Model Nagelkerke's R^2	0.286						
Model correct prediction	79						
Number of households	100						

Note: β is the estimated coefficient, SE is the standard error, Wald is Wald Chi-Squared Test, p is a probability, and OR is the coefficient of determinations. *$p \leq 0.05$, without asterisks value are non-significant at $p > 0.05$. Bold signifies significant value when $p < 0.05$

3.3 Role of IK and LK in household climate decision-making

Of the 73 smallholder farmers that are using IK and LK weather and climate forecasts, 32% depend solely on the forecasts to make decisions on various farm operational measures related to climate risk preparedness, 60% combine IK and LK forecasts with scientific forecasts to make climate risk preparedness decisions relevant to climate adaptation actions implemented, and 8% are doing nothing in response to the available IK and LK forecasts (Figure 4). Over 20 decisions are made by smallholder farmers based on IK and LK forecasts which relate to climate risk preparedness and adaptation. Most of the decisions relate to planning the agricultural calendar, including land preparation (51%), crop variety selection (30%), seed preparation (43%), dry planting (32%), and allocation of cultivation area per crop (8%) (Table 5).

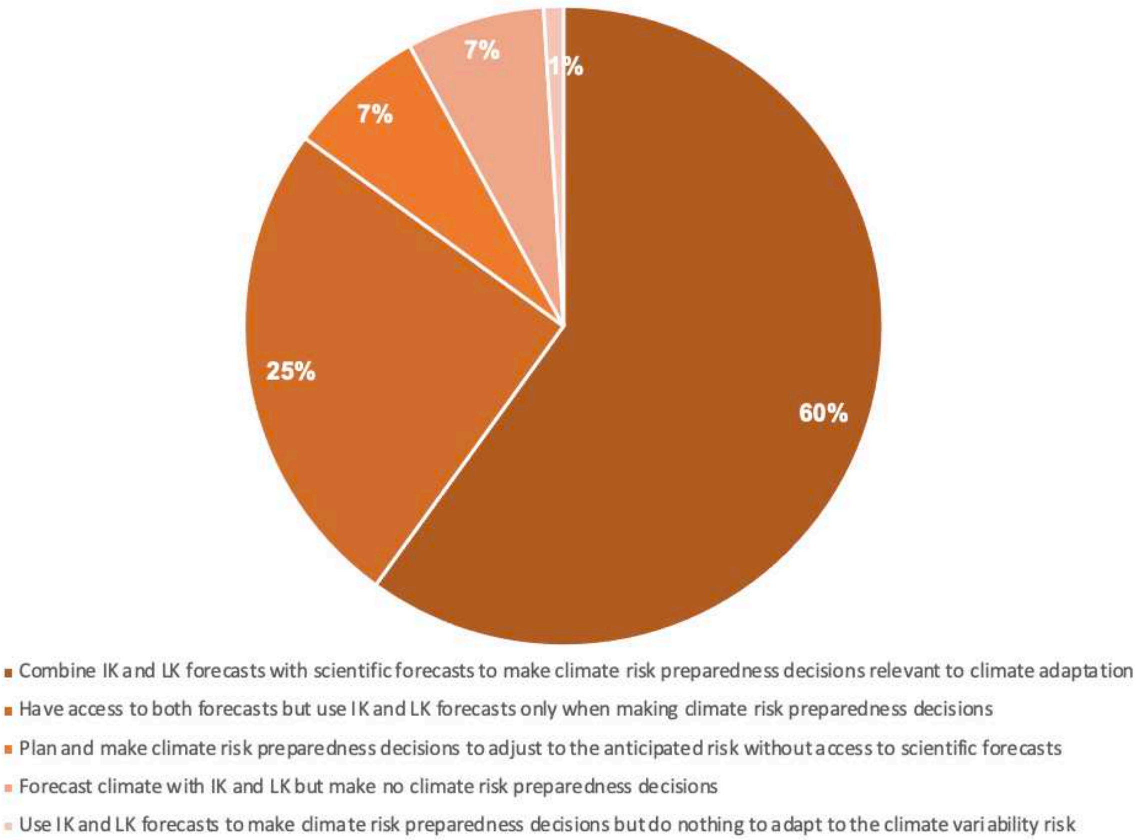


Figure 4: How smallholder farmers are reacting to IK and LK weather and climate forecasts in Chiredzi district

