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Accessibility and utilization of climate information services for decision-making in smallholder farming: Insights from Limpopo Province, South Africa

Lindumusa Myeni [a,b,*], Nkosazana Mahleba [a], Sabelo Mazibuko [a], Mokhele Edmond Moeletsi [a,c], Kingsley Ayisi [c], Mitsuru Tsubo [d]

[a] Agricultural Research Council - Natural Resources and Engineering, Private Bag X79, Pretoria, 0001, South Africa
[b] Department of Geography and Environmental Studies, School of Geo- and Spatial Sciences, North-West University, Mahikeng, South Africa
[c] Centre for Global Change, University of Limpopo, Private Bag X1106, Sovenga 0727, South Africa
[d] International Platform for Dryland Research and Education, Tottori University, Tottori, Mitsuru Tsubo, 680-8550, Japan

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ABSTRACT

The availability, accessibility and use of weather and climate information services (CIS) are essential to enable farmers to minimize losses due to climatic uncertainties and take advantage of opportunities presented by favourable climatic conditions. This study examines the key challenges and determinants of access and the utilization of CIS by smallholder farmers in the drylands of South Africa, using Limpopo Province as the case study. Primary data were collected using a pre-tested, structured questionnaire administered from 240 households and were validated through focus group discussions with key local informants. Descriptive statistics, frequency analysis and a binary logistic model were used for data analysis. The results indicated that most smallholder farmers had access to the daily weather forecasts (76%) that are mainly broadcasted via radio (66%) and television (63%), while very few had access to other types of CIS such as seasonal weather forecasts (7%) and early warnings (10%). The results indicate that most smallholder farmers (56%) were not using any CIS in planning their farm activities. This was mainly due to unreliability, lack of tailored and local-specific CIS (farm or community level) as well as language barriers, difficulty in understanding, decoding and use of supplied information for decision-making. The results also showed that the accessibility and utilization of CIS varies across different locations due to their differences in terms of customs, access to resources and levels of prioritizing farming as a major source of livelihood. The results further indicated that farming being a major occupation and awareness of climate variability were the main factors determining the accessibility of CIS, while utilization of CIS was additionally determined by the level of education and understating of climate change in the study area. The access to internet and mobile applications, awareness campaigns, capacity-building initiatives and co-production of local-specific CIS accompanied by agrometeorological advisories are recommended to overcome these barriers to the access and use of CIS.

* Corresponding author. Agricultural Research Council - Natural Resources and Engineering, Private Bag X79, Pretoria, 0001, South Africa.
E-mail addresses: Lindumusa.Myeni@nwu.ac.za (L. Myeni), nkosazanamahleba@gmail.com (N. Mahleba), MazibukoSM@arc.agric.za (S. Mazibuko), MoeletsiM@arc.agric.za (M.E. Moeletsi), kwabena.ayisi@ul.ac.za (K. Ayisi), tsubo@tottori-u.ac.jp (M. Tsubo).

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1. Introduction

Agriculture is a key pillar for job creation, economic growth and national food security in Africa (Ndhleve et al., 2017; Cammarano et al., 2020; Myeni et al., 2019; Hlophe-Ginindza et al., 2020). However, this region has weather-sensitive and vulnerable agricultural food systems to climatic risks such as elevated air temperatures, irregular rainfall patterns (on-sets, amount and distribution of rainfall), droughts, floods, pests and diseases that are expected to intensify in both frequency and severity due to projected climate change (Cammarano et al., 2020; Nhamo et al., 2019; Mpandeli et al., 2019). Smallholder and emerging farmers are amongst the most vulnerable to the adverse effects of climate variability and change due to their high dependency on weather-sensitive natural ecosystems for food production, with limited access to technologies and resources (Myeni et al., 2019; Myeni and Moeletsi, 2020; Gaveta, 2017; Ali, 2018; Williams et al., 2019; Chisadza et al., 2020).

There is an urgent need to develop and implement effective adaptation and mitigation strategies to combat the adverse effects of climate-related risks on agricultural production (Myeni and Moeletsi, 2020; Lunduka et al., 2019; Agyekum et al., 2022). This is expected to contribute toward the achievement of several United Nations Sustainable Development Goals (SDGs) such as goal 1, 2, 8, 11 and 13, particularly in the most vulnerable communities (Newell et al., 2019; Zougmoré et al., 2021). In this context, the timely availability and utilization of climate information services (CIS) can help to minimize agricultural losses and improve the efficient use of resources through sufficient preparedness, proper planning and informed farm management practices (Agyekum et al., 2022; Ncoyini et al., 2022; Ofoegbu and New, 2022; Ogundeji et al., 2022; Weniga et al., 2019; Henriksson et al., 2021). In this study, CIS refers to the generation, transformation and use of scientific climate data together with other agricultural-related information into tailored products such as weather forecasts, early-warning systems, historical trends, climate projections and agrometeorological advisories for decision-making (Vaughan et al., 2019; Onyeneke et al., 2023; Ouedraogo et al., 2022; Muema et al., 2018).

Previous research across different countries has shown that access and use of timely and precise climatic information by farmers is critical for improving their agricultural productivity, supporting climate adaptation and strengthening resilience to climatic uncertainties associated with climate variability and change (Vaughan et al., 2019; Baffour et al., 2022; Nkiaka et al., 2019; Alidu et al., 2022; Ouedraogo et al., 2021; Sarku et al., 2022). For example, farmers can effectively plan their key agricultural activities such as land preparation, crop type and variety selection, choice of cropping pattern, planting date, scheduling of fertilizer and pesticide application, and harvesting time in advance based on different timescales (e.g., hours, days, seasons and longer) of CIS (Ncoyini et al., 2022; Baffour et al., 2022; Alidu et al., 2022; Amegnaglo et al., 2017; Guido et al., 2020; Djido et al., 2021; Black et al., 2023). Therefore, significant efforts have been directed toward the provision of CIS as the adaptive strategy for farmers to manage the risks associated with climate variability/or change (Ogundeji et al., 2022; Vaughan et al., 2019; Ouedraogo et al., 2022; Ouedraogo et al., 2021; Black et al., 2023; Tarchiani et al., 2021; Zuma-et al., 2016a; Walker, 2020; Alliagbor et al., 2021). For example, in South Africa and many other African countries, the National Meteorological Services (NMS), government agencies, research institutes as well as private enterprises and international development agencies supply weather and climate information at the national scale to support decision-making in farming (Vaughan et al., 2019; Alidu et al., 2022; Tarchiani et al., 2021; Moeletsi et al., 2022). In attempts of ensuring that CIS reach a wide range of different end-users, several platforms including televisions, radios, digital platforms, mobile phone applications, agricultural workshops, extension agents, farmer-to-farmer extension services, bulletins, social media platforms and farmer's groups are used for dissemination (Ofoegbu and New, 2022; Ogundeji et al., 2022; Onyeneke et al., 2023; Alidu et al., 2022; Tarchiani et al., 2021; Sharma et al., 2021; Walker, 2021; Nkuba et al., 2023).

