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

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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.

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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 recognised 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 utilised in formal adaptation efforts by governments and has often been overlooked in policy and research (IPCC 2014). The IPCC AR5 does not

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explore the reasons for this omission (Petzold et al. 2020), but despite this neglect, Indigenous Peoples have long recognised the importance of their knowledge systems in managing change (Ford et al. 2016). 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 LK, 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, it 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. Evidence shows 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, Thompson et al. 2017, Descroix et al. 2018), 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 knowledge for localized 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 in Africa (Hill et al. 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. The tools that can be deployed include the application of LK already embedded within communities. LK is gradually being recognised as an imperative source of information for climate change mitigation and adaptation (Neville 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 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 but apply to the local context. In essence, these knowledge forms have failed to die and are unique to a given society or culture (Kunnie 2019). In this study, these 2 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 valuable in climate change solutions, but in recent years some shift has occurred (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), mostly 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 utilization 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, information on how African communities have used LK to recognise and respond to such changes is scarce (Kupika et al. 2019). Local Indigenous communities remain highly vulnerable to the impacts of climate change because 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 (Ebhouma 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 noneconomic 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, 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 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 explored the various LK-based climate change adaptation strategies applied by the vhaVenda and baTonga communities residing in the LRB and ZRB, respectively, and highlights the unique LK practices within these 2 communities. Historically, both regions have been highly susceptible to climate change-induced extreme weather events, such as heatwaves, floods, and droughts. This study emphasises the distinctive LK approaches used by the vhaVenda and baTonga communities, who employ innovative techniques to sustain livelihoods under harsh climatic conditions.

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 semiarid to arid regions. The LRB is shared among 4 countries—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 because it has witnessed changes within the basin for decades, mostly documented in oral formats. Currently, Beitbridge has an estimated population of 81 000, mostly rural communities. The average daily temperatures in the LRB range between 25 and 31 °C and the average annual rainfall is <450 mm (Tchakatumba et al. 2019).

The ZRB is home to diverse, valuable natural resources for 8 countries that share the basin—Angola, Botswana, Malawi, Mozambique, Namibia, Tanzania, Zambia, and Zimbabwe. Currently, >30 million people live in the watershed, all of whom 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 northwestern Zimbabwe. The baTonga are "the great river people" in the north of Zimbabwe and south of Zambia who 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 et al. 2022). Watersheds shared by countries present management complexities that must be resolved by collaboration strategies towards common objectives (Fig. 1).

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 residents revolved around a combination of fishing and food production (e.g., maize, sorghum, and millet). Crafting and hunting livelihoods also exist but have fallen in their 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 from external shocks, such as droughts and crop failure. According to the 2022 Census, the Binga district has a population of 139 092 people. The annual rainfall in the ZRB is usually <450 mm, and daily temperature ranges between 25 and 33 °C (Gadzirayi et al. 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