Table 5: Role of IK and LK forecasts on decision-making relevant to climate adaptation by smallholder farmers in Chiredzi district

Climate indices and hazards	**IK and LK supported decisions for climate risk preparedness**	**Percentage of responses indicating use of variable (%)**
Onset rains	Land preparation (zero tillage, burn biomass from previous crops to increase fertility for farmers practicing conservation agriculture)	51%
	Seed preparation (indigenous seeds for small grains - sorghum and millet, groundnuts and Bambara nuts)	43%
	Dry planting (or small grains - millet and sorghum, cotton and Bambara nuts)	32%
	Crop variety selection	14%
	Buy appropriate seed varieties (for crops farmers use certified seed) e.g., maize varieties (consider short term varieties when anticipating a short season)	4%
	Plan agricultural calendar	3%
	Prepare housing (roofing/thatching)	3%
	Staggering crop planting dates	3%
	Do nothing, ignore the forecasts	8%
Weather events (storms, rainy day)	Weeding	7%
	When to irrigation	5%
	Cultivation	3%
	Organic fertiliser application dates and timing	3%
	Do nothing, ignore the forecasts	4%
Growing season quality	Crop variety selection	16%
	Cultivation area allocation per crop	8%
	Staggering of planting dates	2%
	Grow small grains when anticipating a drought	1%

Climate hazards (floods, droughts, cyclones)	Crop variety selection	3%
	Prepare housing - cyclones	3%
	Do nothing, ignore the forecasts	1%
Rain cessation	Time to plant beans and other winter crops	4%
	Time to harvest grain crops to avoid rotting of yields	3%
	Time to harvest groundnuts and Bambara nuts when the ground is still wet	3%

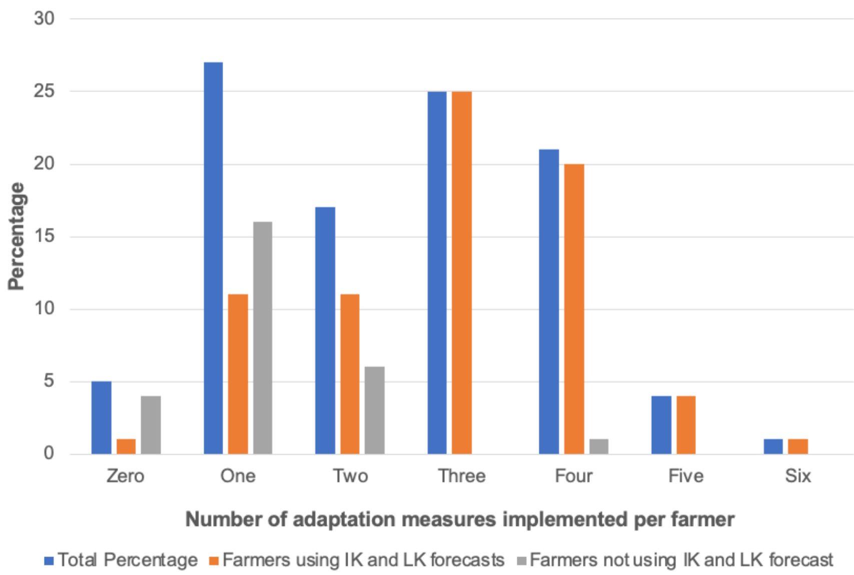
3.4 Climate adaptation and IK and LK in Chiredzi

Taken together, smallholder farmers are implementing seven different climate adaptation response types to cope and adapt to the specific climate risks – of drought and rainfall variability (Table 6). Specific farmer responses include increase area under small grains in anticipation of a dry season or drought (28%), growing of drought tolerant crops (8%), dry planting (21%), zero tillage for CA (15%), irrigation (20%), selling livestock (9%), work in neighbouring communities (19%). Farmers are also diversifying livelihoods through off-farm activities such as trading (7%) and fishing - in Save and Mtirikwi rivers (7%) (table 6). The above measures are implemented to cope to droughts, increased rainfall variability and summer temperature risks. Ninety five percent (95%) of all farmers surveyed are implementing at least one adaptation response and 5% are doing nothing. The majority of the farmers (27%) are implementing only one measure, followed by 25% and 21% implementing three and four adaptation measures respectively. The highest number of adaptation measures implemented by a farmer is six (Figure 5a). Farmers that are using IK and LK climate forecasts are implementing, on average more adaptation responses (3.01) compared to farmers that are not forecasting weather and climate hazards (1.19) (see figure 5b).

