Taylor & Francis
Taylor & Francis Group

Inland Waters

ISSN: (Print) (Online) Journal homepage: www.tandfonline.com/journals/tinw20

Local knowledge of climate change adaptation strategies from the *vhaVenda* and *baTonga* communities living in the Limpopo and Zambezi River Basins, Southern Africa

Newton R. Matandirotya, Walter Leal Filho, Gaathier Mahed, Maria Alzira Pimenta Dinis & Prince Mathe

To cite this article: Newton R. Matandirotya, Walter Leal Filho, Gaathier Mahed, Maria Alzira Pimenta Dinis & Prince Mathe (13 Dec 2024): Local knowledge of climate change adaptation strategies from the *vhaVenda* and *baTonga* communities living in the Limpopo and Zambezi River Basins, Southern Africa, Inland Waters, DOI: 10.1080/20442041.2024.2437932

To link to this article: https://doi.org/10.1080/20442041.2024.2437932

Publisher: Taylor & Francis & International Society of Limnology (SIL)

Journal: *Inland Waters*

DOI: 10.1080/20442041.2024.2437932

Local knowledge of climate change adaptation strategies from the *vhaVenda* and *baTonga* communities living in the Limpopo and Zambezi River Basins, Southern Africa

Newton R. Matandirotya[1,2], Walter Leal Filho[3,4], Gaathier Mahed[1], Maria Alzira Pimenta Dinis[5,6], Prince Mathe[2]

[1]Department of Geosciences, Faculty of Science, Nelson Mandela University, Port Elizabeth 6000, South Africa
[2]Climate Change Adaptation and Resilience Centre, Kgotso Development Trust, P.O. Box 5, Beitbridge, Zimbabwe: Corresponding author: runyamore@gmail.com
[3]Manchester Metropolitan University, Department of Natural Sciences, Chester Street, Manchester M1 5GD, United Kingdom

[4]Hamburg University of Applied Sciences, Germany

[5]Fernando Pessoa Research, Innovation and Development Institute (FP-I3ID), University Fernando Pessoa (UFP), Praça 9 de Abril 349, 4249-004 Porto, Portugal

[6]Marine and Environmental Sciences Centre (MARE), University of Coimbra, Edifício do Patronato, Rua da Matemática, 49, 3004-517 Coimbra, Portugal

Abstract

Communities living within Africa's river basins remain vulnerable to the negative impacts of climate change. This study aimed to explore the various local knowledge (LK)-based climate change adaptation strategies used by the *vhaVenda* and *baTonga* communities, residing in the Limpopo and Zambezi river basins (LRB and ZRB, respectively) in Southern Africa. The study's novelty lies in its assessment of the LK embedded within these indigenous peoples. Data were collected through a questionnaire survey of 35 community members (60% women), with the findings further complemented by a review and analysis of existing literature. The study revealed that 96% of participants were already familiar with the concept of climate change. Additionally, the findings show that communities in both the LRB and ZRB continue to rely on biotic and abiotic indicators to predict weather, while social networks play a crucial role in coping with periodic shocks such as drought-induced food shortages. The vhaVenda and baTonga communities have demonstrated remarkable innovation in developing techniques that support livelihoods in the challenging environments of the LRB and ZRB. Furthermore, both communities displayed a profound understanding of their local ecosystems, enabling them to create adaptation strategies tailored to their specific geographical and environmental conditions, underscoring the value of these approaches. This study has important implications for climate change adaptation policies in low-resource regions, including Zimbabwe, as it highlights that these communities are already equipped with effective strategies for adapting and surviving in harsh climates.

Keywords: Climate change adaptation, water scarcity, extreme weather, drought, Limpopo River Basin, Zambezi River basin, *vhaVenda*, *baTonga*

1 Introduction

Adapting to climate change presents a significant societal challenge, further complicated by the uncertainty of future impacts and issues related to climate justice. The knowledge systems and practices of Indigenous peoples are recognized as a 'major resource' for climate change adaptation (Petzold *et al*., 2020). Yet, they have not been consistently integrated into adaptation efforts and are often overlooked in policy and research (IPCC, 2014). This paper offers the first systematic global evidence map of peer-reviewed literature to facilitate a more comprehensive engagement with existing and emerging research on Indigenous knowledge in the Intergovernmental Panel on Climate Change (IPCC) assessments. It includes an analysis of geographic and thematic gaps and clusters related to Indigenous knowledge on climate change adaptation.

Indigenous knowledge refers to Indigenous peoples' understandings, skills, and philosophies, developed over long, multigenerational histories of interaction with the natural world and adaptation to highly variable and changing ecological and social conditions, including colonization and globalization (Petzold *et al.*, 2020). Despite its value, Indigenous knowledge has not been widely utilized in formal adaptation efforts by governments and has often been overlooked in policy and research (IPCC, 2014). However, the IPCC AR5 does not explore the reasons for this omission (Petzold et al., 2020). Despite this neglect, Indigenous peoples have long recognized the importance of their knowledge systems in managing change (Ford *et al.*, 2020). Traditionally, African communities have relied on Indigenous and local knowledge (LK) to anticipate and respond to climatic variability (Zvobgo *et al.*, 2022). The use of LK in farming systems, including livestock management, is widespread across Africa. For instance, LK is used in early-warning systems and as an indicator of the quality of the rainy season (Soropa et *al.*, 2015). There is growing interest in documenting ILK, both for its intrinsic heritage value and for its potential role in supporting relevant and locally acceptable climate change adaptation strategies (Leal Filho *et al.*, 2021). While a considerable amount of empirical research has been devoted to LK, this knowledge has yet to be adequately integrated into adaptation and mitigation planning, particularly in countries of the Global South (Zvobgo *et al.*, 2022).

The impacts of climate change on local communities extend beyond immediate threats to food supply. There is evidence that climate change has reduced total agricultural productivity growth in Africa by 34% since 1961, more than in any other region (Ortiz-Bobea *et al.*, 2021). Climate change also affects water availability (Biao, 2017; Descroix et al., 2018; Thompson *et al.*, 2017), health and human settlements, which are particularly vulnerable to floods, droughts, and heatwaves (Douglas *et al.*, 2008; Kundzewicz *et al.*, 2014). Recognizing the value of Indigenous and local knowledge (ILK) for more integrated climate risk adaptation—especially in regions reliant on rain-fed agriculture—can contribute to the broader goal of sustainable climate adaptation. Communities living within Africa's river basins remain particularly vulnerable to the effects of climate change, especially those whose livelihoods depend on the health of these river systems. Compared to other continents, Africa remains the most threatened by nature-based disasters (Leal Filho *et al.*, 2023), and climate change is projected to have a negative impact on food security as well as the attainment of sustainable development goals (SDGs) in Africa (Berkes 2020). The effects are expected to be extremely severe in regions of Africa that depend on rainfed agriculture and have limited resources to mitigate and adapt. Amongst the tools that can be deployed include the application of local knowledge (LK) already embedded within communities. The knowledge of local people, referred to as LK, is gradually being recognised as an imperative source of information for climate change mitigation and adaptation (Nevel *et al,* 2021) around the world. Based on past events, the Limpopo River Basin (LRB) and Zambezi River Basin (ZRB) have been prone to extreme weather events such as floods and droughts (Botai *et al.*, 2020), with drought being very prominent in the last decades (Legesse Gebre and Getahun, 2016).

LK refers to the knowledge about nature, including organisms, ecosystems, and ecological interactions, held by local people who interact with and use natural resources (Hadlos et al., 2022). In certain instances, LK also encompasses knowledge held by local people who may not be officially recognised as indigenous (Berkes, 2020) but apply to the local context. In essence, these are knowledge forms that have failed to die and are unique to a given society or culture (Kunnie, 2019). In this study, these two key phenomena have been used based on the understanding that local and indigenous knowledge systems are intertwined aspects that are key in both climate change mitigation and adaptation. In the past, LK has not been considered of much value in climate change solutions. However, in recent years, there has been some shift (Gandure et al., 2013) particularly concerning policy formulation (Leal Filho *et al.*, 2021). Over time, African communities have developed various generation-to-generation adaptation techniques (Leal Filho *et al.*, 2021) that have mostly been orally transferred (Leal Filho *et al.*, 2022). For example, indigenous African farmers have developed a systematic approach to collecting indigenous ecological knowledge for predicting weather patterns through the application of various techniques (Ebhouma, 2020), such as the utilisation of biotic and abiotic indicators to predict weather patterns. Conversely, the observation of global climate change has primarily been based on scientific meteorological data. Yet, there is a paucity of information on how African communities have used local knowledge to recognise and respond to such changes (Kupika et al, 2019). Local indigenous communities remain highly vulnerable to the impacts of climate change as their livelihoods, culture, spirituality, and social systems are rooted in nature. For several millennia, indigenous people have utilised their long-term accumulated knowledge to sustainably explore and adapt to changes within their environment for survival (Ebhuoma, 2020).