Despite significant efforts in research on the development and dissemination of CIS, the accessibility and utilization of such information by smallholder farmers is still low and unsatisfactory in Africa (Chisadza et al., 2020; Onyeneke et al., 2023; Alidu et al., 2022; Tarchiani et al., 2021; Shikwambana and Malaza, 2022; Nkuba et al., 2021). In consequence, most African smallholder farmers continue to solely rely on indigenous knowledge of local agroecological experience to predict weather patterns and make weather-sensitive decisions that are crucial for their agricultural production (Ogundeji et al., 2022; Baffour et al., 2022; Zuma-et al., 2013; Baffour et al., 2021). However, the indigenous knowledge acquired over years of farming experience has become unreliable and insufficient to cope with the current climate variability and change which is beyond their experience scope and traditional coping mechanisms (Ogundeji et al., 2022; Basdew et al., 2017). As a result of poor accessibility and utilization of CIS, the productivity of smallholder farmers remains very low and stagnant while farmers continue to record losses due to climate-related risks (Ncoyini et al., 2022; Shikwambana et al., 2021; Mubangizi et al., 2018). This is a matter of great concern to the government and other development organizations as climate change is already and foreseen to continue threatening the sustainability and resilience of smallholder farming which is critical for food security and livelihoods in rural communities (Cammarano et al., 2020; Myeni and Moeletsi, 2020; Alliagbor et al., 2021; Myeni et al., 2021). Consequently, there have been several studies investigating the determinants and constraints of availability, accessibility and use of CIS in African contexts (Ofoegbu and New, 2022; Henriksson et al., 2021; Vaughan et al., 2019; Baffour et al., 2022; Ouedraogo et al., 2021; Alliagbor et al., 2021).

Previous research has shown that the uptake and use of CIS are influenced by socio-economic factors such as access to media, income, farming experience, gender, age, level of education and access to agricultural extension officers amongst others (Onyeneke et al., 2023; Ouedraogo et al., 2022; Tarchiani et al., 2021). However, the key determinants and constraints limiting the availability, access and utilization of CIS are local-specific due to differences in the availability of climate data and infrastructure as well as local institutions and policies that are mainly driven by political and cultural ideologies (Baffour et al., 2022; Atube et al., 2021; Acevedo et al., 2020). Despite these existing studies, to date, very limited research has been conducted on the availability, accessibility and use of CIS in the southern African region, particularly in smallholder farming conditions (Ncoyini et al., 2022; Zuma-et al., 2016a; Zuma-et al., 2013; A et al., 2018; Mpandeli and Maponya, 2013). Consequently, the key challenges and determinants of the availability, accessibility and use of CIS, as well as which information is more important and how such information is perceived and used by smallholder farmers have been less explored in this region. Given that the agriculture in this region is predominantly rainfed, which is extremely vulnerable to climatic risks, the availability, accessibility and utilization of CIS to manage climate risks are crucial for sustaining agricultural productivity (Mpandeli et al., 2019; Myeni and Moeletsi, 2020; Adisa et al., 2018).

This study aimed at addressing these research gaps by assessing the accessibility and utilization of CIS by smallholder farmers in South Africa, using the Limpopo Province as the case study where climate variability and change threaten the sustainability, food security and livelihoods of communities. It is noteworthy that South Africa is among the few African countries with well-developed weather station networks (some dating back to the early 1900s) and relatively matured CIS (Moeletsi et al., 2022). Hence, the understanding of key determinants and constraints of availability, accessibility and utilization of CIS could give new and profound insights into the significant factors that need to be considered when promoting the wide uptake and use of CIS in smallholder farming conditions. Therefore, the first objective of this study is to assess the farmers' awareness and understanding of climate variability and change in the study area. The second objective is to assess the accessibility and use of CIS. Finally, this study identifies the determinants and barriers to the availability, accessibility and use of CIS. This study is expected to provide crucial information to assist government and other development organizations in developing and implementing effectual policies, programmes and initiatives tailored to advancing the use of CIS by smallholder farmers not only in the study area but in other any other regions facing similar challenges.

2. Materials and methods

2.1. Study site description

This study was conducted in diverse villages surrounding Tzaneen, Giyani and Polokwane towns located in the Capricorn and Mopani districts of the Limpopo Province of South Africa (Fig. 1). The Limpopo Province is generally characterized by arid and semi-arid climatic environments and agriculture in this region is predominantly rainfed (Mpandeli et al., 2019; Shikwambana et al., 2021). The Limpopo Province is a summer rainfall region with mean annual rainfall of 560 mm which is usually received between October to April months. Although the average air temperature is 27 °C in summer, extreme daily temperatures rising to 45 °C can be attained in