Table 6: The adaptation measures implemented by smallholder farmers to cope and adjust to climate risk in Chiredzi

Adaptation type	Specific adaptation actions	Climate variability and hazards adapted to	Percentage (%)
Crop variety selection	Growing small grains (e.g., sorghum, millet)	Drought, poor rainfall distribution, increasing mid-season dry spells	16%
	Growing drought resistant crops and varieties (e.g. cotton, sesame)	Droughts, increasing mid-season Dry spells	8%
	Growing short term varieties	Shortened growing season and early season dry spells	4%
	Growing indigenous varieties e.g., indigenous maize seeds	Delayed onset	5%
Cropping area management	Reduce cultivation of high water demand crops such as maize when anticipating a drought	Droughts, shortened growing season	10%
	Increase area under small grains	Droughts and poor seasonal rainfall distribution	12%
Agricultural calendar planning	Dry planting	Delayed and unpredictable rain onset	21%
	Early planting	Mid-season dry spells; early cessation	6%
	Staggering planting dates	Increased mid-season dry spells, poor season rainfall	16%

		distribution and increased variability	
Farm operational measures	Irrigation	Droughts, increased summer temperatures, increasing mid-season dry spells	20%
	Zero tillage for rain water conservation on plant stations	Reduced seasonal rainfall amount	15%
	Intercropping	Increased rainfall intensity, storms'/	12%
Management measures	Fertilisation; organic manuring	Poor rainfall distribution	16%
	Rainwater harvesting and conservation	Poor rainfall distribution	10%
Off – farm activities	Fishing in the Save and Mtirikwi rivers	Droughts	7%
	Brick making	Droughts	3%
	Trading (buying and selling)	Droughts	7%
	Remittances	Droughts	3%
	Migrate to other areas and countries	Droughts	2%
Livelihood diversification	Sell livestock to buy family food	Droughts	9%
	Provide casual labour in neighbouring communities - sugarcane fields, commercial and irrigation plots	Droughts, poor and unpredictable rainfall	19%
Do nothing			5%



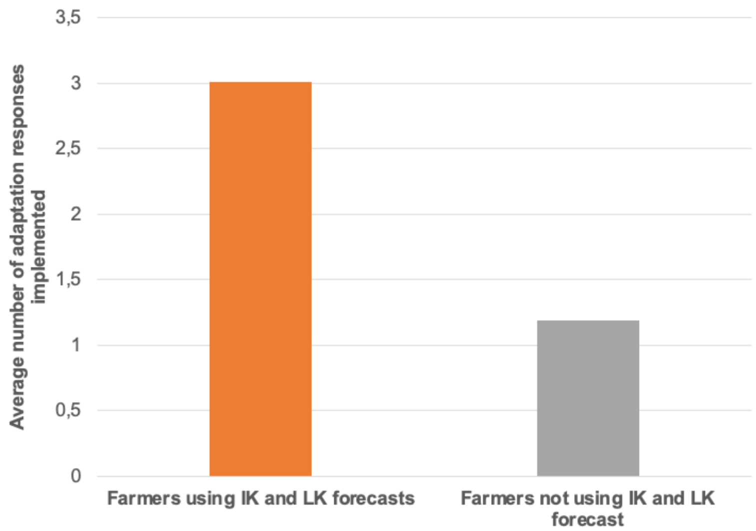


Figure 5: The role of IK and LK forecasts in the implementation of climate adaptation responses by smallholder farmers in Chiredzi: (a) number of adaptation responses implemented per farmer by farmers using IK and LK climate forecasts vs farmers not using IK and LK climate forecasts, b) average number of adaptation responses for farmers using IK and LK climate forecasts vs farmers not using IK and LK climate forecasts