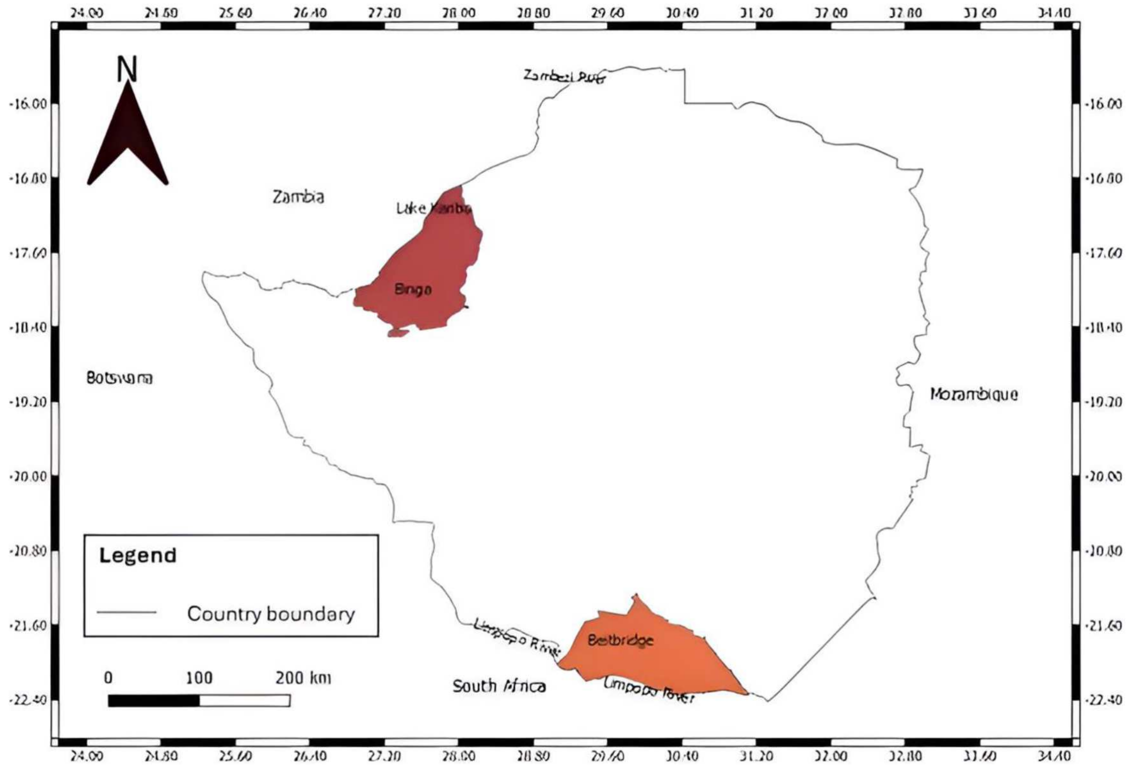

Figure 1. Study regions of Limpopo (Beitbridge) and Zambezi (Binga) River Basins. Outline indicates the latitude and longitude.

change, the impacts they had experienced over the years, and the adaptation strategies they had implemented. We randomly selected 35 rural community members 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 1 of the 2 river basins while the main exclusion criterion was nonresidency in these areas. Study participants were primarily from Ward 15 and Ward 6 of rural Beitbridge and Ward 24 of Binga. All participants were older than 18 and provided verbal consent to participate in the study. Although the study aimed for equal sampling across regions, 5 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.

Table 1. Age, gender, and education level of participants. Total refers to the whole surveyed community.

				Level of education (%)		
Age	Male (%)	Female (%)	Total	Primary	Secondary	Total
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

Results

The study surveyed a diversified group of community members, mostly women (Table 1) because of rural area living patterns where women are predominantly in the majority.

The highest percentage of contributors was in the age group 36–40 while the lowest was age 55 and older (Table 1). Most participants had reached secondary school, with the highest number in the 26–30 group. Study participants had the opportunity to provide multiple responses to their means of survival and gender disaggregation (Fig. 2); 97% indicated that their main source of livelihood is subsistence farming, 66% is part-time informal jobs, and 23% indicated that fishing and remittances also form part of their source of livelihood.

Among all respondents on their awareness of climate change, 91% indicated they had heard about climate change (Fig. 3). Multiple responses were also allowed to address sources of climate change information. The highest percentage of the responses (46%), mostly women, indicated they obtained information on climate change from community meetings, and 40% (16 males

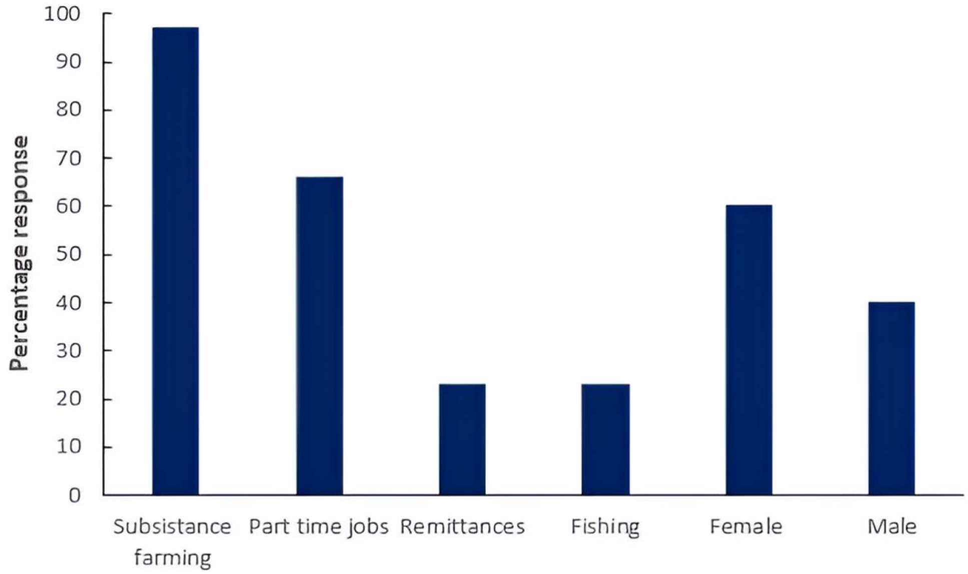

Figure 2. Source of livelihood and gender disaggregation of participants.

