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Assessment of smallholder farmers' perception and adaptation response to climate change in the Olifants catchment, South Africa

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ABSTRACT

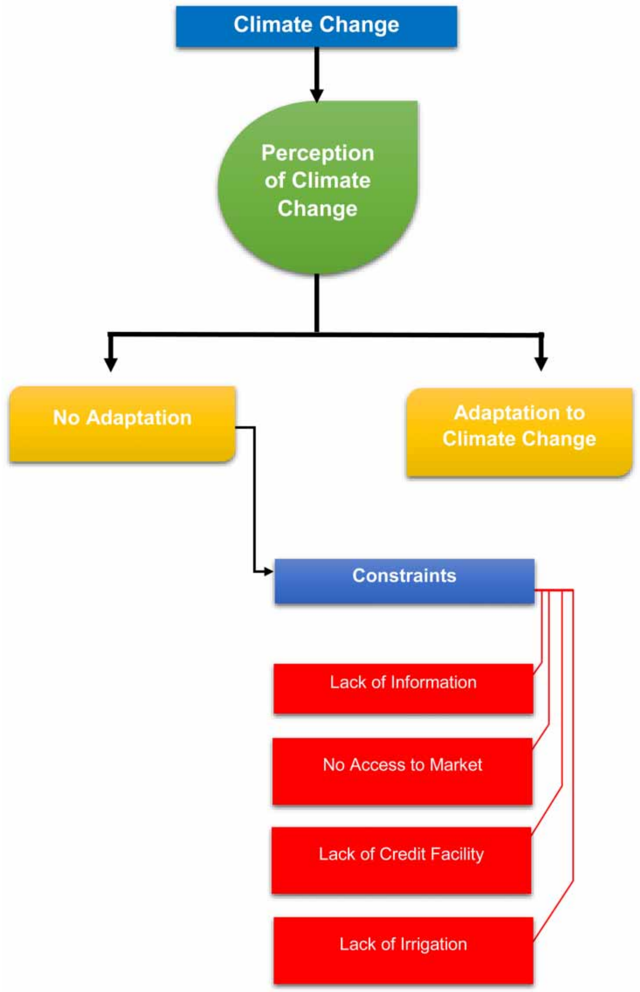
Climate change is expected to affect the livelihood of rural farmers in South Africa, particularly the smallholder farmers, due to their overwhelming dependence on rain-fed agriculture. This study examines smallholder farmers' perception of climate change, the adaptation strategies adopted and factors that influence their adaptive decisions. The unit of data collection was household interview and focus group discussion. Climate data for the Olifants catchment (1986–2015) were also collected to validate farmers' perception of climate change with actual climate trend. Data collected were analysed using descriptive statistics, Mann–Kendall trend, Sen's slope estimator and multinomial logit regression model. Results revealed that smallholder farmers are aware of climate change (98%), their perception of these changes aligns with actual meteorological data, as the Mann–Kendall test confirms a decreasing inter-annual rainfall trend (−0.172) and an increasing temperature trend (0.004). These changes in temperature and precipitation have prompted the adoption of various adaptation responses, among which the use of improved seeds, application of chemical fertilizer and changing planting dates were the most commonly practised. The main barriers to the adoption of adaptation strategies were lack of access to credit facility, market, irrigation, information about climate change and lack of extension service. The implication of this study is to provide information to policy-makers on the current adaptation responses adopted by farmers and ways in which their adaptive capacity can be improved in order to ensure food security.

Key words: adaptation, climate change, farmers perception, Olifants catchment

HIGHLIGHTS

- Farmers perceived changes in temperature and precipitation.
- Perception of climate change aligns with actual climate data.
- Smallholder farmers in the catchment are significantly vulnerable to the impact of climate change.
- Farmers perceived that the adoption of adaptation strategies can improve crop production.
- Age and years of farming had a determining influence on the adoption of changing planting date as an adaptive response.

GRAPHICAL ABSTRACT



INTRODUCTION

Sustainable development in Africa is threatened by the impact of climate change, as it puts additional stress on socio-economic and environmental resources required for sustaining livelihood (Akanbi *et al.* 2021). In many developing countries and regions, climate variability and change are projected to adversely impact agricultural production and access to food (IPCC 2007). The negative consequence of these changes is expected to greatly affect the livelihood of poor and rural farmers, due to their overwhelming reliance on climate-sensitive parameters (i.e. temperature and precipitation). Extreme climate events, such as droughts, floods, heatwave, storms and soil degradation, increase the uncertainty of agricultural production. Crop yields are differently affected by climate change in several regions. The adverse impact of these changes is mostly felt in regions where rain-fed agricultural production is the main staple food, therefore threatening food security (Akanbi *et al.* 2021).

According to IPCC (2007), adaptation to climate change differs across regions and is determined by histories, farmers' perception of climate change and the availability of viable adaptation options. Bonewit & Shreeves (2015) reported that climate change based on historical discourse has not been people-oriented. However, introducing a socio-economic paradigm into this discussion has been very slow and only began to gain some momentum in recent time. With this momentum, there is an increasing concern that the vulnerability of agricultural population to climate change cannot be determined by merely quantifying the bio-physical impacts. However, there is a need to understand the interaction between climate change, farmers' perception, present adaptation measures, local-context challenges and farmers' decision to adapt (Tucker *et al.* 2010). Studies focusing on exploring social vulnerability to climate change with in-depth investigation of the underlying institutional and socio-economic factors should be encouraged in order to provide relevant information to policy-makers aimed at assisting vulnerable populations with the development of suitable adaptation plans (Akanbi *et al.* 2021).

Climate change has caused a decline in global agriculture by about 1–5% in the last decade (Mashizha 2019). According to IPCC (2014), agriculture in African countries is projected to be significantly impacted by climate change, and it is expected to cause about 50% yield loss by the year 2020. The negative impacts of these changes on agriculture will place additional pressure on farmers, particularly the smallholder farmers due to their direct dependence on agriculture, their inability to respond adequately to climate shocks as well as constrained resources, thus making them more vulnerable (Harvey *et al.* 2014). Understanding these smallholder farmers' contextual conditions and adaptation responses to climate shocks is an important step in tackling food insecurity challenges (Harvey *et al.* 2014).