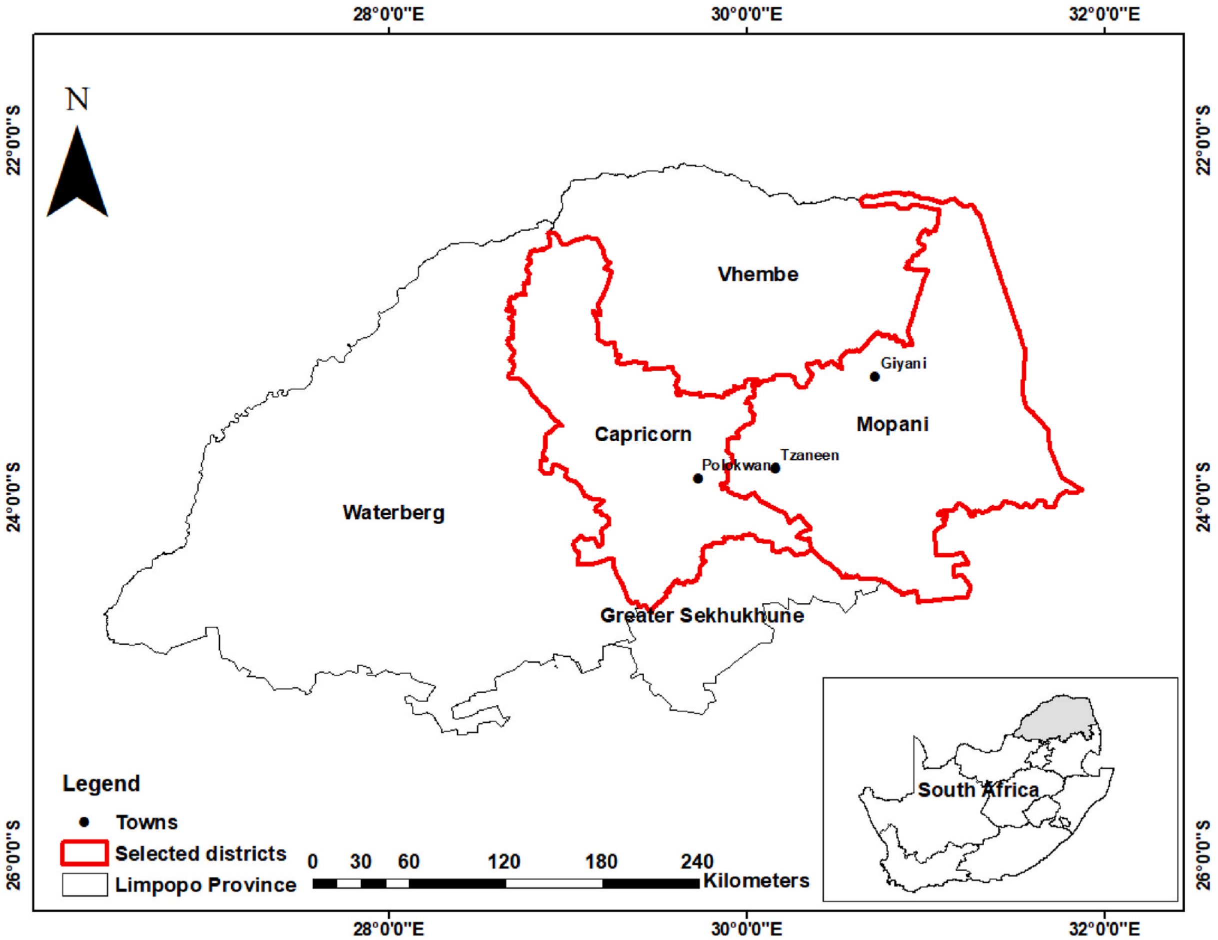

Fig. 1. Location of the study area.

some parts of the province (Cai et al., 2017). There are high spatial distinct climatic conditions in this province due to extensive topographic variation with the mean altitude ranging from 436 m in the eastern Lowveld to greater than 1800 m in the north-eastern escarpment (Nembilwi et al., 2021). Consequently, in the Mopani district, the mean annual rainfall ranged between 400 and 500 mm at the eastward side of the Drakensberg escarpment whilst the footlands and highveld received between 600–800 mm and 800–1000 mm per annum, respectively (Shikwambana et al., 2021). The mean annual rainfall of the Capricorn district varies from less than 400 mm in the north to more than 500 mm in the south of Polokwane (Maponya, 2021). The average annual temperature is between 13 and 27 °C in Mopani district (Shikwambana et al., 2021).

The wide range of climatic conditions in Limpopo Province enables the production of various agricultural commodities that are essential for food security and the economy of the country (Kephe et al., 2022). Despite the greater agricultural potential, this province is vulnerable to climate variability and change due to its high dependency on weather-sensitive natural ecosystems for food production. The recent increase in the incidents of droughts, prolonged dry spells, irregular rainfall patterns (on-sets, amount and distribution of rainfall), rising air temperatures, pests and diseases are major climatic risks threatening agricultural production in this region (Kephe et al., 2022; Mpandeli et al., 2015). Given that most smallholder farmers in this province are highly reliant on rainfed farming systems, the accessibility and use of CIS are of importance paramount for sustainable and climate-resilient agricultural production as climate change is expected to advance in this region.

2.2. Data collection

The study relied on survey data gathered by the Agricultural Research Council (ARC) of South Africa as part of the baseline assessments for the Development of Resilient E-Farming for Agro-climate Risk Management in African Multi-Environments (DREAM) project between November and December 2022. This 3-year international collaborative project was initiated in the year 2021 and is funded by the National Research Foundation (NRF) in South Africa under their Africa-Japan Collaborative Research (AJ-CORE) programme. The DREAM project aimed at advancing science and technology in climate risk management by utilizing weather forecasts and climate projections coupled with a decision support system that generates possible climate change adaptation actions to enhance food and nutritional security in South Africa and Senegal. Primary data were collected using a pre-tested, structured household questionnaire in the villages around the Tzaneen, Giyani and Polokwane towns. A systematic random sampling technique was used for the selection of participants while deliberately targeting smallholder farmers practicing crop production. It is noteworthy that although this study was mainly targeting crop producers but smallholder farmers who were practicing mixed farming were also included. From each location, about ten graduates with National Diploma or equivalent in agricultural-related fields and fluent in the local languages were hired and trained as enumerators for this study. Primary data were collected through face-to-face interviews while targeting smallholder farmers who were willing to participate in the survey voluntarily. Data collected from a total of 300 smallholder farmers were assembled in a spreadsheet within Microsoft Excel software. The quality of these data was evaluated to flag and eradicate incomplete, suspicious and specious questionnaires. Additionally, focus group discussion meetings were held with multiple stakeholders such as farmers, traditional leaders and local extension personnel from the Department of Agriculture, Land Reform and Rural Development (DALRRD) as part of data validation. Subsequently, 240 questionnaires of good-quality data were preserved for further analysis. A similar approach has been used to gather and process data on farmers' perceptions and use of climate-smart technologies (Myeni et al., 2019; Myeni and Moeletsi, 2020).