4. Discussion

The majority of smallholder farmers in Chiredzi are using IK and LK systems for seasonal climate forecasting and use the forecast information to make relevant climate risk preparedness decision that are key for local level adaptation and resilience to climate risks. Farmers aged 50 years and above especially in old, communal wards have developed strong IK and LK systems for both climate forecasting and adaptation. This was supported by the regression analysis as we found that farmers' age significantly determines the use of IK and LK forecasts. However, length of stay in an area was found to have no influence on the use of IK and LK. This contradicts previous qualitative studies such as Chisadza et al. (2013) and suggest that farmers move with their Indigenous and local knowledge systems, practices and ways of doing things to new areas they inhabitation.

On the accessibility and use of climate information services, our study discovered that there was high reliance on and trust in IK and LK forecasts compared to scientific weather forecasts as they were readily available to the farmers for use. Although majority of the farmers are relying on IK and LK forecasts, the accuracy of these forecasts is not yet established in this study since the accuracy of climate forecasts determines the relevance of the actions implemented based on the forecasts (Guido et al., 2021).The ways in which scientific/radio climate forecasts were accessed influenced farmer reliance to the forecasts as well as their sharing between farmers and use in climate decision-making. The majority of the farmers (51.1%) do not have direct access to scientific weather information and updates. Instead, they receive forecasts shared through social networks and neighbours that own either a radio or television. This further support the notion that the adoption, use and trust of the climate forecasts among smallholder farmers depends on how well individuals relate and trust the person or source delivering the forecast information. Only one third (31.8%) of the interviewed farmers in Chiredzi owned a radio and only 2.3% own a television which they use to have direct access to the climate forecasts. Our results confirm the findings of Churi et al. (2012) that lack of direct access to scientific weather information updates and how they are shared between smallholder farmers affects use and trust in scientific climate forecasts.

Another important finding was that farmers trust meteorological weather forecasts provided by government agriculture extension officers more than the same forecasts when communicated through radio and television. This could be because the farmers work with these extension officers on a daily basis. Trust in extension officers is built up over time through advice on other technical farming issues. This observation aligns with Okwu and Umoru (2009) who found weather forecasts shared by government extension officers to farmers are generally well received. Importantly, farmers who receive advice from extension officers are more likely to implement adaptation measures (on average 2.6 adaptation measures) compared to the overall average adaptation measures (2.4 measures) implemented by smallholder farmers in Chiredzi.

In terms of the predictor variables that determine the use of IK and LK forecasts by smallholder farmers in Chiredzi, only two of the independent variables made a unique statistically significant contribution to the BLR model - age of the farmer and farmland size (Table 4). Farmers aged 40-49 years have a higher probability of using IK and LK climate forecasts, implying that farmers in this older age group have learned to apply weather information through experience, as opposed to the younger group, who are likely to have little experience in farming-related activities. Farmers with larger farm sizes were more likely to use IK and LK weather forecasts, as farm size appears to influence the extent of weather or climate-related damages or losses that a famer may incur from extreme weather or climate events. In contrast with observations of Vietnamese farmers by Van Huynh et al. (2020), we did not find years living in the area, farm-monthly income, and perception of climate change to correlate with farmers' use of indigenous climate change adaptation practices.

However, concerns on whether current and future generations be able to use IK and LK forecasts as effectively due to raised intergenerational disconnections remains a grey area as far as the use of IK and LK is concerned to smallholder farmers. This is crucial on establishing the consistency and effectiveness of the knowledge in future as well as its relevance to climate adaptation. Further research on this is necessary to establish the long term contribution of IK and LK to climate forecasting and climate adaptation to smallholder farmers and communities.

4.1 IK and LK climate forecasting and decision-making

Most of the IK and LK climate forecasting (see Table 2) performed by smallholder farmers in Chiredzi ranges from short-term (hours, days, weeks) to longer-term seasonal forecasting. This means the decisions from these forecasts are important for day to day running of farm operations and the implementation of short-term climate coping measures. It is important to note that with the current IK and LK climate forecasting, few longer-term farm planning and decisions go beyond a single growing season that can be made from the forecasts. Although these decisions are short-term in nature, our study revealed that they are critical to the farmers’ everyday climate adaptation and decision-making. For example, measures such as the selection of a suitable crop variety based on IK and LK season quality and length forecast, dry planting dates, crop area management highest implemented in the study.