LK has evolved into knowledge reservoirs that help indigenous local people cope with extreme weather events and other related challenges. According to Ajibade and Eche (2017), LK-generated knowledge remains embedded within agricultural, hunting, fishing, and medicinal practices and may offer valuable knowledge on climate change adaptative strategies. The knowledge based on observed and projected impacts and risks generated by climate hazards, exposure, and vulnerability has increased with impacts attributed to climate change (IPCC, 2022). The IPCC (2022) categorises impacts and risks in terms of the magnitude of damage, harm, and economic and non-economic losses. Furthermore, LK has been recognised for contributing to various climate adaptation forms (Mekonnen et al., 2021). Additionally, LK can contribute to the formulation of planned adaptation measures, which are conscious policy options aimed at altering the adaptive capacity system (Mugambiwa and Rukema, 2019). The past decades have seen growing interest in the potential role of LK in managing climate change impacts and uncertainties (Masinde *et al,* 2018). The growing body of knowledge on LK about climate change impacts on biophysical systems provides a novel contribution towards our understanding of local climate change impacts and the responses in rural communities that can help to develop sustainable environments (Kupika *et al.,* 2019). At the same time, (Mugandani and Mafongoya, 2019) assert that local communities have the knowledge and practices to cope with adverse environmental conditions that might occur in their localities. The paradigm shift stems from the recognition of both the increasing threats of climate change and the value that LK has for impact identification and adaptation (Chanza and Mafongoya, 2017) using low-cost interventions.

This study aimed to explore the various LK-based climate change adaptation strategies applied by the *vhaVenda* and *baTonga* communities residing in the LRB and ZRB, respectively. Additionally, the study highlighted the unique local knowledge practices within these two communities. Historically, both regions have been highly susceptible to climate change-induced extreme weather events, such as heatwaves, floods, and droughts. This study emphasizes the distinctive LK approaches used by the *vhaVenda* and *baTonga* communities, who employ innovative techniques to sustain livelihoods under harsh climatic conditions. The analysis proceeds with Section 2, which covers the materials and methods, Section 3 presenting the results, Section 4 discusses the findings, and Section 5 offering conclusions and policy implications.

2 Materials and methods

Study area description

The study was conducted in the LRB and ZRB, with a focus on the Beitbridge and Binga districts in Zimbabwe, both classified as semi-arid to arid regions. The LRB is shared among four countries, namely, Botswana, Mozambique, South Africa, and Zimbabwe, with an area covering 416,296 km^2 that meets the Indian Ocean in Mozambique (Botai *et al.*, 2020) and supports a predominantly rural population of 14 million people. The study focused on communities residing within the basin on the Zimbabwean side but bordering Messina on the South African side. The *vhaVenda* communities are indigenous groups that have lived on both sides of the river between South Africa and Zimbabwe for decades, estimated as such since the early 18th century. This community was chosen for this study as it has witnessed changes within the basin for decades, though most of the changes are documented in oral formats. Currently, Beitbridge has an estimated population of 81,000, with the majority being rural communities. The average daily temperatures in the LRB range between 25°C-31°C (Mugari et al, 2023), while the average annual rainfall is < 450 mm (Tchakatumba *et al.*, 2019).

The ZRB is home to diverse, valuable natural resources for eight countries that share the basin - Angola, Botswana, Malawi, Mozambique, Namibia, Tanzania, Zambia and Zimbabwe. Currently, more than 30 million people live in the watershed, which must satisfy their social and economic needs as well as maintain the health of the natural environment (Sainz, 2018). Therefore, this study focused on the communities situated on the Zimbabwean side of the river basin in Binga District, which lies in the northwestern area of Zimbabwe. The *baTonga* are "the great river people" in the north of Zimbabwe and south of Zambia that were forced to move into arid regions of their country when the construction of the Kariba dam, completed in 1959, swelled the Zambezi River into a lake that filled in the valley they called home (Leal Filho, 2022). Shared watersheds by countries present management complexities that must be resolved by collaboration strategies towards common objectives. **Figure 1** shows the study regions.

Large basins like the Zambezi exhibit variable climatic conditions that distribute precipitation spatially and differently across the region. Historically, the livelihoods of the Zambezi Valley revolved around a combination of fishing and food production, e.g., maize, sorghum, and millet (Binga North Constituency Profile 2015). Crafting and hunting livelihoods also exist but have reduced in terms of contribution to household income, hence increasing both income and non-income poverty. Zambezi Valley is highly vulnerable to climate change-induced extreme weather events and chronic food insecurity due to external shocks such as droughts and crop failure. According to the 2022 Census, the Binga district has a total population of 139,092 people. The annual rainfall in the ZRB is usually <450 mm and daily temperature ranges between 25°C-33°C (Gadzirayi, 2013).

Data collection

The study employed a mixed methods approach, combining qualitative and quantitative research (Granikov et al., 2020). Data were collected using a questionnaire comprising 32 closed and open-ended questions. The questionnaire was pre-tested on 10 community members prior to the main survey. Based on the feedback from these participants, necessary corrections and adjustments were made. The questionnaire aimed to assess community members' knowledge of climate change, the impacts they had experienced over the years, and the adaptation strategies they had implemented. A total of 35 rural community members were randomly selected to participate, with 20 from the Binga-ZRB and 15 from the Beitbridge-LRB. The key inclusion criterion was that participants had to be permanent residents of one of the two river basins, while the main exclusion criterion was non-residency in these areas. Study participants were primarily from Ward 15 and Ward 6 of rural Beitbridge and Ward 24 of Binga. All participants were above 18 years of age and provided verbal consent to participate in the study. Although the study aimed for equal sampling across regions, five respondents from the LRB who had initially been identified could not provide their responses during the survey period. The data were analysed using descriptive statistics in Microsoft Excel (Version 2305) and thematic analysis in Atlas.ti (Version 23). The primary survey data were supplemented by secondary literature synthesis. The study applied the IPCC (2022) definitions of adaptation, resilience, and risk.

3 Results

The study surveyed a diversified group of community members, with women participants as the majority, as highlighted in **Table 1**. This can be attributed to rural area living patterns where women are predominantly in the majority.

Table 1 shows that the highest percentage of contributors were in the age group 36-40, while the least contributors were from the age group 55 and above. On the other hand, the majority of participants had reached secondary school, with the highest coming from the 26-30 group. **Figure 2** highlights the means of survival for the study participants and the gender disaggregation. Participants had the opportunity to provide multiple responses. As shown in **Figure 2**, 97% of the participants indicated that their main source of livelihood is subsistence farming. In comparison, 66% indicated that they derive their livelihood from part-time informal jobs, with 23% indicating that fishing and remittances also form part of their source of livelihood.

As shown in **Figure 3**, among all the respondents, on their awareness of climate change, a total of 91% of participants indicated that they had heard about climate change before. Multiple responses were also allowed to address sources of climate change information. The highest percentage of the responses (46%) indicated that the participants obtained information on climate change from community meetings, the majority of which were women. A total of 40% (16 males and 24 females) indicated that their climate change information came from radio transmissions. WhatsApp was the least indicated source of information.

Table 2 indicates that the shortage of grazing land ranked the highest in threats from climate change, at 97%, while livestock death was ranked the second highest risk at 86%. Poor quality water was the climate change impact that participants least indicated. On changes observed, 100% of the participants were of the view that droughts had increased in frequency over the last ten years. On the other hand, 86% of the participants stated that there has been an increase in ambient temperatures as characterised by episodes of heat waves.

Figure 4 highlights the various LK weather prediction techniques applied in both the LRB and ZRB. To reduce the negative impacts of climate change, the study ascertained that the communities in the two basins are applying different LK-based techniques that are biotic and abiotic in nature to predict weather patterns. One of the most common techniques is the reliance on moon cycle observation.