Developing countries are faced with numerous other non-climatic stressors such as pest and disease infestation, market shock, lack of capital/credit and post-harvest losses, among others that constrain agricultural production and livelihoods of smallholder farmers (Morton 2007). Climate change is predicted to further worsen the plight of smallholder farmers. A study conducted by Morton (2007) reported a decrease in smallholder farmers' cereals production (maize, wheat and rice) under modest increases in temperatures. Countries in the Tropical regions like those in Africa with already high numbers of poor and smallholder farmers will be hardest hit by the impact of climate change (Hertel & Rosch 2010). Following the projected worsening of climatic conditions, it is important that efforts be channelled towards assisting smallholder farmers to identify effective adaptation measures in building strong resilience to climate change (Harvey *et al.* 2014).

South Africa is characterized as a water-scarce country and it is further subjected to the impacts of climate change due to its location in a semi-arid region (Nhamo *et al.* 2020; Akanbi *et al.* 2021). Agricultural production in the country is practised mostly under rain-fed conditions, which makes it particularly vulnerable to climate risk (Ndhleve *et al.* 2017). South Africa's agriculture plays an important role in the country's food security and economy, as it sustains more than 70% of the region's food, income and employment (Cammarano *et al.* 2020). Apart from the constraints posed by climate change on agriculture, farmers in South Africa are subjected to other non-climatic factors such as high production cost, insufficient arable land, poorly implemented policy initiatives and lack of technological support, which further aggravate the challenges experienced by farmers trying to respond adequately to climate threats (Mapfumo *et al.* 2014).

Field crops, such as maize, wheat, soya beans and dry beans, are the most important food crops in South Africa and are largely produced by both large- and small-scale farmers. South Africa remains the largest producer and exporter of these crops, particularly maize within the Southern African Development Community (SADC) (Dabrowski *et al.* 2009). A decline in the rate of crop production has already been experienced in the country, and it is expected to continue into the future as a result of the anticipated increase in temperature and decrease in rainfall (Oduniyi *et al.* 2019a, 2019b). For example, Blignaut *et al.* (2009) reported a decrease in summer maize and winter wheat by 1.1 and 0.5%, respectively. A study by Mangani *et al.* (2019) attributed a 24.3% decline in maize yield in the 2014/2015 planting season to increased drought and heatwaves. According to DAFF (2019), maize production decreased by 21.4% in the 2017/2018 planting season compared to the previous season. These decreasing production trends were, however, attributed to delayed rainfall in most parts of the maize-producing areas at the beginning of the planting season (DAFF 2019). In response to the declining trends of crop production to climate change, adaptation is increasingly seen as an absolute necessity towards improving crop production, sustaining food security and livelihoods. The changes in climatic conditions and their associated impacts on crop production make South Africa a region where understanding farmers' perception and adaptation response to climate change is of critical importance for policymaking. For instance, Gbetibouo *et al.* (2010), who examined climate adaptation strategies of farmers in the Limpopo Basin of South Africa, reported that a lot of farmers noticed the long-term changes in temperature and precipitation, but the majority of the farmers could not take remedial action due to lack of credit facilities and access to water.

Elum *et al.* (2017), in examining farmers' perception of climate change and response strategies in three selected provinces in South Africa, found that climate parameters have significantly changed over time and were substantiated by farmers' experience. The study further revealed that farmers are engaging in various climate–response strategies, among which planting drought-tolerant crops was the most common.

Wiid & Ziervogel (2012) assessed commercial farmers' perception and response to climate change. Their study found that farmers have perceived a gradual but dramatic shift in climate over almost four decades, including increasing temperature, changing annual rainfall pattern and a shift in predominant wind direction. Their study concluded that farmers' experience with shifting climate has played a significant role in driving their decision to adapt. Other studies, such as Gandure *et al.* (2013), Maponya *et al.* (2013) and Mpandeli *et al.* (2015), have examined farmers' awareness and adaptation response to climate change in South Africa. However, none of these studies have investigated the vulnerability of smallholder farmers to climate change or validated farmers' perception of climate change with actual observed climate data. Since smallholder farmers represent the largest proportion of population in South Africa's agricultural system, it is imperative to understand their perception of climate change and identify possible adaptation barriers in order to provide relevant information to policymakers on ways to improve their adaptive capacity.

This study thus aims to assess smallholder farmers' perception of climate change and identify their adaptation response in the Olifants catchment, South Africa. The selection of the Olifants catchment is based on its importance to food security for most of the country as well as its vulnerability to global climate change.

METHODOLOGY

This study employed a multi-dimensional method, which utilizes both quantitative and qualitative data. Household crop farmers were the unit of assessment in the area. A combination of structured close-ended questionnaires ($n = 120$) and semi-structured open-ended focus group discussions ($n = 5$) was used. Actual meteorological data were also analysed to validate the level of agreement between climatic trends and smallholder farmers' perception of climate in the study area. The data obtained from the questionnaires were statistically analysed using Statistical Package for the Social Science (SPSS 26), while the climate data were analysed using XLSTAT 2020.3.1. In addition, a multinomial logit (MNL) model was used to determine the factors influencing smallholder farmers' adaptive response to climate change.

Study area

The Olifants catchment is located in the north-eastern part of South Africa and southern Mozambique at 24–26°S and 29–32°E (Figure 1). The bulk of the basin lies in the Limpopo and Mpumalanga provinces, with a small portion located in the Gauteng province. The catchment has an estimated size of 54,600 km^2, with an approximated population of 3.4 million (7% of the national population). About two-thirds of the population in the Olifants catchment resides in the rural areas. The climate of the catchment is semi-arid, with rainfall occurring during the spring/summer months of October–April. The catchment mean annual rainfall is 630 mm, and potential evaporation is 1,700 mm. Annual average rainfall along the escarpment separating the Highveld from the Lowveld can be as high as 2,000 mm and as low as 440 mm in parts of the Middleveld (de Lange *et al.* 2005). The elevation of the catchment ranges between 300 and 2,200 meters above sea level. This explains its winters and the annual wide temperature variation, which ranges from −4 to 45 °C.