2.3. Data analysis

Data were coded by allocating an algebraic value in the Microsoft Excel spreadsheet and were analysed using a Statistical Package for the Social Sciences (SPSS) version 23.0. Demographic and socio-economic characteristics such as age, gender, occupation, level of

Table 1
Description of the explanatory variables used in a binary logistic regression model and their expected effects.

Independent Variables	Description and Measurement Type	Variable Type	Expected outcome (±)
Location	Name of the village (1/0)	dummy	+/−
Gender	Female (1/0)	dummy	−
Age	Age of the farmer (years)	continuous	−
Level of education	Level of education (years)	continuous	+
Occupation	Own or family farming (1/0)	dummy	+
Off-farm income	Household off-farm income (Rands)	continuous	+
On-farm income	Household on-farm income (Rands)	continuous	+
Years of farming experience	Years of farming experience (years)	continuous	+
Access to media	Access to media source (1/0)	dummy	+
Ownership of livestock	Ownership of livestock (1/0)	dummy	+
Farm size	Size of land under agricultural production (ha)	continuous	+
Awareness of climate variability	Awareness of change in weather patterns over the last 5 years (1/0)	dummy	+
Understating of climate change	Correct understating of the concept of climate change (1/0)	dummy	+
Access to farmer associations	Access to farmer associations (1/0)	dummy	+
Access to extension services	Access to extension services (1/0)	dummy	+

(±) indicates a positive or negative correlation with the dependent variable.

education and monthly income were analysed using descriptive statistics. Farmers' perceptions of climate variability and change, as well as their access to and use of CIS for decision-making, were evaluated using a frequency analysis. A binary logistic regression model, with the dependent variable (either the access or use of CIS) against demographic and socio-economic characteristics of the household heads as the explanatory variables was used to investigate the factors determining the accessibility and utilization of CIS (Table 1). The selection of the possible demographic characteristics that are more likely to have significant effects on the accessibility and utilization of CIS was based on the literature (Henriksson et al., 2021; Onyeneke et al., 2023; Baffour et al., 2022; Alidu et al., 2022; Ouedraogo et al., 2021; Mubangizi et al., 2018). A similar set of statistics have been extensively used to investigate the key challenges and determinants for the adoption of accessibility and utilization of CIS in smallholder farming conditions (Baffour et al., 2022; Ouedraogo et al., 2021).

3. Results and discussion

3.1. Farmers' awareness and understanding of climate variability and change

Data obtained from the household survey on farmers' awareness and understanding of climate variability and change are presented in Table 2. The results indicate that most smallholder farmers perceived that weather patterns had changed over the past five years (91%), thereby suggesting a high level of awareness of climate variability in the study area. Furthermore, the majority of smallholder farmers identified drought (74%), changing rainfall patterns (65%), and rising temperatures (63%) as the most significant weather-related risks posed by climate change in the study area. In contrast, increased pest and disease incidence (36%), flooding (18%) and hailstorms (7%) were the least climatic risks perceived. These farmers' perceptions are in agreement with the previous studies that have reported that the frequent occurrence of droughts, irregular rainfall patterns and rising air temperatures were among the major climatic risks threatening the sustainability of agricultural production in Limpopo Province (Kephe et al., 2022; Mpandeli et al., 2015).

Although the majority of smallholder farmers (65%) have heard about climate change, only 47% of them had the correct understanding of the concept of climate change. These findings suggest the adequate level of awareness of climate change by the majority of farmers in the study area. Furthermore, results revealed that most of the smallholder farmers have heard about climate change from television (54%) and radio (54%) while government agencies (3%) and the internet (3%) were the least sources of information pertaining to climate change. The low utilization of the internet as a source of information could be attributed to old age and low literacy levels of the farmers in the study area. The average age of farmers was 66 years and the majority of farmers (59%) indicated that they had no formal education. Thereby, suggesting the necessity of simplifying the complex climate-related information and translating it into local languages. Furthermore, the insignificant role of government agencies in providing climate-related information could be attributed to the poor access to extension services and government institutions in the study area which was confirmed during focus group discussions. These findings agreed with previous studies that reported poor extension services due to limited capacity, knowledge and resources as the major constraint that limits the dissemination of climate information and related adaptation strategies to the smallholder farmers in South Africa (Myeni and Moeletsi, 2020; Ncoyini et al., 2022). This suggests the need for continuous provision of extension practitioners with climate-related training and workshops as well as with resources and infrastructure to improve the quality and outreach of the extension services in smallholder farming conditions (Myeni et al., 2021).

Table 2
Awareness of climate variability and the understanding of climate change (n = 240).

Climate information	*Indicators*	*Responses (%)*
Have you experienced any change in weather patterns in the past five years?	Yes	91.3
	No	8.8
Which weather problems attributed to climate change have you experienced? +	Flooding	17.5
	Drought	74.2
	Changing rain patterns	65.0
	Increased temperatures	62.9
	Hailstorms	7.1
	Increased pest and disease incidence	35.8
Have you heard of "climate change"?	Yes	64.6
	No	35.4
What do you know about climate change?	Correct understanding	47.5
	Incorrect understanding	52.5
Where did you hear about climate change? +	Television	53.8
	Radio	54.2
	Newspaper	8.3
	Internet	3.3
	Government agencies	2.5
	Friends/family	11.3

+ indicate a question where a farmer can select more than one choice.