The study established that the two communities are using various LK biotic and abiotic approaches to predict droughts, with one being the moon observation technique. The participants in ZRB reported that when the moon has a small circle or a sign of a pool of water around it, it is interpreted as a sign that the community will experience droughts for that particular year. These moon observations are performed just before the commencement of the summer season in the month of October.

> *"The common approach is the use of the pool around the moon; when it has a smaller pool that is an indication that the area will face low rainfalls. This is one of the strategies that has been used for a long time even our grandparents used this strategy. This circle is only seen around October or November before the rains start, and it continues even during the rains". (Participant 18: ZRB)*

> *“Some people examine the moon's position when it is quarter- or half-shaped in addition. I'm still unsure on how it should appear in that condition”. (Participant 2: ZRB).*

In the LRB, it was further reported that the communities use a slightly different moon observation technique than the ZRB. The communities indicated that when a moon looks very bright and clear, it is interpreted as an indicator of an upcoming drought.

"The second sign of drought which symbolises drought is when the moon appears clear without black cloud surrounding it”. (Participant 1: LRB).

Another way of predicting droughts that is more similar across the LRB and ZRB is the wild fruit monitoring and observation technique. In the event of a tree species that usually does not flower or bear fruit, if it does produce flowers or fruits, it means that drought is coming. The other way of predicting droughts used across the two basins was the availability, movement, and behaviour of wild birds and animals.

> *“We notice the “**mnyii”** tree having a lot of flowers; that's a sign that a drought is coming. It predicts that there will be very little rainfall in that year”. (Participant 2: ZRB).*

> *"A sign of drought includes fruiting of wild trees that normally do not have such fruits; for example, when “**muthobi”** has many fruits, it means the upcoming season will be droughty”. (Participant 5: LRB)*

The availability of wild fruits is an important indicator in determining droughts in the LRB and ZRB. The communities observe wild fruits as a way to ascertain the amount of rain to anticipate for the next farming season.

The study participants highlighted that observations of birds, frogs, and rats shape indications in predicting droughts with LK. For example, the shortage of rain birds near the approach of the rainy season clearly indicates that a drought will be experienced. The communities in ZRB said that the “***siaympembezya***” birds are only seen during rainy seasons; they fly in a group, usually in the early morning or in the evening, and they are also seen flying around at times when it is cloudy.

*"The approach we use to predict drought shortage of the birds is called "**siyampembezya**". Like most of us who spend a lot of time at the river, we usually monitor these birds to see how they fly and if there are many or not. If they are few by that year, this means that there are low rainfalls, which results in having a drought." (Participant 16: ZRB)*.

"When fewer wild birds are moving around in the forest, particularly towards the rainy season." (Participant 3: LRB)

*"When we hear the noisy sounds of frogs as well as some wild birds called "**maguthuguthu**" will be seen flying all over the place." (Participant 9: LRB).*

Besides wild birds, some participants in the LRB indicated the use of wild rat populations as a predictor of drought. This strategy was only found in the v*haVenda* community, where rats are monitored, and this LK tends to give dependable outcomes that they have come to trust and believe in.

"In our community, we usually predict an upcoming drought through the emergency of a high rat population" (Participant 5: LRB).

On the contrary, the *baTonga* indicated the use of mist as a predictor of drought.

"When there is little to no morning mist in the area, it is a sign that can be observed to predict droughts. Early in the morning in September and October, the mountains should be covered with mist" (Participant 6: ZRB).

"If the sun is overcast with mist in the morning that year and not shining, there won't be much rain. If the community detects this occurring in that year, it will begin acting properly." (Participant 15, ZRB).

The *baTonga* community uses a different way to predict droughts, as they observe the mist levels in their communities. Thus, if the levels of mist are low, it is interpreted that the community will have limited rains that might lead to drought. The study further reported that the communities in the LRB and ZRB observe wind speed to predict floods. The high prevalence of high-speed winds indicates an upcoming flood event.

"As a community, we predict upcoming floods through the blowing of high-speed winds" (Participant 15: LRB).

"A sign of upcoming floods include strong winds that blow periodically towards the rainy season" (Participant 3: ZRB).

The two communities exhibited similarities in how they applied the moon predictor techniques about the commencement of the rainy season. Key to using the moon are several signs and symbols, with their interpretation being guided by LK references accumulated over decades of moon pattern monitoring.

"The rainy season is shown when the moon is surrounded by a black cloud while having a white ball inside the moon." (Participant 2: LRB).

Participants also expressed similar sentiments in the ZRB:

"A moon normally indicates the indicator of a rainy season with a small round cloud surrounding." (Participant 18: ZRB).

The two LRB and ZRB communities also indicated the use of biotic signs to predict the onset of the rainy season, including monitoring the behaviour of wild animal species such as frogs, butterflies, ants, and elephants. Movement patterns and population levels are of importance to the technique. Interpretation is based on decades of accumulated LK references.

> *"The start of a rainy season can be shown by frogs and birds clucking and croaking with loud sounds." (Participant 3: LRB).*

ZRB participants highlighted the dependency on observing elephant behaviours:

> *"When the rains are about to start, the elephants start disappearing, that they will not be troublesome like they are now. Participant 18: ZRB)*

As shown in **Figure ,** communities in the two LRB and ZRB basins indicated the application of several strategies to deal with negative climate change-induced challenges. As part of dealing with lean season food shortages, participants indicated approaches such as relying on social networks and supplementing with wild fruits.

Community Adaptation to Food insecurity

The study reported that communities in the two LRB and ZRB basins are using a range of coping mechanisms to deal with food shortages, with a majority indicating a reliance on social networks as buffers during periodic shocks, such as lean season food shortages that are usually triggered by droughts. Such social networks typically include friends, relatives and neighbours.

> *"Some coping mechanisms households use during food shortages include borrowing food, mainly maize, from neighbours". (Participant 5: LRB).*

> *"The first strategy we do in dealing with food shortages is through asking our close relatives" (Participant 20: ZRB).*

Supplementing household food shortages with wild-harvested fruits was another common strategy to reduce the impact of drought-induced shortages in the two basins. Even though the regions are arid and dry, there is seemingly a wild abundance of wild fruits that can be processed for consumption using different approaches. One common fruit of choice is the baobab fruit (**Figure S1**), whose consumption can be in its raw form or combined with other additives.

> *"To deal with food shortages, we normally use baobab fruit that can be consumed raw or made into porridge or can be eaten as thick porridge by both adults and children." (Participant 9: LRB).*

> *"The region has baobab trees (**mabuyu**), which are used to make juice or porridge that can be used as food during times of food scarcity." (Participant 16: ZRB).*

The baobab fruit is usually ground into some powder that is then prepared into consumable porridge. The porridge is recommended for its high vitamin and micro-nutrient content. In certain instances, the study also reported that some community members resort to negative coping strategies to provide food for households, including selling off livestock.

> *"To cope with food shortages, community members sell livestock and in turn buy food from the proceeds of selling off the livestock." (Participant 1: LRB)*

"After this, someone looks into his kraal, starting with goats, where we sell the goats either with money to buy our food or through barter trade. We sell goats because it's hard for us to sell big livestock like a cow. When we sell goats, we can get money for our groceries" (Participant 17: ZRB).

Grazing land shortage mitigation strategies

To cope with the shortage of grazing land (**Figure S2)**, the study also established that the temporary relocation of livestock to areas with better pasture was a common practice in the two basins. In both regions, these pastured range fields are referred to as "***emlageni***". The distinct feature was that it was mostly practised by cattle-owning households and not those with small livestock.

The temporary relocation is usually abandoned soon after the onset of the rainy season, which brings an improvement in the status of pastures.

"We move our livestock to areas with greener pastures for example near the Limpopo River. Young boys will stay with the animals through the dry season until the first rains." (Participant 8: LRB).

"When grazing lands become scarce, some of the communities tend to move their livestock, especially cattle, to places where there are more grazing areas. For our communities, they send them to the Nkweeba, Sizimba and Luunga areas. We usually send cattle to those places during the dry spell when the pastures are finished in the area around August." (Participant 1: ZRB).