Agriculture is a major land-use sector in the catchment with dry land covering about 8,160 km^2 and irrigation land about 800 km^2 (Le Roy 2005). Cultivated land in the catchment is divided into two agricultural sectors representative of South African agriculture: the commercial sector comprising large farms, which are mainly owned by white farmers (Le Roy 2005) and a small-scale production sector. The subsistence/small-scale sector comprises small farms located mainly in the former homelands (i.e. areas occupied by black people prior to 1994). Commercial farming represents about 80% of the cultivated area of the catchment and nearly the total of the irrigated area in the basin. In this study, the emphasis was on the small-scale farmers as they form the largest group in the agricultural system, and a large number of the small-scale farmers practise rain-fed agriculture, which makes them more vulnerable to the impact of climate change. Data were collected from five districts located in the Olifants catchment: Witbank, Middleburg, Belfast, Douglass and Kriel. The choice of these districts was based on the fact that they are the major crop-producing areas in the catchment. The major crops produced in these areas are maize, soya beans and dry beans. Other crops, such as citrus and vegetables, are also cultivated in the catchment. The crop-planting season, which is 90% rain-fed operated mostly by smallholder farmers, starts at the beginning of October and runs through January, while the harvesting period occurs between mid-May and August depending on the time of planting and the type of crops (DAFF 2019).

Data collection

Sampling technique and sample size

A multi-stage sampling technique was employed in this study, where a combination of sampling techniques was used to select the catchment and households in the catchment for interviews. In the first stage, the Olifants catchment was purposively selected from other catchments in South Africa because it is one of the most severely affected by climate change (Olabanji *et al.* 2020). In the second stage, five districts were purposively selected in the Olifants catchment because they are the highest crop-producing districts with homogenous climate. For the purpose of this study, the population size of smallholder farmers

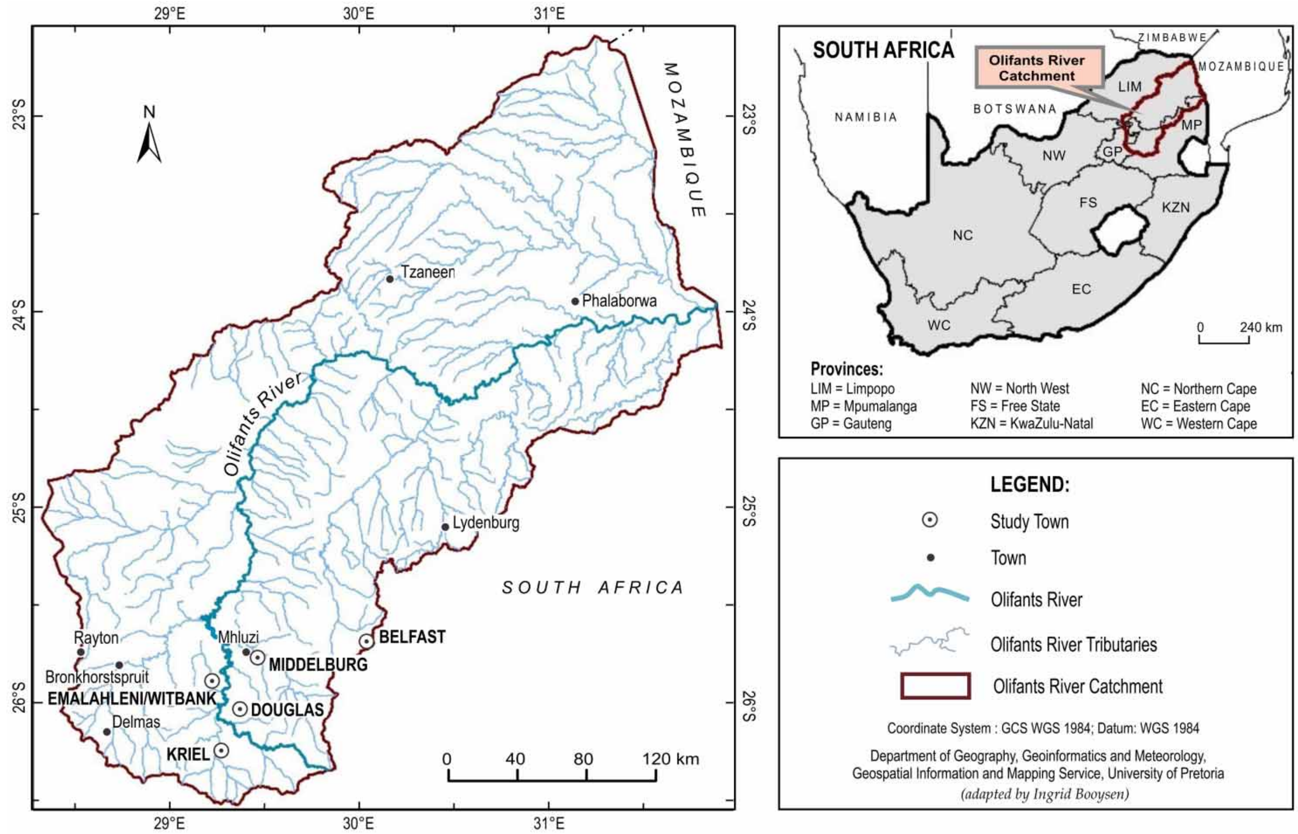


Figure 1 | Map of Olifants catchment showing the study sites.