3.2. Accesses and use of climate information services by smallholder farmers

3.2.1. Climate information services accessed by smallholder farmers

Data obtained from the household survey on the accessibility of CIS by smallholder farmers in the study area are presented in Table 3. The majority of smallholder farmers had access to CIS (79%) while only about 21% had no access. The results also showed that the majority of farmers had access to daily weather forecasts (76%) that are mainly broadcasted via radio (66%) and television (63%). Despite radio and television being affordable and easy means for conveying CIS, the information obtained from these media sources are generic meteorological forecasts instead of tailored impact-based forecasts coupled with response adaptation strategies that are essential for decision-making (Myeni and Moeletsi, 2020; Agyekum et al., 2022). Furthermore, CIS broadcasted via radio and TV follows a top-down approach which confines interaction between CIS developers and the end-users. This prohibits smallholder farmers from understanding and decoding the supplied climate-related information. Nevertheless, radio and television remain the most widely used channels for disseminating climate information in smallholder farming conditions (Myeni and Moeletsi, 2020; Ncoyini et al., 2022; Onyeneke et al., 2023; Baffour et al., 2022). Therefore, the experts on CIS are encouraged to frequently participate in media interviews at local media stations where they can share insights on the expected weather conditions and advise farmers on local-specific adaptation strategies following an interactive approach and using the local languages.

The results revealed that very few farmers had access to seasonal weather forecasts (7%) and early warning systems (10%). This suggests that the majority of smallholder farmers had very low access to other forms of CIS, particularly seasonal weather forecasts and early warnings that are crucial to informing agricultural management decisions and strategic plans in advance. These results corroborate the findings of previous studies that have reported that the majority of smallholder farmers have very limited access to meaningful and useful CIS despite their high access to daily weather forecasts from media sources such as radio and televisions (Myeni and Moeletsi, 2020; Ncoyini et al., 2022; Baffour et al., 2022). The poor access to CIS that are relevant and critical for decision-making in farming (e.g., 7–10 days forecast, seasonal forecast and early warning system with agrometeorological advice) restrict the adaptive capacities of smallholder farmers to cope effectively with climate variability and change (Ogundeji et al., 2022). This is a serious concern as this region continues to battle with the adverse effects of climate variability and change on smallholder farming, particularly under dryland which is the major source of food security and livelihoods for the majority of African rural communities. Consequently, the integration of indigenous knowledge and science-based meteorological forecasts could enhance adaptation capacity and strengthen the resilience of smallholder farmers to climate change (Basdew et al., 2017; Zuma-et al., 2016b).

The results from the study also revealed that the majority of smallholder farmers would like to access or receive CIS through direct SMS (40%) and workshops (39%) while mobile applications (7%) and direct emails (3%) were the least preferred methods. The focus group discussions revealed that most of the smallholder farmers prefer receiving climate and agricultural information that is simplified and translated into their local languages through pre-season workshops or direct voice messages. These findings suggest that the use of Information and Communications Technology (ICT) such as the use of mobile applications, WhatsApp, Facebook, internet and web-based applications that enable the dissemination of climate and agricultural information to a large number of farmers in a timely and cost-effective approach is amongst the least preferred methods to access or receive CIS by smallholder farmers. This is mainly due to smallholder farming in rural communities being predominantly elderly farmers who often have low levels of education. Consequently, the low involvement of youth in agriculture and high levels of illiteracy in the study area limits the use of technologies and innovations that are key for sustainable and climate-resilience agricultural production. Furthermore, the results showed that the majority of smallholder farmers were not willing to pay anything for improved and tailored climate services (81%) mainly due to their low incomes.

Table 3
Accesses and use of climate information services ($n = 240$).

Climate information	Indicators	Responses (%)
Do you have access to weather or climate information?	Yes	78.8
	No	21.2
Which weather or climate information do you have access to?+	Daily weather forecast	75.8
	Seasonal weather forecast	6.7
	Early warnings	10.0
What are your main sources of weather or climate information? +	Radio	66.3
	Television	62.9
	Internet	7.9
	Extension services	0.8
How will you like to access or receive climate services in the future? +	Workshops	38.8
	Direct email	2.9
	Direct database access	0.4
	Direct SMS	39.6
	Mobile applications	6.7
Would you pay for tailored weather or climate information?	Yes	19.2
	No	80.8

+ indicate a question where a farmer can select more than one choice.

3.2.2. Use of climate information services in smallholder farming

Data obtained from the household survey on the utilization of CIS by smallholder farmers in the study area are presented in Table 4. The results showed that the majority of smallholder farmers were not using any CIS in planning their farm activities (56%) while about 40% of farmers indicated that they were using daily weather forecasts. These results suggest that the majority of smallholder farmers relied on indigenous knowledge and personal experiences to make farm management decisions that are weather-sensitive. Furthermore, some of the farmers who were not using any CIS cited that the existing CIS were not relevant to their farm activities (33%) while some farmers indicated that they never knew their existence (16%) or where to access them (13%). Moreover, some farmers indicated that they didn't know how to use the CIS for decision-making in their farm activities (13%). These findings suggest that the lack of tailored and local-specific CIS (farm or community level) as well as the limited understanding and decoding of supplied information were the key challenges limiting the use of CIS by smallholder farmers for decision-making in the study area. These barriers to the use of CIS are consistent with the findings of the previous African studies (Ncoyini et al., 2022; Baffour et al., 2022; Sultan et al., 2020). Furthermore, the focus group discussions revealed that disengagement between producers and end-users of climate information as well as the insufficient institutional capacity to deliver and promote the use of timely and precise climatic information are among the major constraints restricting access and utilization of CIS in smallholder settings as also reported by previous studies (Ncoyini et al., 2022). Thereby suggesting that the awareness campaigns, capacity-building initiatives and co-producing of local-specific CIS accompanied by agrometeorological advisories is crucial in overcoming these barriers to the use of CIS. The establishment and proper maintenance of spatially distributed weather station networks that provide quality data is a prerequisite for the development of localized CIS, particularly in rural communities where weather stations are very sparse. Furthermore, the co-producing of CIS should involve multiple stakeholders such as researchers, agricultural extension officials and farmers through an interactive approach for the development of effective and relevant CIS that fit-for-purpose.