Reasons behind the community vulnerability

The respondents highlighted that they continue feeling vulnerable to climate change risks and shocks despite having all these available LK indicators. They emphasised that their vulnerability is a result of the failure to have mitigation strategies - that after being able to predict poor rains and droughts, the communities have no capacity to mitigate the effects but are just affected by such information. One respondent indicated the following:

"*As a community, we are able to predict the amount of rain and all this might come to be true, but the only challenge is how to avert the effects. We do not have irrigation schemes that we can use during the prolonged dry spell. When this happens, our early warning indicators become of no importance because we have no capacity to address those effects." (Participant 4: LRB)*

This indicates that despite the communities having the LK-based early warning indicators to predict droughts and rains, they still remain vulnerable because they do not have adequate resources and plans to avert the effects of these droughts. The respondents also highlighted access to water has been negatively impacted due to climate change. There is a shortage of water and the communities have to dig deeper wells in order to access water and to move far towards Zambezi River as its tributaries are drying off.

4 Discussion

In relation to climate change adaptation, this study found that LK remains invaluable for Indigenous communities in both the LRB and ZRB, particularly in areas such as weather prediction, drought early warning, managing seasonal food scarcity, and determining the start and end of rainy seasons. The generational knowledge passed down through the *vhaVenda* and *baTonga* communities has enabled them to survive in the harsh climatic conditions of these regions. The study highlighted that LK, refined over decades, can now be used with some accuracy to predict extreme weather events and serve as an early warning system for droughts and floods (Roncoli et al., 2002). There are notable similarities in both abiotic and biotic techniques used by the communities. For example, moon monitoring was a prominent practice in both. In both regions, the appearance of a halo around the moon is believed to signal an upcoming drought. Similarly, Middle Eastern communities, with their long histories of agriculture and pastoralist life, have traditionally relied on the moon as a tool for predicting weather patterns, including droughts. Historically, timekeeping, religious rituals, and agricultural practices have all been influenced by the moon in Middle Eastern societies. The moon cycle was especially important for rural societies because it could be used to predict weather patterns, such as rainfall and droughts, which were critical for managing water resources and crop viability. These customs are a result of the region's need to adjust to its arid climate (Al-khalidi, 2019).

Notably, both the LRB and ZRB communities use the moon shape and the circle around it as an indicator to predict and forecast drought existence. These findings are similar to a study by Radeny *et al.* (2019) establishing that the occurrence of a haloed moon, i.e., a moon surrounded by a yellow ring, a moon with different colours like a rainbow, and the appearance of a moon in a *normal* circular shape are all indicators of the onset of rains for long-rain and short-rain seasons in Lushoto, Tanzania. A moon surrounded by heavy clouds is a sign of a good rainfall season. The moon orientation can also be used to predict a drought season. A slanted position of the crescent moon is an indicator of a drought season, with less rain expected on the inclined side. All this, supported by the respondents' statements, shows the similarities in LK shared by African communities in the application of biotic and abiotic signs to predict drought. The same authors further asserted that strong winds and a red moon are indicators of the onset of a short-rain season, and a white moon indicates the onset of rain for the long rain season. The corroboration of these study findings through the mentioned literature studies indicates that the use of LK in the prediction of droughts is more prevalent in the two communities for example utilisation of wind direction techniques.

The results of this study align with findings from other regions, such as Brazil, where Indigenous and rural communities also rely on LK to anticipate and adapt to climate variability. In Brazil, communities like the Sertanejos in the Caatinga and Quilombola villages closely observe the behaviour of wild trees and plants to predict droughts or the likelihood of rain (Santos and Ramos 2018). Similarly, the *vhaVenda* and *baTonga* communities in the LRB and ZRB use abiotic and biotic indicators, such as moon monitoring, to forecast weather patterns. In both cases, generationally inherited knowledge plays a critical role in managing agricultural practices, responding to food scarcity, and surviving in harsh climatic conditions. For example, just as Brazilian communities track tree phenology to adjust their planting and harvesting seasons (Albuquerque et al., 2002), the *vhaVenda* and *baTonga* rely on signs such as a halo around the moon to signal an impending drought.

The other significant biotic strategy highlighted in both the LRB and ZRB communities was the observation of wild fruits and trees. The communities indicated that they monitor and observe certain trees in the community, looking at how they sprout their leaves and what flowers they have. The study of wild trees has been predominant in the LRB and ZRB climate change adaptation strategies context, where communities assess the trees to predict the likelihood of a drought in their communities. This finding is similar to a study by Mashoko (2019), highlighting that the most common local indicator for drought prediction was the bearing of large quantities of wild fruits by specific trees, in particular the *Parinari curatellifolia*, *Lannea discolor* and *Lannea edulis*. The same study asserted that if the *Brachystegia spiciformis* (*msasa*) tree shoots are dark maroon in colour, a drought is imminent. The study also established that access to climate information remains a challenge in the two regions, as 43% indicated that they are currently getting information from community gatherings while 11% still do not have any source. The lack of climate information in African communities is mostly due to the lack of data and scientific capacity (Lamptey *et al.*, 2024), thus communities end up turning to LK as a viable option.

The climate information scarcity is even worse in rural communities of Africa (Okoronkwo *et al.*, 2024), where in some instances the infrastructure and communication channels are even non-existent, especially in the hard to reach rural communities. In instances where climate information is available to communities, sometimes it is presented in formats that are too technical and difficult to understand and interpret. Additionally, sometimes communities in Africa are also not aware of the existence of vital climate information (Dinku *et al.*, 2014, Leal Filho *et al.*, 2023). Since communities in the two study regions indicated that they sometimes have access to climate information through digital platforms like WhatsApp, it suggests that authorities can make available such information in the local languages. The LRB and ZRB communities also reported the use of a common abiotic indicator, i.e., wind. For instance, the higher the wind speed, the more probability there is of high rains occurring, potentially causing floods. This was also supported by a study conducted by Mashoko (2019), who reported that when the winds blow in a south-to-north direction in the rainy season, it indicates little rainfall. If the winds are strong and blowing from the north to the southeast, it is a sign of good rain in that particular community. Similarly, Radeny *et al.* (2019) pointed out that the north-south wind direction in September is believed to be a sign of the onset of a short rain season and heavy rainfall in the upcoming season.

The observation of wild animal behaviours and mannerisms is also common in both the LRB and ZRB communities. An example is the sudden proliferation and increase in the rat population, thus symbolising a forthcoming drought event. A similar finding was established in a study by Ayal *et al*. (2015), which found that the Borana people in Ethiopia also use wild animals and insects for weather forecasting. For example, in that community if a ground squirrel is busy digging holes, a normal rainy season is expected. Similarly, an army of ants moving along in a nearly straight line indicates a normal rainfall season, while if they are dispersed in search of food, it signifies the likelihood of drought. The migration of bees from north to south during seasons of resource abundance is also a sign of drought, while migration in the reverse direction indicates a normal rainfall season. Similarly, Kom *et al.* (2023) established that communities in Vhembe district, Limpopo-South Africa also confirmed ant movement as a predictor of weather. The use of wild animals and insects as weather predictors across the LRB and ZRB featured prominently in this study, highlighting similar practices with other African communities, as the monitoring of animal behaviours is useful in planning farming events (Mugi-Ngenga *et al.*, 2021). This shows that across African societies, LK is considered important in predicting droughts through nature observations. Meanwhile, during food shortage episodes, both communities implement strategies such as borrowing food from their relatives or their neighbours, thus showing the value of social networks in both study regions.

The LK approaches used by the *vhaVenda* and *baTonga* communities are not only notable but also invaluable for several reasons. Firstly, the innovative strategies devised by these communities showcase their profound connection with and reliance on their natural surroundings. By utilising their LK, the *vhaVenda* and *baTonga* have managed to adapt to the specific challenges posed by the adverse climate in their communities, demonstrating a harmonious coexistence with the environment. Secondly, these approaches have proven highly effective in establishing sustainable livelihoods. The *vhaVenda* and *baTonga* communities have developed practices that not only ensure their own survival but also contribute to the preservation and conservation of their ecosystems. This is a testament to their wisdom and the value of their knowledge systems. Furthermore, the study of these adaptation strategies could offer broader insights into the potential for incorporating LK into modern resource management and development practices. The *vhaVenda* and *baTonga* communities' success in utilising their LK can serve as a model for the integration of traditional wisdom into contemporary approaches to sustainable development, thereby fostering a more holistic and inclusive approach to environmental and livelihood management. Thus, the *vhaVenda* and *baTonga* communities' unique LK adaptation approaches in the LRB and ZRB are not only locally valuable but also a source of inspiration and learning for other peoples around the world towards the quest for climate change adaptation. They exemplify the potential for blending traditional knowledge with modern practices to achieve both environmental sustainability and improved livelihoods, making them a valuable subject of study and admiration in the field of LK.