($n = 1{,}800$) obtained from Grain SA was adopted as the total population of smallholder farmers in the districts. In the third stage, a simple random sampling technique was used in selecting the household heads from a database accessed through extension services and farmers' associations. The sample size was determined using the sample size formula of Yamane (1967), which is expressed as follows:

$$\frac{N}{1 + N(e)^2} \tag{1}$$

where N is the estimated sample size ($n = 1{,}800$) of the population of farming households in the selected districts, e is the margin of error (estimated at 0.0872), at a 95% confidence level. The calculation of the sample size resulted in a total number of 120 smallholder farmers used in this study. A structured questionnaire consisting of both open- and closed-ended questions was administered to household farmers in the districts through face-to-face interviews. The questionnaires captured the demographic profile of farmers, farming history, farmers' perception of climate change and level of vulnerability, adaptation strategies adopted, as well as farmers' challenges and needs. The household survey was then followed by a focus group discussion consisting of five farmers with in-depth knowledge about the climate of the area and the dynamics of crop production. The selection of farmers for the focus group discussion was based on a convenient sampling approach. They assisted with the verification of data obtained during the field survey between August and September 2019.

Climate data

To examine the consistency of farmers' perception of climate change and actual climate change in the Olifants catchment, meteorological station records were used to calculate the actual climate change in the catchment. Monthly rainfall (mm) and temperature (°C) over the study area for the period of 1985–2015 were obtained from the South African Weather Service (SAWS). The raw data sets from SAWS are achieved as monthly values using climate computing format. Stations considered in this study were based on the length of time. In total, six stations located within the Olifants catchment were considered. Climate data were quality controlled by addressing the occurrence of missing values in the data sets, particularly the rainfall data. The missing values were filled using the simple arithmetic mean method. This method is commonly used to fill in missing meteorological data if the normal annual precipitations at surrounding gauges are within the range of 10% of the normal annual precipitation at station X (Tabios & Salas 1985). The method assumes the equal mean of all nearby gauge stations and uses the arithmetic mean of their precipitation records as an estimate (Tabios & Salas 1985). The formula for calculating the simple arithmetic mean is expressed as follows:

$$P_x = \frac{1}{m}[P_1 + P_2 + \cdots + P_m] \quad (2)$$

where P_x is the estimated value of the missing data, P is the value of same parameter at mth nearest weather station, and m is the number of the nearest stations.

The simple arithmetic mean was considered satisfactory in this study because the gauges were uniformly distributed over the area and the means do not vary greatly.

Data analysis

Data obtained from field survey were analysed by descriptive statistics using Statistical Package for Social Science (SPSS 26). The descriptive statistics were employed to describe farmers' perception of climate shocks, responses implemented to address the shocks and the constraints faced in implementing the responses. In addition, the determinant of farmers' decision to adapt to climate change was analysed using an MNL regression model. This method was used to analyse crop farmers' choice of adaptation strategies employed and the factors determining those choices. According to Belay *et al.* (2017), the advantage of the MNL model over other models, such as the binary logit model, is that it allows for the analysis of decisions across multiple categories, as well as the determination of choice probabilities for different categories. The dependent variables used for this assessment were the five main adaptation measures used by the smallholder farmers in the catchment. The MNL regression model used in this study is expressed as follows:

$$Y_i = \mathrm{F}(X_1, X_2, \ldots, X_9) \quad (3)$$

where Y_i is the dependant variable denoting the method of choice among other alternatives, i.e. the use of improved seed, changing planting dates and crop rotation. The exploratory/independent variable X demotes the demographic factors such as gender, age, farming experience, educational level, farm size and farm location.

To analyse the current climate conditions of the catchment, monthly temperature and precipitation data over a period of 30 years were evaluated to assess monthly and inter-annual variations and trends. The Man–Kendall test and Sen's slope estimator were used to determine climate trends and slope magnitude. Before assessing climate trend, the data were first tested for the existence of significant autocorrelation in other to prevent a misleading trend result. The result presented in Figure 2 shows that values for the autocorrelation function were within 95% confidence interval of lags >0, which verifies that data used in this study have no autocorrelation.

The Mann–Kendall trend test was then used to detect the presence of monotonic increasing or decreasing trends in climate variables of the study area as well as to determine whether the trends are statistically significant (Asfaw *et al.* 2018). The Mann–Kendall test S is expressed as follows:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \mathrm{sgn}\,(T_j - T_i) \quad (4)$$