and 24 females) indicated their climate change information came from radio transmissions. WhatsApp was the least indicated source of information.

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% (Table 2). Poor quality water was the climate change impact that participants least indicated. On changes observed, 100% of the participants believed droughts had increased in frequency over the last 10 years, and 86% believed ambient temperatures have increased as characterised by episodes of heat waves.

LK weather prediction techniques applied in both the LRB and ZRB involve use of the moon and behaviour of wild animals in drought prediction and use of the moon for rainy season prediction. To reduce the negative impacts of climate change, the study ascertained that the communities in the 2 basins apply different LK-based techniques, biotic and abiotic, to predict weather patterns. One of the most common techniques is the reliance on moon cycle observation. The participants in ZRB reported that they interpret a moon with a small circle or a pool of water around it as a sign that the community will experience droughts for that

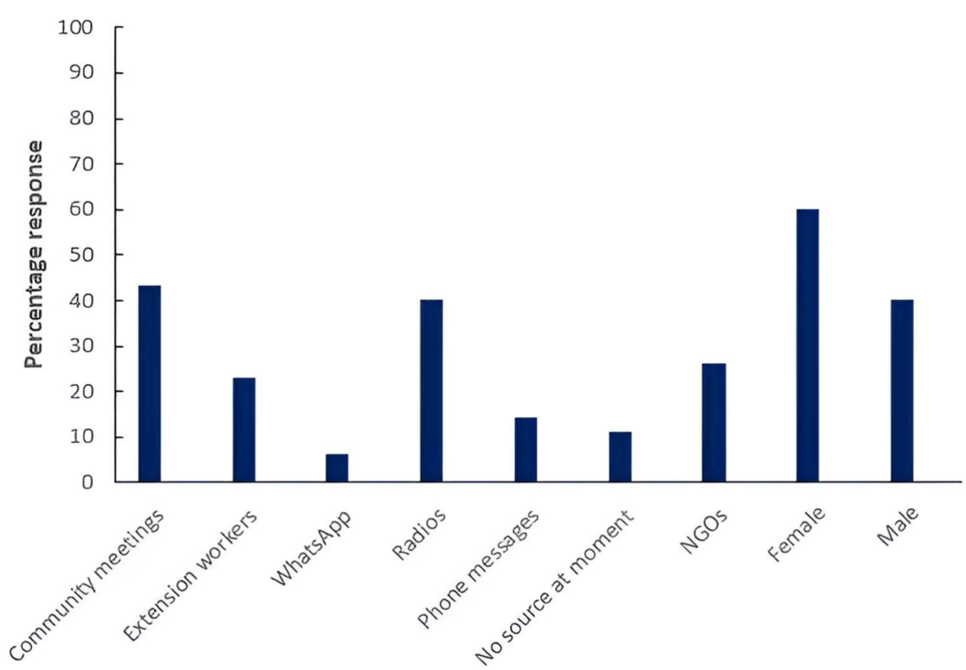

Figure 3. Source of climate information and gender disaggregation of participants.

Table 2. Climate change risk posed and changes observed.

Climate change risk posed	%	Climate change observed	%
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

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 they interpret a bright and clear moon 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 observation technique to predict droughts that is similar across the LRB and ZRB is monitoring wild fruit. If a tree species that usually does not flower or bear fruit produces flowers or fruits, drought is coming. The other way to predict droughts used by both basins is 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 to anticipate the amount of rain for the next farming season.