Similar to the *vhaVenda* and *baTonga* communities in the LRB and ZRB, who have developed strategies to manage water resources amidst changing climate conditions, Indigenous peoples around the world have long employed traditional knowledge to safeguard vital water supplies. Accordingly, the care of wetlands has long been a method of managing inland water supplies by the Coast Salish people of the Pacific Northwest. Wetlands were managed to support fish populations and plant species that provided food, medicine, and materials for the community. Wetlands are essential for water purification and groundwater recharge (Gammage, 2011). The Australians who lived in the Western Desert excavated groundwater wells and controlled natural soaks by covering them with rocks to keep contaminants and evaporation out. Even during dry spells, these wells which were frequently handed down through the generations provided consistent supplies of potable water (Lansing, 2012). For the communities in ZRB and LRB have also implemented and adopted measures to promote inland water management skills in the face of climate change through digging wells along the distributaries and tributaries from the Zambezi and Limpopo rivers. This indicates that the findings link well with previous findings which indicate that the use of LK can be key towards management of inland water resources.

The implementation of climate change response programs for adaptation and resilience often relies heavily on Western scientific knowledge, which can lead to the marginalization of indigenous knowledge, deeming it less relevant in this context. However, and as resulting from this study, knowledge systems do not evolve in isolation, interacting and enhancing one another. In this context, it is crucial to recognize that indigenous knowledge holds equal significance to scientific knowledge. An integrated approach that combines both forms of knowledge through a multifaceted evidence base is essential for effective climate change adaptation and mitigation (Makondo and Thomas, 2018).

5 Conclusion and policy implications

Communities living in African river basins, particularly in the LRB and ZRB, remain susceptible to the adverse impacts of climate change, manifesting as hot, arid conditions and water scarcity, characterized by a shortage of grazing land and food shortages resulting from persistent drought events. Food shortages are further exacerbated by the fact that a majority of farmers rely on rain-fed agriculture. This study investigated the LK-based strategies that the *vhaVenda* and *baTonga* communities in Southern Africa employ to adapt to climate change. Data were collected using questionnaires administered to 35 community members, and the results obtained were further enhanced through a synthesis of existing literature on LK and a comprehensive analysis. The *vhaVenda* and *baTonga* communities have developed sophisticated techniques for weather prediction, utilizing observations of the moon's appearance, wild fruits, and wind patterns. These methods are corroborated by both the questionnaire data and the literature, demonstrating their effectiveness in disaster prevention and mitigation. However, access to formal climate information remains limited, with many community members relying on gatherings for information or lacking access altogether. This scarcity often drives communities to depend on LK. Furthermore, socio-economic factors and limited access to technology affect the utilization of modern climate prediction tools. The study underscores the importance of integrating LK into contemporary climate strategies, showcasing how these communities' deep ecological understanding and innovative practices contribute to sustainable livelihoods and ecosystem conservation. These findings suggest that blending traditional knowledge with modern technology could enhance climate resilience and sustainable development in similar regions. The significance of LK, as described in this study, cannot be overstated, particularly in the context of the LRB and ZRB communities.

Several key points emerging from the analysis and discussion highlight the critical role of LK in these regions:

- ***Weather Prediction and Disaster Preparedness***. It becomes clear that the LK of the studied communities is crucial for predicting upcoming weather conditions, such as droughts, the onset of the rainy season, and floods. LK allow these communities to prepare for and mitigate the impact of these natural disasters. It is a matter of survival for these communities, as they rely on agriculture and natural resources for their livelihoods.
- ***Cultural Significance***. The LK, including the interpretation of the moon's appearance, wind direction, and the behaviour of wild animals, is deeply embedded in the culture of the studied communities. It reflects their strong connection to their environment and traditions, passed down through generations.
- ***Resilience***. The studied communities have adapted to their specific environmental challenges over time, developing strategies for disaster prevention and preparedness. This adaptability and resilience are significant for their continued existence and well-being.
- ***Community Consensus***. The fact that different studies support the findings of this study underscores the credibility and reliability of the LK used by these communities. It indicates that this knowledge is shared across different African societies and has stood the test of time.
- ***Sustainability.*** The LK approaches mentioned, such as monitoring wild trees and animals, highlight the sustainable nature of these communities' practices. By relying on nature's cues, they can make informed decisions about resource use and management, contributing to climate change adaptation strategies.
- ***Local Resource Management***. LK used to predict droughts and other climate-related events enables more effective local resource management. It empowers the LRB and ZRB communities to make informed decisions about agricultural practices, water usage, and food storage.
- ***Ecological Awareness***. LK emphasises the importance of observing and understanding natural signs and phenomena within the African context of perception and beliefs. This is an important aspect of promoting ecological awareness and conservation in these communities.
- ***Traditional Knowledge Preservation.*** By recognising and valuing LK, there is an opportunity to preserve and protect these traditional knowledge systems, which are increasingly at risk due to modernisation and cultural shifts.

The LK of the communities in the LRB and ZRB is of extraordinary importance for the survival, resilience, and sustainable management of natural resources among the *vhaVenda* and *baTonga* communities. This knowledge encompasses traditional practices, ecological insights, and cultural understandings that have been passed down through generations, enabling these communities to effectively navigate and adapt to the challenges posed by climate change. This study contributes significantly to the body of knowledge regarding how low-cost, locally rooted approaches—such as LK—can be integrated into mainstream strategies to enhance local adaptation mechanisms for Indigenous communities. Given the unique socio-economic and environmental contexts these communities face, leveraging LK offers a practical and culturally relevant pathway to bolster resilience against climate-related impacts. However, more efforts are needed to systematically document and preserve LK practices, as the current reliance on oral transmission poses risks to the continuity and accuracy of this vital knowledge. By investing in formal documentation and education initiatives, we can ensure that this rich heritage is not lost but rather celebrated and utilized as a powerful resource for adaptation. This study further highlights the effectiveness of combining traditional wisdom with scientific knowledge to address climate-related challenges. Such an integrative approach not only benefits the *vhaVenda* and *baTonga* communities but also serves as a valuable asset to the broader field of climate change adaptation and disaster risk reduction, especially in developing countries where resources are often limited. Nonetheless, it is important to acknowledge the limitations of this study, as the survey focused primarily on climate change-related adaptation techniques. Future research will aim to explore the full spectrum of LK practices, including those related to resource management, agricultural practices, and community governance, to gain a more comprehensive understanding of how these systems can be effectively mobilized in the face of climate change. By recognizing and elevating the role of local knowledge in climate adaptation strategies, we can enhance the resilience of not only the LRB and ZRB communities but also other Indigenous populations facing similar challenges worldwide.

Acknowledgements

This study was supported by the the Climate Change Adaptation and Resilience Centre at Kgotso Development Trust, Zimbabwe, Nelson Mandela University, South Africa, the International Climate Change Information and the Research Programme (ICCIRP) at the Hamburg University of Applied Sciences, Germany. This paper is part of the “100 papers to accelerate climate change mitigation and adaptation” initiative led by the International Climate Change Information and Research Programme (ICCIRP).

Competing Interest

The authors have declared that no competing interests exist.

Funding

The study did not receive any funding.

References

Ajibade LT, Eche JO. 2017. Indigenous knowledge systems and climate change management in Nigeria. In Mafongoya, P.L. and Ajayi, O.C. (editors), 2017, Indigenous Knowledge Systems and Climate Change Management in Africa, CTA, Wageningen, The Netherlands, 316pp.

Albuquerque U, Andrade LH. 2002. Use of Plant Resources in a Seasonal Dry Forest (Northeastern Brazil). Journal of Ethnobiology and Ethnomedicine, 8(4), 15-23

Al-Khalidi S. 2019. Traditional Ecological Knowledge and Weather Forecasting in the Arabian Peninsula. Journal of Environmental Anthropology, 15(3), 132-148.

Ayal DY, Desta S. Radeny M. 2015. Opportunities and challenges of indigenous biotic weather forecasting among the Borena herders of southern Ethiopia. SpringerPlus 4, 617 (2015). https://doi.org/10.1186/s40064-015-1416-6

Berke PR. 2002. Does Sustainable Development Offer a New Direction for Planning? Challenges for the Twenty-First Century. Journal of planning literature. 2002 Aug; 17(1):21-36.