Farmers in Chiredzi district are combining IK and LK climate forecasts with scientific weather forecasts to adapt and increase their resilience to climate risks. A coordinated framework is, therefore, needed that promotes a blended approach of integrating various climate forecast sources to increase reliability and access to climate services for smallholder farmers in Chiredzi. Other blended approaches such as integrated probability forecasting has shown that integrating indigenous and scientific forecasting has improved climate forecasting and decision-making of smallholder farmers (Nyadzi et al., 2022). Farmers in Chiredzi show high reliance on IK and LK forecasts compared to scientific forecasts (see Figure 3). This was in agreement with previous research in Zimbabwe and other parts of Africa Fitchett and Ebhuoma (2018); Tanyanyiwa (2018); Grey (2019). The high reliance on, and trust of IK and LK climate forecasts in Chiredzi district were influenced mostly by ways in which scientific weather forecast information was shared between farmers.

The majority of smallholder farmers in Chiredzi use IK and LK to forecast the onset of rains, mid-season storms and quality of the growing season (see figure 2). These are the climate parameters most predicted by smallholder farmers (Gwenzi et al., 2016; Fitchett and Ebhuoma, 2018). These parameters are important to rainfed smallholder farmers for both planning and implementation of climate adaptation measures (Nkomwa et al., 2014). Farmers in Chiredzi use IK and LK forecast for short term agricultural planning and decision-making, which is critical for climate adaptation. The unique indigenous knowledge resource we found in Chiredzi that was used to forecast key climate forecasts was the use of weather dreamers. Unlike in most cases where a farmer makes a decision using personal interpretation and beliefs of the local environment, the unique character about the weather dreamers in Chiredzi is their sphere of influence. On average, these dreamers were influencing 5 to 10 households in terms of agricultural decision-making. Also, the advice from climate dreamers is very specific, for example, the issuing of specific crop types to grow and size of crop area management according to how they received the dreams. The advice plays a key role on the coping mechanisms implemented by farmers. Importantly, this advice is some cases conflict with advice from government extension officers. It is critical to note that, the farmers in Chiredzi strongly rely on the forecasts and advice from the climate dreamers in making climate decision with the indicators scoring highest on reliability (also see Table 2).

We note through the study that despite the majority of the farmers relying on IK and LK forecasts to make climate risk preparedness decisions, the forecasts did not provide specific information such as the total expected seasonal rainfall which are also equally important in climate decision-making and adaptation of smallholder farmers. However, this knowledge remains a priority and basis for decision-making to these farmers as they profoundly revealed that even the scientific updates they receive do not show the exact expected rainfall amounts seasonally. Therefore, it would be helpful if farmers could receive more exact climate forecast information for accurate decision-making regarding how to cope, and implement adaptation measures. On the other hand, smallholder farmers mentioned that climate variability and change are affecting the reliability of local indicators they are using for IK and LK climate forecasting, for example, cuckoo birds are not as regular as before in the 1990s. In terms of making decisions based on these forecasts, other farmers revealed that are taking note of changes in variables of the IK and LK forecasts but do nothing in response, as the indicator is no longer trusted. This transition away from certain compromised indicators provides descriptive example of the impacts of climate change on IK and LK and Indigenous communities. Conversely, trust in compromised indicators can lead in future to poor decision-making and maladaptation for those farmers continuing to rely on compromised indicators.