The seasonal characteristics such as rainfall onset date (87%), rainfall amounts (69%), rain cessation date (65%), rainfall distributions (57%) and growing season length (59%) were amongst the key climate information that were perceived by smallholder farmers to be most important for their decision-making (Table 4). Moreover, some farmers perceived that temperature reports (68%) and drought alerts (51%) were also crucial for their farm management decision-making mainly due to the frequent occurrences of droughts and prolonged dry spells in the area. These findings suggest that information regarding rainfall characteristics, droughts and

Table 4
Utilization of climate information services (n = 240).

Use of climate information services	Indicators	Responses (%)
Which climate services do you use in planning your farm activities? +	None	55.8
	Climate raw data	1.7
	Daily weather forecasts	40.4
	Seasonal weather forecast	2.6
	Early warning systems	6.3
If not, why are you not currently using CIS? +	No relevant CIS are available	33.3
	Data quality is not good enough	5.0
	Climate data are too expensive	3.8
	I don't know how to use them	13.3
	I don't know where to access it	12.5
	Never knew it exists	16.3
Which climate information is most important for your decision-making? +	Growing season length	58.8
	Rainfall onset date	87.1
	Rain cessation date	65.0
	Rainfall amounts	69.2
	Rainfall distributions	57.1
	Extreme rainfall	14.2
	Dry spell distribution	22.5
	Temperature reports	68.3
	Drought alerts	51.3
	Flood alerts	32.5
	Evaporation	9.6
	Wind speed reports	25.0
	Frost days	3.3
Which farm management decisions do you make based on CIS? +	Land preparation	37.1
	Crop type and variety selection	16.7
	Choice of cropping pattern	10.0
	Planting date selection	32.9
	Plan day-to-day farming activities	17.5
	Fertilizer and pesticide application	4.2
	Irrigation scheduling	1.25
	Long-term strategic planning	1.7
What are the major constraints that you have experienced when using CIS? +	Information was unreliable	55.4
	Information was too complicated	13.6
	Load shedding	15.8
	No constraint	4.6

+ indicate a question where a farmer can select more than one choice.

temperature were the key climate-related information required by smallholder farmers for their decision-making, particularly under rainfed agricultural production as also reported by previous studies (Agyekum et al., 2022; Ncoyini et al., 2022; Ouedraogo et al., 2021; Mubangizi et al., 2018).

The results indicated that land preparation (37%) and planting date selection (33%) were key farm management decisions made by farmers based on the existing CIS that were accessible to them. In contrast, only 1.7% of farmers indicated that they use existing CIS for planning their long-term strategies, thereby suggesting the lack of information on localized future climate projections that are crucial for the development of informed long-term adaptation strategies. The lack of reliable long-term historical observations at high spatial resolution is one of the key challenges limiting both the understanding of the current climate at the local-scale and also hindering the evaluation and downscaling of climate projections from global models (Singh et al., 2018). Therefore, the down-scaling and capacity building on future climate projections is crucial to enhance farmers' adaptive capacity and climate resilience (Chisadza et al., 2020).

The unreliability (55%), persisting load shedding (16%) and limited understating or poor decoding of CIS due to its high complexity (14%) were the major constraints experienced by smallholder farmers when using the existing and accessible CIS in the study area. The unreliability of CIS could be because the national meteorological agencies provide forecasts at a large geographical area (e.g., town or city) which fails to represent the high spatial variability of climatic conditions that might occur across different villages even in the same town. This could be attributed to the lower forecasting skills and limited weather stations in certain areas, particularly in remote rural areas and which in turn results in nonrepresentative climate information. The focus group discussions revealed that complexity and forecast terminology, language barriers and difficulty in understanding, decoding and applying the supplied information in decision-making were some of the major constraints experienced by smallholder farmers when using CIS as also reported by previous studies (Onyeneke et al., 2023; Mubangizi et al., 2018; Feleke, 2015).

3.3. Factors influencing the accessibility and utilization of climate information services by smallholder farmers

3.3.1. Differences in characteristics of smallholder farmers by access and use of climate information service

i. Characteristics of smallholder farmers with and without access to climate information services

There were significant mean differences between farmers who had access and no access to CIS only regarding gender, level of education, occupation, years of farming experience, access to media, awareness of climate variability and understating of climate change (Table 5). The results suggested that most female farmers had no access to CIS at a 10% significance level compared to their counterparts in the study area. Probably because in most instances female farmers are too busy with other family chores leaving no time to access CIS and other related agricultural information. Our findings are in agreement with the previous studies that postulate that female farmers had limited access to CIS and resources in general (Ogundeji et al., 2022; Henriksson et al., 2021; Alidu et al., 2022). The farmers with high levels of education were likely to have access to CIS compared to their counterparts at a 5% significance level probably due to their ability to search and access CIS via ICT-based approaches such as smartphones. The farmers whose major occupation was farming were more likely to have access to CIS compared to their counterparts at a 1% significance level. Probably because farmers who relied on their agricultural production for their food security turn to prioritize searching and accessing any information that could help them to improve their agricultural production.

The results of this study indicated that farmers who did have access to CIS had significantly more farming experience than their counterparts at the 10% significance level. These results could be attributed to the fact that more experienced farmers are aware of the factors that are more likely to affect their agricultural production, and as a result, they acquire knowledge about these factors. The

Table 5
Characteristics of farmers based on their accessibility and utilization of climate information services ($n = 240$).