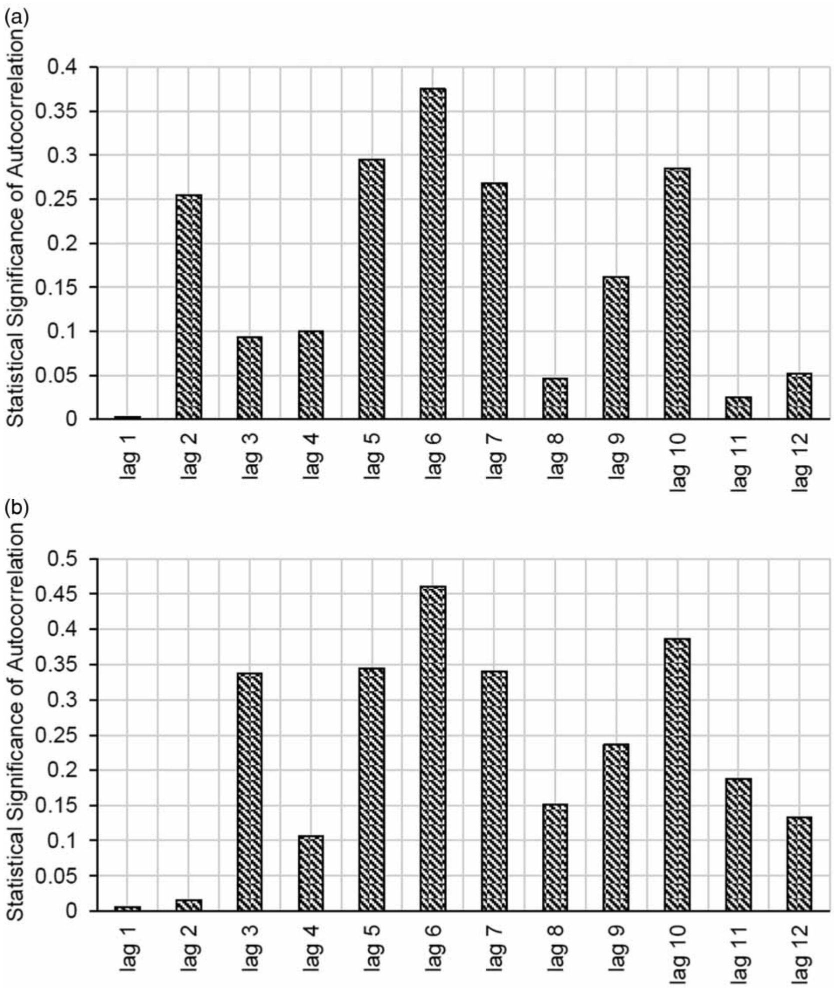


Figure 2 | Results showing the absence of significant autocorrelation for (a) temperature and (b) precipitation at 95% confidence interval for lags >0.

where T_j and T_i are the annual values in years j and i, $j > i$, respectively, n is the number of data points and $\mathrm{Sgn}(T_j - T_i)$ is calculated using the following equation:

$$\mathrm{sgn}(T_j - T_i) = \begin{cases} 1 & \text{if} \quad T_j - T_i > 0 \\ 0 & \text{if} \quad T_j - T_i = 0 \\ -1 & \text{if} \quad T_j - T_i < 0 \end{cases} \tag{5}$$

The application of trend test is done to a time series X_i that is ranked $j = i + 1, 2, \ldots, n$. Each of the data points X_i is taken as a reference point, which is compared with the rest of the data points. A positive value of S indicates an upward (increasing) trend, while a negative value indicates a downward (decreasing) trend. The null hypothesis (H_0) of the Mann–Kendall test assumes that there is no trend, while the alternative hypothesis (H_a) indicates a significant trend.

Sen's slope non-parametric estimation method is used for predicting the magnitude of hydro-meteorological time series data (Hussain *et al.* 2015). Sen's slope estimator uses a linear model for the trend analysis. The slope (T_i) for all data pairs is calculated using the following equation:

$$T_i = \frac{x_j - x_k}{j - k} \quad \text{for} \quad I = 1, 2, 3, \ldots, n \tag{6}$$

where x_j and x_k are data values at time j and k $(j > k)$ separately. The median of these n values of T_i is represented by Sen's slope of estimation (true slope), which is calculated using the following equation:

$$Q_i = \begin{cases} T_{\frac{n+1}{2}} & \text{for } n \text{ is odd} \\ \frac{1}{2}\left(T_{\frac{n}{2}} + T_{\frac{n+1}{2}}\right) & \text{for } n \text{ is even} \end{cases} \quad (7)$$

Sen's estimator Q_{med} is calculated using the above equation depending upon the value of n, which is either odd or even, and then computed as 100 $(1 - \alpha)$ % confidence interval to obtain the true slope for the non-parametric test in the series. A positive value of Q_i indicates an increasing (upward) trend, while a negative value of Q_i represents a downward or decreasing trend of time series data.

RESULTS

Results from this analysis highlighted the nature of the linkages between the demographic characteristics of smallholder farmers in the Olifants catchment, their perception of climate change and the extent of alignment between farmers' perception of climatic trends and actual meteorological data. The analysis also revealed the level of vulnerability of farmers to climate risk, the most favoured adaptation measures employed in response to climate threats and the factors determining farmers' choice of adaptation. Moreover, results from this analysis also highlighted the most critical adaptation barriers and needs identified by the farmers.

Demographic characteristics of respondents

Table 1 presents the demographic characteristics of smallholder farmers in the catchment. Results show that about two-thirds of the total respondents were male (64%) and 36% were female. More than 30% of respondents were between the age of 50 and 69 years old and 27% were above 69 years. The result of this analysis indicates that the most active farmers in the catchment fell within the age of 50–69 years. These findings, however, align with Obayelu *et al.*'s (2014) study in Nigeria and Kom *et al.*'s (2020) study in South Africa, which revealed that socio-economic aspect on the perception of climate change can be influenced by household age. As older farmers participated more in agricultural activities than youth, they are able to detect

Table 1 | Demographic characteristics of smallholder farmers ($n = 120$) by frequency and percentage of respondents from each district in which data were collected

	Kriel		Douglass		Middleburg		Witbank		Belfast		
Variable	***n***	**%**	***n***	**%**	***n***	**%**	***n***	**%**	***n***	**%**	**Total (%)**
Gender											
Male	9	45	15	56	19	83	13	52	21	84	64
Female	11	55	12	44	4	17	12	48	4	16	36
Age (years)											
50–59	11	55	2	7	8	35	7	28	12	48	33
60–69	5	25	12	45	8	35	12	48	11	44	40
>70	4	20	13	48	7	30	6	24	2	8	27
Level of education											
Non-formal	8	40	2	8	9	39	1	4	6	24	22
Primary/basic	9	45	9	33	11	48	8	32	11	44	40
Secondary	2	10	13	48	1	4	11	44	8	32	29
Tertiary	1	5	3	11	2	9	5	20	0	0	9
Years of experience											
30–39	12	60	2	8	8	35	7	28	12	48	34
40–49	4	20	12	44	7	30	11	44	11	44	38
>50	4	20	13	48	8	35	7	28	2	8	28

Source: Field Survey Data 2019.

and perceive the changes in climate variables. Also, results presented in Table 1 showed that out of the total 120 respondents surveyed in the catchment, 28% of the respondents had above 50 years of experience, about 35% of the respondents had 30–39 years of farming experience and the majority (38%) had 40–49 years of experience. It could therefore be assumed that farmers' perception and awareness of climate change could also be influenced by the number of years of farming experience, as more experienced farmers would have the tendency to detect long-term climate shifts.