Biao EI. 2017. Assessing the impacts of climate change on river discharge dynamics in Oueme River Basin (Benin, West Africa). Hydrology 4(4):47

Botai CM, Botai JO, Zwane NN, Hayombe P, Wamiti EK, Makgoale T, Murambadoro MD, Adeola AM, Ncongwane KP, De Wit JP, Mengistu MG. Hydroclimatic extremes in the Limpopo River Basin, South Africa, under changing climate. Water. 2020 Nov 24;12(12):3299.

Chanza N, Mafongoya PL. 2017. Indigenous-based climate science from the Zimbabwean experience: From impact identification, mitigation and adaptation. Indigenous knowledge systems and climate change management in Africa. 15:67.

Descroix L, Guichard F, Grippa M, Lambert LA, Panthou G, Mahé G, Gal L, Dardel C, Quantin G, Kergoat L, Bouaïta Y.2018. Evolution of surface hydrology in the Sahelo-Sudanian strip: an updated review. Water. 2018 Jun 8;10(6):748.

Dinku T, Block P, Sharoff J, Hailemariam K, Osgood D, del Corral J, Cousin R, Thomson MC. 2014. Bridging critical gaps in climate services and applications in Africa. Earth Perspectives. 2014 Dec;1:1-3.

Douglas I, Alam K, Maghenda M, Mcdonnell Y, McLean L, Campbell J. 2008.Unjust waters: climate change, flooding and the urban poor in Africa. Environment and urbanization. 20(1):187-205.

Ebhouma EE. 2020. A framework for integrating scientific forecasts with indigenous systems of weather forecasting in southern Nigeria. Development in Practice. Vol.30 Issue 4.

Ford JD, Cameron L, Rubis J, Maillet M, Nakashima D, Willox AC, Pearce T. 2016. Including indigenous knowledge and experience in IPCC assessment reports. Nature Climate Change. 6(4):349-53.

Gandure S, Walker S, Botha JJ. 2013 Farmers' perceptions of adaptation to climate change and water stress in a South African rural community. Environmental Development. 5:39-53.

Granikov V, Hong QN, Crist E, Pluye P. 2020. Mixed methods research in library and information science: A methodological review. Library & Information Science Research. 42(1):101003.

Hadlos A, Opdyke A, Hadigheh SA. 2022. Where does local and indigenous knowledge in disaster risk reduction go from here? A systematic literature review. International journal of disaster risk reduction. 79:103160.

Intergovernmental Panel on Climate Change. 2014. Human security. In Intergovernmental Panel on Climate Change (Ed.), Climate change 2014 – impacts, adaptation and vulnerability: Part A: Global and sectoral aspects: Working Group II Contribution to the IPCC Fifth Assessment Report (pp. 755–792). Cambridge University Press

Kom Z, Nethengwe NS, Mpandeli S, Chikoore H. 2023. Indigenous knowledge indicators employed by farmers for adaptation to climate change in rural South Africa. Journal of

Environmental Planning and Management. 66(13):2778-93.

Kundzewicz ZW, Kanae S, Seneviratne SI, Handmer J, Nicholls N, Peduzzi P, Mechler R, Bouwer LM, Arnell N, Mach K, Muir-Wood R. 2014. Flood risk and climate change: global and regional perspectives. Hydrological Sciences Journal. 59(1):1-28.

Kunnie J. 2019.The cost of globalization to indigenous peoples: The need for decolonization and constructive social work strategies in turtle island (North America). Recognition, reconciliation and restoration: applying a decolonized understanding in social work and healing processes.

Kupika OL, Gandiwa E, Nhamo G, Kativu S. 2019. Local Ecological Knowledge on Climate Change and Ecosystem‐Based Adaptation Strategies Promote Resilience in the Middle Zambezi Biosphere Reserve, Zimbabwe. Scientifica. 2019(1):3069254.

Lamptey B, Sahabi Abed S, Gudoshava M, Mutemi J, Bopape MJ, Adefisan EA, Igri MP, Seidou Sanda I, Ndiaye O, Parker DJ, Dougill AJ. 2024.Challenges and ways forward for sustainable weather and climate services in Africa. Nature Communications. 2024 Mar 26;15(1):2664.

Lansing JS. Perfect order: Recognizing complexity in Bali. InPerfect Order 2012 Sep 16. Princeton University Press.

Leal Filho W, Matandirotya NR, Lütz JM, Alemu EA, Brearley FQ, Baidoo AA, Kateka A, Ogendi GM, Adane GB, Emiru N, Mbih RA. 2021.Impacts of climate change to African indigenous communities and examples of adaptation responses. Nature Communications. 12(1):6224.

Leal Filho W, Barbir J, Gwenzi J, Ayal D, Simpson NP, Adeleke L, Tilahun B, Chirisa I, Gbedemah SF, Nzengya DM, Sharifi A. 2022.The role of indigenous knowledge in climate change adaptation in Africa. Environmental Science & Policy. 136:250-60.

Filho WL, Wolf F, Totin E, Zvobgo L, Simpson NP, Musiyiwa K, Kalangu JW, Sanni M, Adelekan I, Efitre J, Donkor FK. 2023. Is indigenous knowledge serving climate adaptation? Evidence from various African regions. Development Policy Review. 41(2):e12664.

Gebre SL, Getahun YS. 2016.Analysis of climate variability and drought frequency events on Limpopo River Basin, South Africa. Hydrology current research. 7:249.

Makondo CC, Thomas DS. 2018.Climate change adaptation: Linking indigenous knowledge with western science for effective adaptation. Environmental Science & Policy. 2018 Oct 1;88:83-91.

Kufakunesu M, Mavezera TF, Mashoko D, Malasha SL. Professional Enhancement or Needless Baggage: Attitudes of Undergraduate In-Service Secondary School Student Teachers towards Educational Psychology in Zimbabwe.OSR Journal Of Humanities And Social Science (IOSR-JHSS) 24 (9) Series. 5

Masinde M, Mwagha M, Tadesse T. 2018. Downscaling africa's drought forecasts through integration of indigenous and scientific drought forecasts using fuzzy cognitive maps. Geosciences. 8(4):135.

Mugambiwa SS, Rukema JR. 2019. Rethinking indigenous climate governance through climate change and variability discourse by a Zimbabwean rural community. International Journal of Climate Change Strategies and Management.11(5):730-43.

Mugandani R, Mafongoya P. 2019.Behaviour of smallholder farmers towards adoption of conservation agriculture in Zimbabwe. Soil use and management. 35(4):561-75.

Mugari E, Vambe AT, Tatsvarei S, Nethengwe NS, Mutambara J. 2023. Factors influencing smallholder farmers' climate change risk perceptions: A behavioral approach in semi-arid regions of Zimbabwe. Environmental Research Communications.

Mugi-Ngenga EW, Kiboi MN, Mucheru-Muna MW, Mugwe JN, Mairura FS, Mugendi DN, Ngetich FK. 2021. Indigenous and conventional climate-knowledge for enhanced farmers' adaptation to climate variability in the semi-arid agro-ecologies of Kenya. Environmental Challenges. 5:100355.

Ortiz-Bobea A, Ault TR, Carrillo CM, Chambers RG, Lobell DB. 2021.Anthropogenic climate change has slowed global agricultural productivity growth. Nature Climate Change. (4):306-12.

Okoronkwo DJ, Ozioko RI, Ugwoke RU, Nwagbo UV, Nwobodo C, Ugwu CH, Okoro GG, Mbah EC. 2024Climate smart agriculture? Adaptation strategies of traditional agriculture to climate change in sub-Saharan Africa. Frontiers in Climate. 6:1272320.

Petzold J, Andrews N, Ford JD, Hedemann C, Postigo JC. 2020. Indigenous knowledge on climate change adaptation: A global evidence map of academic literature. Environmental Research Letters. 15(11):113007.

Radeny M, Desalegn A, Mubiru D, Kyazze F, Mahoo H, Recha J, Kimeli P, Solomon D. 2019. Indigenous knowledge for seasonal weather and climate forecasting across East Africa. Climatic Change. 156:509-26.

Roncoli C, Ingram K, Kirshen P. 2002. Reading the rains: Local knowledge and rainfall forecasting in Burkina Faso. Society & Natural Resources. 15(5):409-27.

Sainz G. 2018. The Zambezi River Basin: Water resources management: Energy-food-water nexus approach.

Santos L, Ramos F. 2018. Antimicrobial resistance in aquaculture: Current knowledge and alternatives to tackle the problem. International journal of antimicrobial agents. 52(2):135-43.