Independent Variables	Accessibility			Utilization		
	Had no access	Had access	Difference	Non-users	Users	Difference
Location	1.90	2.04	−0.14	2.16	1.82	0.34***
Gender	0.71	0.60	0.11*	0.66	0.58	0.08*
Age	67.29	65.84	1.45	65.76	66.63	−0.87
Level of education	4.57	5.96	−1.39**	5.19	6.27	−1.08**
Occupation	0.27	0.56	−0.29***	0.49	0.51	−0.02
Off-farm income	2484.78	2860.21	−375.43	2528.38	3099.06	−570.68*
On-farm income	268.24	194.67	73.57	150.23	286.24	−136.01
Years of farming experience	28.93	33.41	−4.48*	28.34	31.84	−3.5*
Access to media	0.82	0.91	−0.09*	0.84	0.96	−0.12***
Ownership of livestock	0.49	0.46	0.03	0.46	1.50	−1.04
Farm size	1.49	1.59	−0.1	1.64	1.57	0.07
Awareness of climate variability	0.84	0.93	−0.09*	0.87	0.96	−0.09***
Understating of climate change	0.37	0.50	−0.13**	0.46	0.49	−0.03
Access to farmer associations	0.08	0.05	0.03	0.08	0.03	0.05**
Access to extension services	0.10	0.05	0.05	0.10	0.01	0.09***

where * $p < 0.1$, ** $p < 0.05$ *** $p < 0.01$.

ii Characteristics of users and non-users of climate information services results also showed that farmers who had access to media sources were more likely to have access to CIS compared to their counterparts at a 10% significance level probably due to media being the major source of CIS in the study area as also reported by (Baffour et al., 2022). The results revealed that farmers who were aware of climate variability were more likely to have access to CIS at a 10% significance level. The results further showed that the farmers who understood the concept of climate change were more likely to have access to CIS at a 5% significance level. These findings suggest that the awareness of climate variability and understanding of climate change was more likely to trigger the enthusiasm of farmers to access CIS to enhance their adaptive capacity and climate resilience.

Table 5 show significant mean differences between users and non-users of CIS only regarding location, gender, level of education, off-farm income, years of farming experience, access to media, awareness of climate variability, access to farmer associations and access to extension services.

The use of CIS varied significantly across different locations at a 1% significance level, thereby suggesting that farmers at Tzaneen were more likely to use CIS while farmers at Polokwane had low rates of using CIS. This could be probably because the majority of the households in Tzaneen are highly reliant on farming activities for their food security and livelihood compared to those in peri-urban villages surrounding Polokwane where the majority of households relied on purchased food. Thus, farming villages prioritize the search and utilization of any information that could help them to improve their agricultural production. Furthermore, most female farmers were not using CIS at a 10% significance level compared to their counterparts in the study area. Our findings are in agreement with the previous studies that reported the limited use of CIS by female farmers due to their restricted access to resources (Henriksson et al., 2021; Onyeneke et al., 2023; Alidu et al., 2022). The results also indicated that the majority of farmers who were using CIS had better levels of education compared to their counterparts at a 5% significance level. This suggests that farmers with high levels of education are likely to use CIS due to their abilities to search, access, understand, decode and apply the supplied information in their decision-making. The off-farm incomes for users were significantly larger than that of non-users of CIS at a 10% significance level. Thereby suggesting that farmers with higher incomes were more likely to use CIS compared to their counterparts probably because large incomes enable farmers to afford media devices that can be used to access climate information as also reported by previous studies conducted in Ghana and Nigeria (Onyeneke et al., 2023; Alidu et al., 2022). Furthermore, results indicated that years of farming experience for farmers who were using CIS were significantly greater than non-users at a 10% significance level. These findings corroborate other previous studies that more experienced farmers were likely to use CIS because they have acquired more knowledge about climatic factors that influence their agricultural production and are more familiar with where to access relevant CIS (Ogundeji et al., 2022; Onyeneke et al., 2023; Alidu et al., 2022). Farmers who had access to variety of sources of media were more likely to use CIS compared to their counterparts at a 1% significance level probably due to media being the major source of CIS in smallholder farming conditions as also reported by Onyeneke et al. (2023) and Mubangizi et al. (2018). The results also showed that farmers who were aware of climate variability were more likely to use CIS compared to their counterparts at a 1% significance level. Furthermore, the results showed that the farmers who had access to farmer associations were more likely to use CIS compared to their counterparts at a 5% significance level, thereby suggesting that access to farmer's associations had a positive effect on the use of CIS as also reported by previous studies in Ghana and Senegal (Alidu et al., 2022; Ouedraogo et al., 2021). Farmers who had access to extension services were more likely to use CIS compared to their counterparts at a 1% significance level. These findings complement the previous studies that reported that access to extension services has a positive effect on the use of CIS (Alidu et al., 2022).

3.3.2. Factors affecting the accessibility and utilization of climate information services by smallholder farmers

i. Factors affecting the accessibility of climate information services

The results estimated using a binary logistic regression model showed that location ($p < 0.1$), occupation ($p < 0.05$) and awareness

Table 6
Estimated results on the factors affecting the accessibility and utilization of climate information services by smallholder farmers ($n = 240$).

Explanatory Variables	Accessibility of CIS		Utilization of CIS	
	Coefficients	SE	Coefficients	SE
Location	−0.662*	0.344	−1.259***	0.281
Gender	−0.369	0.400	−0.0285	0.314
Age	−0.001	0.017	0.017	0.014
Level of education	0.020	0.045	0.083**	0.036
Occupation	2.116***	0.522	1.103***	0.376
Off-farm income	0.001	0.001	0.002	0.004
On-farm income	0.001	0.001	0.001	0.002
Years of farming experience	−0.020	0.013	0.004	0.011
Access to media	−0.331	0.604	0.356	0.513
Ownership of livestock	−0.271	0.349	−0.212	0.303
Farm size	−0.008	0.140	−0.144	0.115
Awareness of climate variability	1.686***	0.600	0.816	0.617
Understating of climate change	0.431	0.392	0.622*	0.327
Access to farmer associations	0.095	0.812	0.213	0.695
Access to extension services	−0.332	0.815	−0.407	0.752

SE is the Standard Error in parentheses (*$p < 0.1$, **$p < 0.05$ ***$p < 0.01$).

of climate variability ($p < 0.01$) were the key explanatory variables that had a significant effect on the accessibility of CIS by smallholder farmers in the study area (Table 6). Thus, in this sub-section, only the key factors that had a significant influence on the accessibility of CIS by smallholder farmers are briefly discussed.