Perception of climate change

Farmers are directly impacted by climate change due to their dependence on climate-sensitive parameters and are more sensitive to this change. Hence, assessing farmers' perception of climate change is very important in understanding their adaptive behaviour (Wang *et al.* 2014). Climate change in this study is defined as the perceived changes in average temperature and rainfall over the last 30 years. Therefore, the perception of climate change from respondents was based on their farming experience over the last 30 years. Of the total 120 household farmers surveyed in the catchment, descriptive analysis revealed that 98% of respondents are aware of the changes in the climatic conditions in the area, based on perceived changes in temperature and rainfall. Table 2 indicates that crop farmers in the Olifants catchment are observing climate change in the form of increased temperature (87%), decreased duration of rainfall (76%) and early cessations of rainfall. Respondents also perceived a decrease in temperature (37%) and rainfall events (65%). Most of the smallholder farmers expressed their perception based on their observation of a colder winter and warmer summer temperatures as well as increased rainfall variation over the last 30 years. Descriptive statistics, which include percentages and frequencies, were used to evaluate farmers' perception of climate change and are summarized in Table 2. When asked about their major source of climate information, respondents revealed that climate information was received through farmers' associations and media, only 26% of respondents received information about climate change from extension officers, while 84 and 38% of respondents obtained their climate information from media and farmers association, respectively.

Alignment between farmers' perception and actual climate data

Crop farmers in the Olifants catchment have experienced decreased rainfall and a delay in the starting of rainfall during the planting season. They have also perceived colder winter and warmer summer temperatures. Figure 3(a) presents the inter-annual temperature anomaly departure from the observed 30-year average (1986–2015). Results from the analysis show that temperature has been increasing since the early 2000s, peaking in 2006. The lowest departure from the 30-year average was observed between 1996 and 2000 and the highest between 2003 and 2006. With regard to precipitation, analysis shows a constant variation of increase and decrease in annual precipitation, with the peak decrease occurring in the years 1993 and 2005 and the highest precipitation occurring between 1986 and 2000 as shown in Figure 3(b). To assess whether there is an agreement between farmers' perception of climate variation in the catchment and observed climate data, the Mann–Kendall trend test was used to determine the trend and level of significance of climate variables (temperature and precipitation).

Results of the Mann–Kendall trend test show a decreasing inter-annual precipitation trend of −0.172 and Sen's slope magnitude of −6.662, although there was no statistical significance as *p*-value was greater than 0.05. The decreasing trend in observed precipitation of the catchment aligns with farmers' perception of decreasing precipitation. Their perception of decreased precipitation at the onset of the planting season was also confirmed, as a decline in rainfall was observed in the

Table 2 | Smallholder farmers' perception of climate change in the Olifants catchment

Perceived change in climate	Frequency	Percentage
Changes in climate	118	98
Increased temperature	104	87
Decreased temperature	44	37
Increased rainfall duration	35	29
Decreased rainfall duration	91	76
Increased rainfall intensity	25	21
Decreased rainfall intensity	78	65

Over 95% of respondents ($n = 120$) perceived changes in temperature and rainfall. *Source*: Field Survey Data 2019.

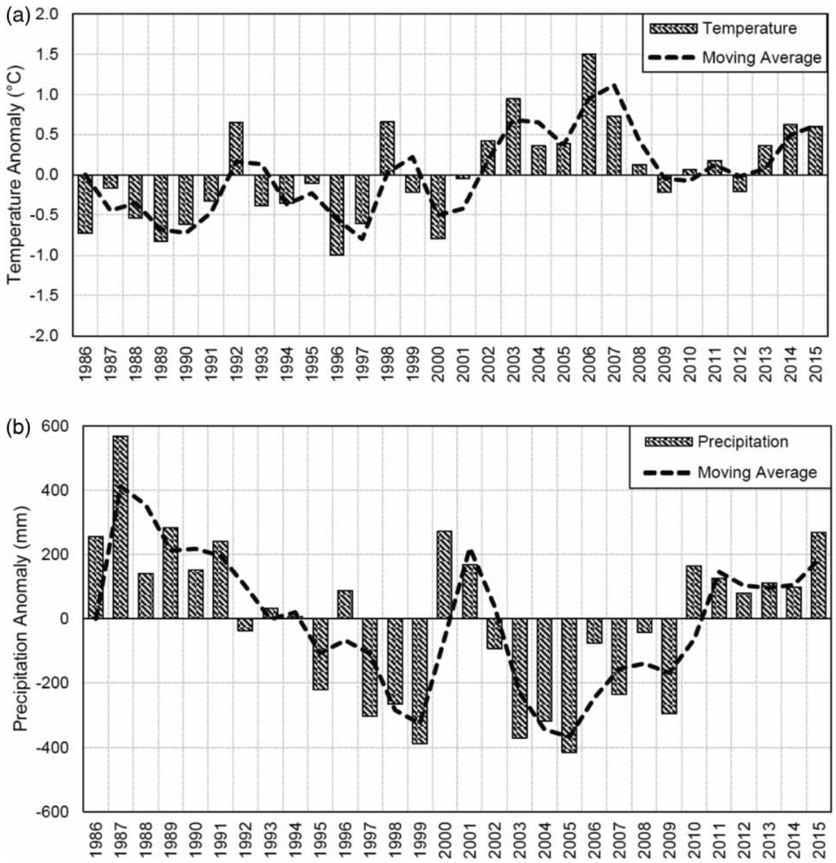


Figure 3 | (a) Temperature (with moving average) and (b) precipitation departure from 30-year inter-annual average (1986–2015). The moving average for temperature and precipitation shows increasing and decreasing variations.

month of October, which is the beginning of planting for most crops in the catchment. Only the month of January experienced an increased rainfall (Figure 4(a)). With regard to temperature, the Mann–Kendall trend test shows a statistically significant annual temperature trend (0.400; $p < 0.05$), thus accepting the alternative hypothesis and rejecting the null hypothesis. The intra-annual temperature also shows an increasing trend in most of the months with the exception of April, which showed a slight decrease. The months of June, August and September showed a statistically significant increased temperature (Figure 4(b)), confirming farmers' perception of increasing temperature in the study area.