The study participants highlighted that LK observations of birds, frogs, and rats shape drought prediction. 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 around 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)

In addition to wild birds, some participants in the LRB indicated using high wild rat populations as a predictor of drought. This LK strategy was only found in the vhaVenda community where rats are monitored, yielding outcomes 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)

The baTonga community uses a different way to predict droughts,

> 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 community interprets low levels of mist to mean 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, with a high prevalence of high-speed winds indicating 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)

Community adaptation to food insecurity

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

> 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 2 basins. Even though the regions are arid and dry, an abundance of wild fruits can be processed for consumption, including the common baobab fruit (Supplemental Fig. S1), which can be consumed raw or combined with other ingredients.

> 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 powder to make a consumable porridge, recommended for its high vitamin and micronutrient 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 (Supplemental Fig. S2), the study also established that the temporary relocation of livestock to areas with better pasture, referred to as *emlageni*, was a common practice in both basins, mostly by cattle-owning households and not those with small livestock. The temporary location is usually abandoned soon after the onset of the rainy season, which improves 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 a continuing feeling of vulnerability to climate change risks and shocks, despite all the available LK indicators. They emphasised that their vulnerability is a failure to have mitigation strategies; that even after predicting poor rains and droughts, the communities have no capacity to mitigate the effects but are still 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 comment 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 that access to water has been negatively impacted because of climate change. There is a shortage of water, and the communities have to dig deeper wells to access water and must move towards the Zambezi River as its tributaries are drying up.

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). The similarities in both abiotic and biotic techniques used by the communities are notable. For example, moon monitoring was a prominent practice in both; 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 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).

LRB and ZRB communities use the moon shape and the circle around it as an indicator to predict and forecast drought. These findings are similar to a study by Radeny et al. (2019) 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 long-rain and short-rain seasons in Lushoto, Tanzania. 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 2 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, just as Brazilian communities track tree phenology to adjust their planting and harvesting seasons (Albuquerque and Andrade 2002).

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 Grey et al. (2020), 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, a drought is imminent. The study also established that access to climate information remains a challenge in the 2 regions; 43% indicated they are currently getting information from community gatherings while 11% still have no 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 turn 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 nonexistent, especially in the hard to reach rural communities. Climate information available to communities is sometimes 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). Community access to climate information in the 2 study regions through digital platforms like WhatsApp suggests that authorities can make such information available in the local languages. The LRB and ZRB communities also reported the use of wind, a common abiotic indicator. For instance, the higher the wind speed, the higher probability rains occurring, potentially causing floods. This indicator was also supported by Grey et al. (2020), who reported that winds blowing in a south-to-north direction in the rainy season indicate little rainfall. Winds strong and blowing from the north to the southeast are a sign of rain in that particular community. Similarly, Radeny et al. (2019) noted 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, whereas if they are dispersed in search of food drought is likely. The migration of bees from north to south during seasons of resource abundance is also a sign of drought, whereas 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 because monitoring animal behaviours is useful in planning farming events (Mugi-Ngenga et al. 2021). These practices show that across African societies, LK is considered important in predicting droughts through observations of nature. 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. First, the innovative strategies devised by these communities showcase their profound connection with and reliance on their natural surroundings. By utilising 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. Second, 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, 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 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 in 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). The communities in ZRB and LRB have also implemented and adopted measures to promote inland water management skills in the face of climate change by digging wells along the distributaries and tributaries from the Zambezi and Limpopo rivers. This practice indicates that the findings link well with previous findings, indicating 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 resulting from this study, knowledge systems do not evolve in isolation; rather they interact and enhance one another.

In this context, recognising that Indigenous knowledge holds equal significance to scientific knowledge is crucial. 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).

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, characterised by a shortage of grazing land and food shortages resulting from persistent drought events. Food shortages are further exacerbated by farmers' reliance 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, socioeconomic factors and limited access to technology affect the utilization of modern climate prediction tools. The study emphasizes 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*. 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. Doing so is a matter of survival for these communities because as they rely on agriculture and natural resources for their livelihoods.
- *Cultural significance*. 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, reflecting the 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*. Different studies support the findings of this study, supporting the credibility and reliability of the LK used by these communities and indicating that this knowledge is shared across different African societies and has stood the test of time.
- *Sustainability*. LK approaches 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, empowering 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, an important aspect of promoting ecological awareness and conservation in these communities.
- *Traditional knowledge preservation*. Recognising and valuing LK provides 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 extraordinarily important 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 socioeconomic 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 because 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 utilised 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 because the survey focused primarily on climate change-related adaptation techniques. Future research should 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 mobilised 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.

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