The results of this study showed that location had a negative and significant effect (−0.662) on the accessibility of CIS at a 90% confidence level. The results indicated that accessibility of CIS by smallholder farmers varied across different locations probably due to different institutions and access to resources. These findings complement the previous studies that have indicated that accessibility to CIS is location-specific due to differences in the availability of climate information and resources as well as cultural ideologies (Baffour et al., 2022; Atube et al., 2021; Acevedo et al., 2020). The results showed that occupation had a positive and significant effect (2.116) on the accessibility of CIS at a 99% confidence level. Thereby, suggesting that farmers whose major occupation was farming were more likely to have access to CIS compared to their counterparts. As previously stated, farmers who are highly reliant on their agricultural production for their food security prioritize searching and accessing any information that could help them to improve their agricultural production and climate resilience. The results indicated that awareness of climate variability had a positive and significant effect (1.686) on the accessibility of CIS at a 99% confidence level. Thereby, suggesting that farmers who were aware of climate variability were more likely to have access to CIS compared to their counterparts. These findings are aligned with previous studies that climate variability experienced by the farmers triggers their enthusiasm for searching and accessing any information on averting climatic risks (Onyeneke et al., 2023).

ii. Factors affecting the utilization of climate information services

The results estimated using a binary logistic regression model showed that location ($p < 0.01$), level of education ($p < 0.5$), occupation ($p < 0.01$) and understating of climate change ($p < 0.1$) were the key explanatory variables that had a significant effect on the utilization of CIS by smallholder farmers in the study area (Table 6). Thus, in this sub-section, only the key factors that had a significant influence on the utilization of CIS by smallholder farmers are briefly discussed.

The location had a negative and significant effect (−1.259) on the utilization of CIS at a 99% confidence level. The results indicated that utilization of CIS by smallholder farmers varied across different locations probably due to differences in terms of their availability and accessibility of CIS as well as prioritizing farming for food security (Ouedraogo et al., 2021). The results showed that the level of education had a positive and significant effect (0.083) on the utilization of CIS at a 95% confidence level. Thereby, suggesting that farmers with higher levels of education were more likely to use CIS compared to their counterparts probably because formal education enables farmers to easily search, access, decode and use information from different sources. These findings agreed with previous studies that had reported that the level of education has a positive and significant influence on the use of CIS in smallholder farming conditions (Ncoyini et al., 2022; Ogundeji et al., 2022; Alidu et al., 2022; Ouedraogo et al., 2021; Mubangizi et al., 2018). The results showed that occupation had a positive and significant effect (1.103) on the utilization of CIS at a 99% confidence level. Thereby, suggesting that farmers whose major occupation was farming were more likely to use CIS compared to their counterparts. As previously stated, farmers who rely heavily on their agricultural production for their food security prioritize searching for, accessing and utilizing any information that could help them to improve their agricultural production and climate resilience. The results indicated that understating of climate change had a positive and significant effect (0.622) on the utilization of CIS at a 90% confidence level. Thereby, suggesting that farmers who understood the concept of climate change were more likely to use CIS compared to their counterparts. A possible reason for this is that the understanding of climate change prompts their interest in searching, accessing and utilizing any information on averting weather-related hazards associated with climate change.

4. Conclusions and recommendations

The accessibility and wider use of climate information services (CIS) are essential to enable farmers to minimize losses due to climatic uncertainties and take advantage of opportunities presented by favourable climatic conditions. This is expected to improve agricultural production and build climate-resilience in the most vulnerable smallholder farming, particularly under rainfed farming systems. This study was undertaken to understand the key challenges and determinants of access and the utilization of CIS by smallholder farmers in South Africa, using Limpopo Province as the case study. The majority of smallholder farmers had access to the daily weather forecasts that are mainly broadcasted via radio and television while very few had access to other types of CIS such as seasonal weather forecasts and early warnings that are essential to inform agricultural management decisions and strategic plans in advance. Furthermore, the majority of smallholder farmers prefer receiving climate and agricultural information that is simplified and translated into their local languages through pre-season workshops or direct voice messages and they were not willing to pay anything for improved and tailored CIS.

The majority of smallholder farmers were not using any CIS in planning their farm activities mainly due to unreliability, lack of tailored and local-specific CIS (farm or community level) as well as language barriers, difficulty in understanding, decoding and use of supplied information for decision-making. Information regarding rainfall characteristics, droughts and temperature were the key climate-related information required by smallholder farmers for their decision-making in partitioning land preparation and planting date selection. The accessibility and utilization of CIS vary across different locations due to their differences in terms of institutions, access to resources and levels of prioritizing farming as the major occupation and source of food security. Occupation and awareness of climate variability were the main factors that had a positive and significant effect on the accessibility of CIS, while the level of education, occupation and understating of climate change had a positive and significant effect on their utilization.

From the findings of our study, awareness campaigns, capacity-building initiatives and co-production of local-specific CIS accompanied with agrometeorological advisories are recommended to overcome these barriers to the access and use of CIS. Despite the uncertainties associated with CIS derived from indigenous knowledge but it remains the main source of climate information in smallholder settings. Therefore, the integration of indigenous knowledge and science-based meteorological forecasts is recommended to enhance adaptation capacity and strengthen the resilience of smallholder farmers to climate variability and change. Given that extension service could play a crucial role in the dissemination of CIS, the continuous provision of extension practitioners with climate-related training and workshops as well as with resources and infrastructure to improve the quality and outreach of the extension services in smallholder farming conditions is highly recommended.

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CRediT authorship contribution statement

Lindumusa Myeni: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Software, Validation, Visualization, Writing – original draft, Writing – review & editing. **Nkosazana Mahleba:** Data curation, Formal analysis, Methodology, Writing – review & editing, Conceptualization, Investigation, Visualization. **Sabelo Mazibuko:** Data curation, Methodology, Writing – review & editing. **Mokhele Edmond Moeletsi:** Conceptualization, Data curation, Methodology, Supervision, Validation, Visualization, Writing – review & editing, Funding acquisition. **Kingsley Ayisi:** Conceptualization, Funding acquisition, Supervision, Visualization, Writing – review & editing. **Mitsuru Tsubo:** Funding acquisition, Validation, Visualization, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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