Vulnerability of farmers to climate change

Farmers' vulnerability to the impact of climate change was measured using a 5-point scale, with 1 representing non-vulnerable and 5 extremely vulnerable. Farmers perceived various degrees of changes in climate and the effects based on their level of exposure, resilience and capacity to adapt. As illustrated in Table 3, smallholder farmers in the study area perceived that they are very vulnerable to decreased precipitation and poor distribution of rainfall during the planting season (31%). They also expressed their vulnerability to increased temperature (46%) and drought during the cropping season (37%). According to the farmers, these outlined conditions have the potential to impact crop growth, maturity and consequently could lead to yield loss and food insecurity. More than 70% of the respondents also observed that their livelihoods are under serious threat arising from increasing temperature coupled with the frequent drought occurring during the cropping season.

Adaptation strategies adopted by farmers

This study assessed smallholder farmers' adaptation response to climate change. The result from our evaluation revealed that smallholder farmers in the Olifants catchment are deploying various forms of adaptation strategies to stabilize or increase crop yield (Figure 5). Among the different strategies employed, the most common strategies adopted are the planting of improved seed (72%) and the application of chemical fertilizer (72%). Other adaptation strategies used by farmers in response

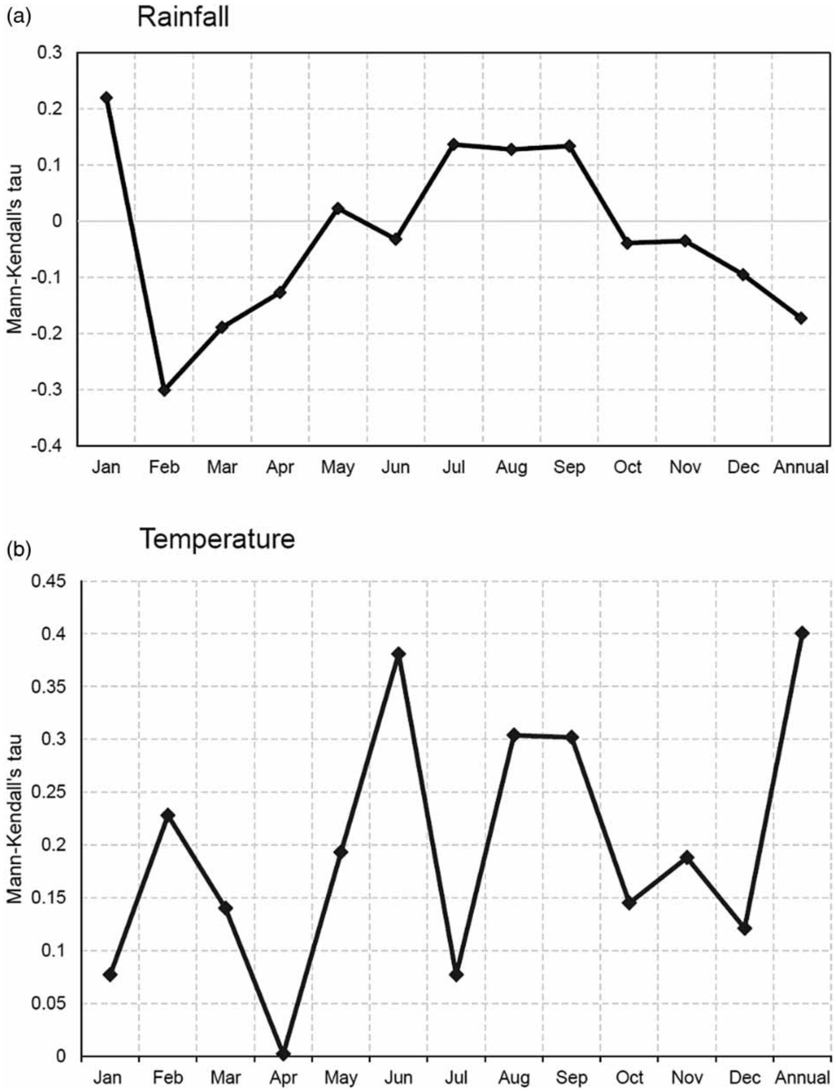


Figure 4 | Results of Man–Kendall trend test for (a) rainfall and (b) temperature for the Olifants catchment.

Table 3 | Vulnerability of smallholder farmers to climate change in the Olifants catchment

	Non-vulnerable		Somewhat vulnerable		Vulnerable		Very vulnerable		Extremely vulnerable	
Vulnerability	***n***	**%**	***n***	**%**	***n***	**%**	***n***	**%**	***n***	**%**
Decreased rainfall/poor distribution during the planting season	23	19	6	5	30	25	37	31	24	20
Increased temperature	12	10	14	12	29	24	55	46	10	8
Drought during the cropping season	25	21	4	3	36	30	44	37	11	9
Flood	55	46	39	33	23	19	2	2	1	1
Changes in the timing of rainfall	2	2	22	18	52	43	37	31	7	6

($n = 120$) by frequency and percentage. *Source*: Field Survey Data 2019.

to climate change include: changing planting date, application of pesticide/herbicides, mixed cropping, mulching, adoption of rainwater harvest, irrigation and planting of trees. Farmers expressed their preference for adopting improved seed and the application of fertilizer to boost their production during the period of reduced rainfall.