4.2 Role of IK and LK on climate adaptation in Chiredzi

The number of adaptation responses implemented by farmers using IK and LK climate forecasts has increased with the increase of the number of adaptation responses implemented per farmer. For farmers that implementing adaptation measures 4, 5 and 6, it was observed that number of farmers using IK and LK to inform adaptation responses was 100%. On average, farmers that use IK and LK forecasts are implementing as many as triple the adaptation responses compared to farmers that are not using IK and LK. The major observation from this empirical evidence is how critical IK and LK contribute to the planning, selection and implementation of adaptation responses and actions by smallholder farmers in Chiredzi and other communities especially from global south. This also point out to how IK and LK is relevant and responsible for the implementation of the majority of behavioural and cultural adaptation measures as most of the measures associated with IK and LK in Chiredzi relates to agricultural calendar year planning, crop type and variety selection, crop area management, farm operational and management measures such as when to irrigation, weeding and fertiliser application. This has further revealed the critical role and influence of indigenous and local knowledge on decision-making that informs how farmers respond to climate variability risks. However, the efficacy of the IK and LK-based climate adaptation responses on reducing the climate risk is yet to be established in the study area and globally. Risks of maladaptation associated with the IK and LK climate adaptation responses knowledge also need to be established. This further highlights a gap on IK and LK identified in Zvobgo et al. (2022).

Farmers in Chiredzi are mostly adapting to drought and rainfall variability - increased rainfall unpredictability, increased delayed and unpredictable onset rains, prolong mid-season dry spells, increased shortened growing season length, poor temporal rainfall distribution. The lack of technological measures that is evident in this study emphasises the lack of indigenous and local knowledge to drive a transformative adaptation process. This observation from the study is in agreement with the global evidence on household and local level climate adaptation, mostly in

Africa and Asia, which is described as incremental (Berrang-Ford et al., 2021). Reflecting and promoting these measures in policy and programming improves the effectiveness of these measures to promote transformational adaptation.

Our study revealed that some common adaptation strategies employed by smallholder farmers in Chiredzi are already threatened by climate variability and change, e.g., the selling of livestock (mostly cattle, goats and pigs) that have been traditionally used by farmers to adapt to the drought impacts. Farmers indicated that the droughts in recent years have increased in frequency and intensity and that this is affecting the availability of the pastures for their livestock. Previously, during a drought farmers could sell one of their cattle and the returns were enough to buy food for the average family in Chiredzi. However, interviews with farmers showed that with recent droughts affecting pastures, farmers need to sell at least two head of cattle due to poor condition of the livestock. This implies that with current and future climate variability and change risks, what has been used traditionally as adaptation measures may not be sufficient to address the climate risks. This means such measures in future can easily reach the adaptation limits. This therefore confirms the need for transformative adaptation measures that can be achieved if IK and LK is blended by other knowledge types.

Conclusion

Indigenous and local knowledge plays a key role in climate forecasting and household climate decision-making that shapes smallholder farmers' adaptation to climate variability risks in Chiredzi. The IK and LK climate forecasting performed by smallholder farmers are used for both short-term forecasting, which is influencing immediate crop cultivation and livelihood decision-making and adaptation responses, and long-term forecasting (up to a seasonal forecasting). The IK and LK-based long-term forecasting have significant influence on the long-term resilience to climate risk. Age of the farmer and farmland size significantly determines farmers use of IK and LK forecasts in Chiredzi. Education of the farmer, irrigation use, farming type (communal or resettled), and access to scientific weather forecasting information positively influence farmer's use of IK and LK climate forecasts; but were not statistically significant.

Smallholder farmers in Chiredzi trust and rely on IK and LK climate forecasts more than they do on scientific weather forecasts in climate decision-making. This reveals the importance of recognising the accessibility and reliability characteristics of IK and LK for climate information services. Farmers that were using IK and LK climate forecasts were implementing, on average, triple the number of adaptation measures compared to farmers that were not using IK and LK climate forecasts. This highlights an important link between IK and LK and implemented adaptation actions. Concretising the significant role IK and LK can play in climate change adaptation, as they demonstrate the importance of recognising the instrumental values of IK and LK and how a blended approach to using multiple ways of knowing can improve interventions targeting resilience for climate exposed communities like smallholder farmers.

The evidence is overwhelming from our case study that IK and LK is increasing the resilience of smallholder farmers to the current climate risks. However, concerns on the accuracy of the IK and LK-based climate forecasts in Chiredzi are not known as well as the effectiveness and efficacy of the associated climate adaptation measures at reducing the climate risk. Future research is required that address the accuracy and effectiveness of the IK and LK.

CRediT

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