Soropa G, Gwatibaya S, Musiyiwa K, Rusere F, Mavima GA, Kasasa P. 2015. Indigenous knowledge system weather forecasts as a climate change adaptation strategy in smallholder farming systems of Zimbabwe: Case study of Murehwa, Tsholotsho and Chiredzi districts. African Journal of Agricultural Research. 10(10):1067-75.

Tchakatumba PK, Gandiwa E, Mwakiwa E, Clegg B, Nyasha S. 2019. Does the CAMPFIRE programme ensure economic benefits from wildlife to households in Zimbabwe?. Ecosystems and people. 15(1):119-35.

Thompson LR, Sanders JG, McDonald D, Amir A, Ladau J, Locey KJ, Prill RJ, Tripathi A, Gibbons SM, Ackermann G, Navas-Molina JA. 2017. A communal catalogue reveals Earth's multiscale microbial diversity. Nature. 551(7681):457-63.

United Nations. 2015. *THE 17 GOALS*. Retrieved 16 October 2023 from https://sdgs.un.org/goals

Zvobgo L, Johnston P, Williams PA, Trisos CH, Simpson NP, Global Adaptation Mapping Initiative Team. 2022.The role of indigenous knowledge and local knowledge in water sector adaptation to climate change in Africa: a structured assessment. Sustainability Science. (5):2077-92.

Table 1: Age, gender and education level of participants

Age	Male (%)	Female (%)	Total	Level of Education (%)		Total
				Primary	Secondary	
26-30	2	12	14	5	22	27
31-35	10	20	30	13	15	28
36-40	20	14	34	21	10	31
46-50	8	7	15	6	4	10
55+	0	5	5	1	3	4
	40	60	100	46	54	100

Table 2: **Climate change risk posed and changes observed**

Climate change risk posed	Percentage	Climate change observed	Percentage
Shortage of fishing opportunities	97	Increase in temperatures	86
Livestock death	86	Increase in extreme weather events	51
Poor water quality	26	Droughts	100
Shortage of Grazing land	97	Shortage of food	75

Figure 1: Study regions of Limpopo and Zambezi River Basins

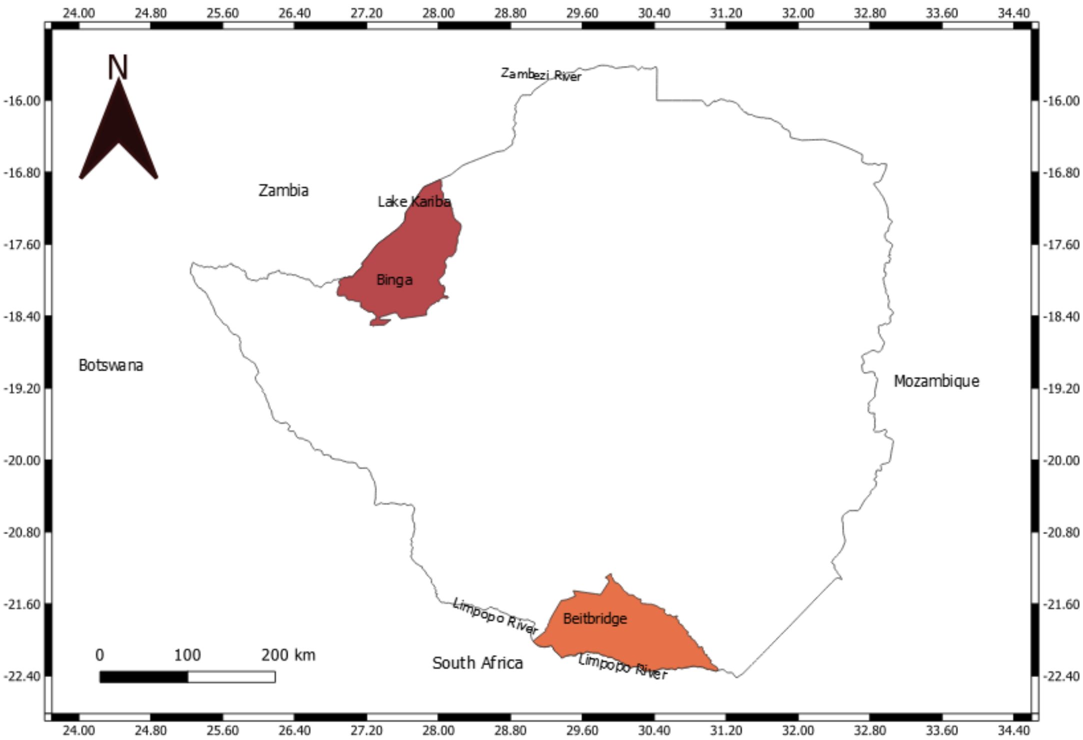

Figure 2: Source of livelihood and gender disaggregation of participants

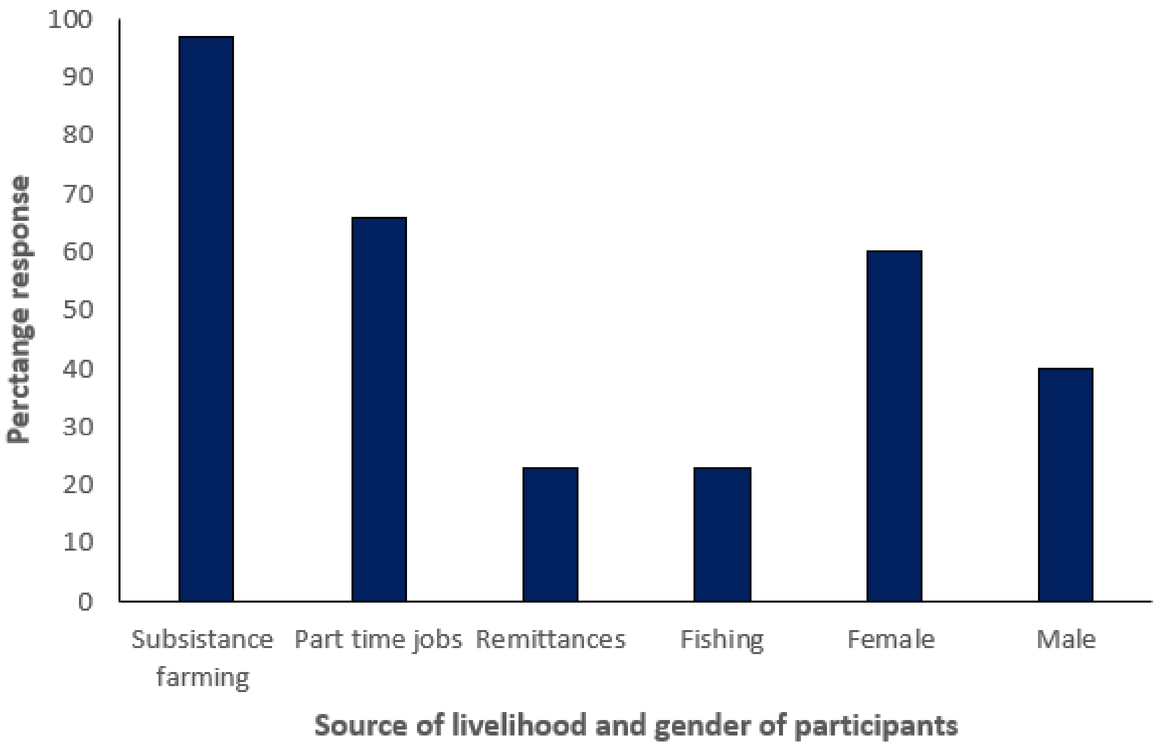

Figure 3: Source of climate information and gender disaggregation of participants

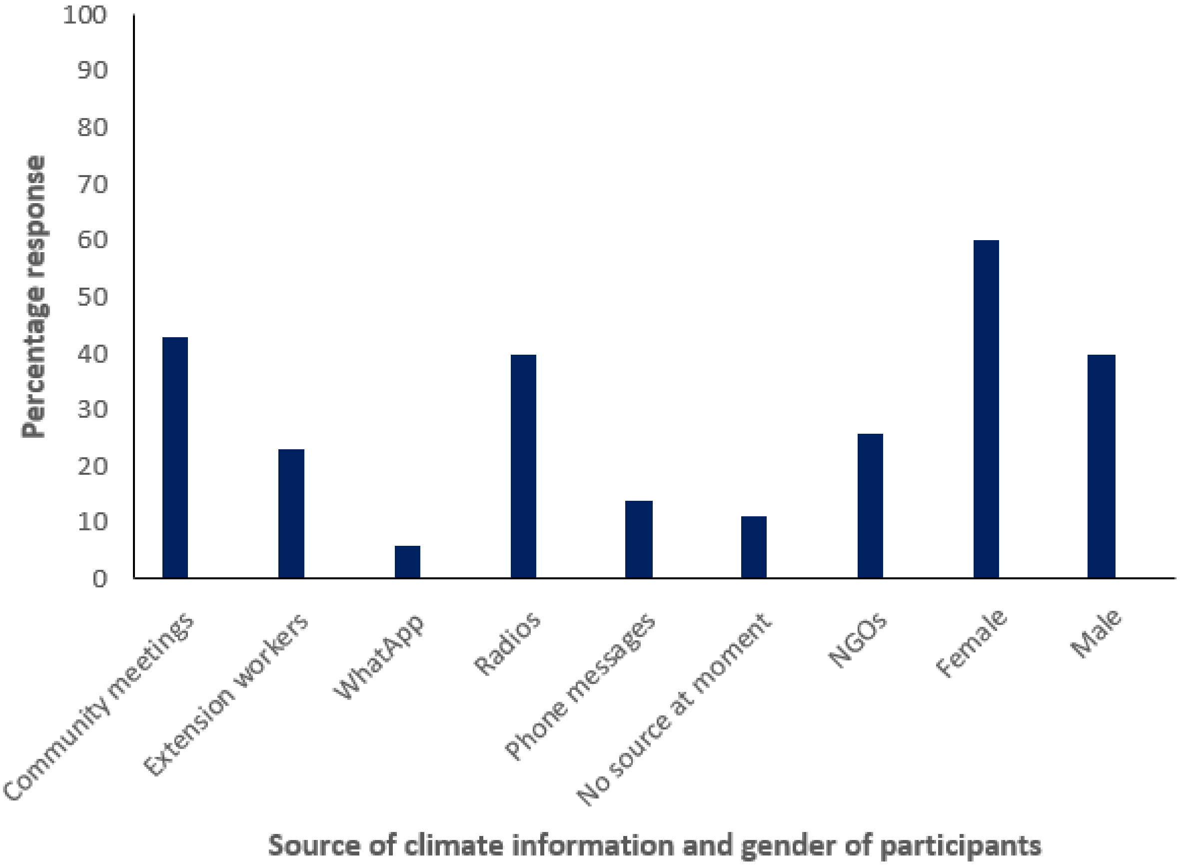

Figure 4: Local knowledge-based weather predictors applied in the Limpopo and Zambezi River Basins

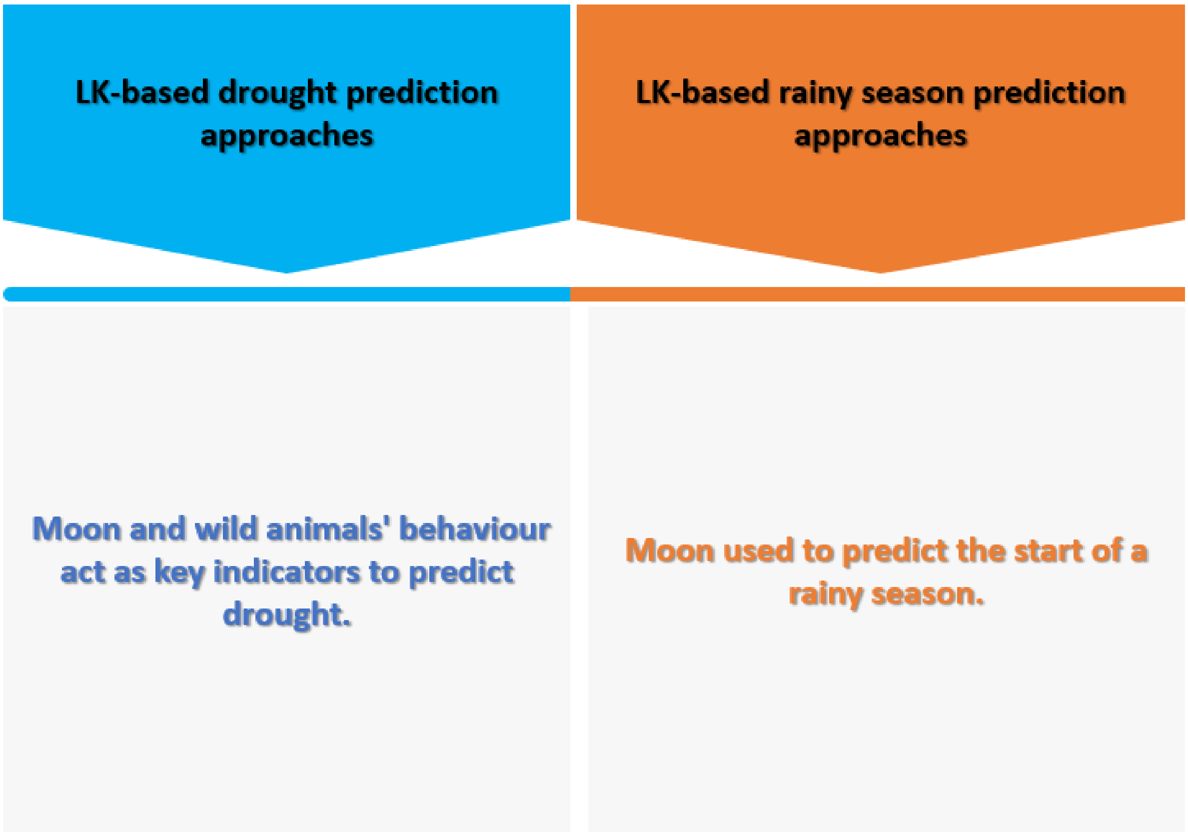

Figure 5: Local knowledge-based strategies to deal with climate change induced challenges

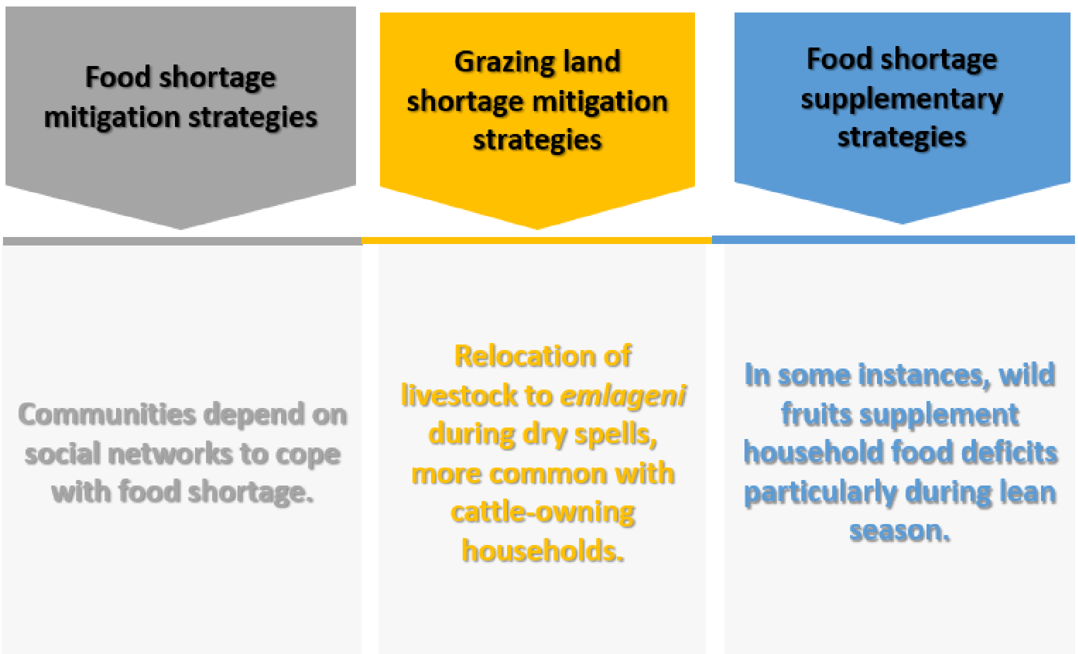

Figure S1: Baobab tree in fruit

Figure S2: State of rangelands in the Limpopo River Basin