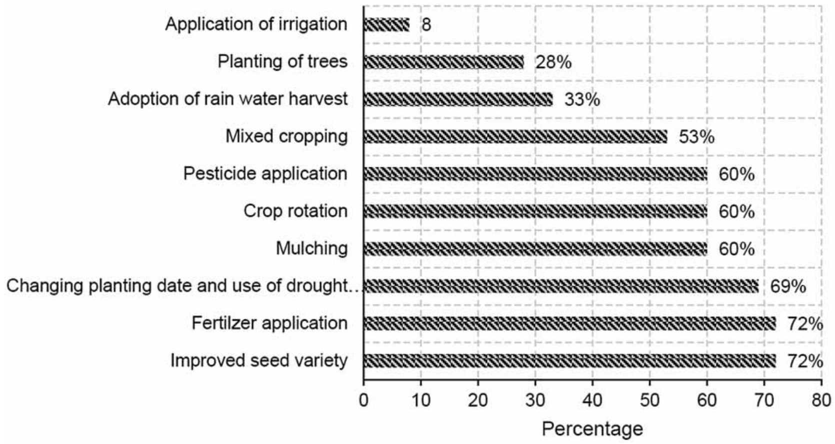


Figure 5 | Smallholder farmers' adaptation to climate change in the Olifants catchment. *Source*: Field Survey Data 2019.

Other farmers preferred the adoption of changing planting date, which is triggered by the later onset of rainfall, as farmers are forced to shift their planting date to the period when the first rainfall is observed. The application of irrigation was less exploited by smallholder farmers, as only a few respondents (8%) adopted this strategy.

Determinant of farmers' choice of adaptation

This study used the MNL regression analysis to estimate the factors influencing the choice of adaptation response to climate change. The dependent variables are choices of adaptation strategies mostly employed by household farmers in the catchment, while the independent or explanatory variables are centred on the available demographic data. In this analysis, no adaptation option was used as the reference category and the estimated coefficient compared with the reference category. Table 4 presents the independent variables that have significance at 1% significance level. Results of the analysis show that the following indicators have significantly influenced smallholder farmers' adaptation choice. Indicators, such as age and years of experience, significantly influenced the adoption of changing planting date as an adaptive strategy. Other indicators, like gender, farm location and farm size, did not influence adaptation choices deployed by farmers in the study area.

Farmer's constraints to adaptation and needs

The findings from this study revealed that smallholder farmers are vulnerable to the impacts of climate change, and this impact not only affects their livelihood but also reduces their assurance of food security, as the majority of these farmers consume and sell their produce. Climate change in terms of precipitation and temperature has significantly affected farmers' crop production, as more than 80% of farmers practised rain-fed production, with only 32% practising both irrigation and rain-fed. Information obtained through the focus group discussion indicated that the adoption of irrigation as an adaptation measure is constrained by the cost of purchasing irrigation equipment and water policy restrictions. This limitation tends to aggravate farmers' vulnerability. Farmers in the catchment have adopted other strategies to help reduce the impact of climate

Table 4 | MNL regression model showing the factors determining farmers' choice of adaptation strategies in the Olifants catchment

	Improved seed variety			Crop rotation			Changing planting dates		
Adaptation	**Coef.**	**SE**	***p***	**Coef.**	**SE**	***p***	**Coef.**	**SE**	***p***
Gender	0.450	0.619	0.467	−0.366	0.609	0.548	−0.123	0.679	0.856
Age	0.644	0.427	0.988	1.397	1.598	0.382	0.790	0.485	**0.000***
Farm location	−0.044	0.227	0.846	0.314	0.221	0.157	0.273	0.243	0.261
Years of experience	−0.656	1.427	0.987	−0.604	1.476	0.683	−2.632	0.003	**0.001***
Farm size	0.191	0.254	0.470	−0.33	0.255	0.897	−0.453	0.312	0.147

Reference category: no adaptation; number of respondents: 120.
$^*p \leq 0.01$.

change on their production. However, a few of the farmers who have perceived these changes but did not adapt pointed out some factors limiting them from responding. Figure 6 presents the factors limiting farmers from adapting to climate change. Some of the barriers include lack of market, credit facility, extension service, access to climate information, soil infertility, access to irrigation and delay in obtaining farm inputs. Farmers also stated areas of adaptation needs, which include access to more lands, access to loan to purchase irrigation equipment and farm machinery, access to water for a successful irrigation during the period of reduced or no rain. Other needs pointed out by farmers were access to extension services, timely access to farm inputs, access to market and access to information on forecasted climate change to enable them make necessary plans and adjustments.

DISCUSSION

The assessment of smallholder farmers' perception of climate change, level of vulnerability and adaptation adopted in the Olifants catchment suggests that most of the farmers were aware of the climatic changes happening in the area and were already adjusting their farm practices to cope with the impact. It is therefore evident that adaptation responses in the Olifants catchments are seen as a necessity to stabilize and increase crop yield under climatic and non-climatic stressors. The adaptive responses already perceived by farmers in the Olifants catchment are in agreement with the call for a proactive intervention, particularly in regions faced with underdevelopment, marginalization and low adaptive capacity (Nhamo *et al.* 2020).

Farmers' perception of climate change in the Olifants catchment included their observation of increased temperature extreme, decreased rainfall, poor distribution and delay in the onset of rain, and drought during cropping period, among others. These observations are in accordance with Elum *et al.*'s (2017) study. Akanbi *et al.* (2021) reported a similar trend in their study of climate change and farmers' awareness, perception and adaptation strategies in the Vaal catchment of South Africa. It is equally important to note that farmers' perception about climate change was not only informed by their observations of changes in climatic conditions, but also by the information received through media and farmers' associations. Remedial adjustments deployed by farmers in response to climate change in this study include planting improved seed varieties, application of chemical fertilizers, changing planting dates, crop rotation and mixed cropping. Contrary to the outcomes from other studies, farmers in this study do not consider the diversification of livelihood as the most appropriate adaptation choice. More than 80% of farmers opted for the use of improved seed varieties as the best adaptation approach to boost their production. Also, most farmers adopted change in planting date as a response to delay in the onset of rain and fluctuations in temperatures. In the past decades, early rainfall in the catchment usually commences at the beginning of spring month (September), which prompted the start of the planting season; however, this has now shifted to October–November due to climate change (Shoko *et al.* 2019). Similar findings were also reported in Roffe *et al.* (2020), indicating the delay in wet season start date along with a reduction in summer wet season rainfall.

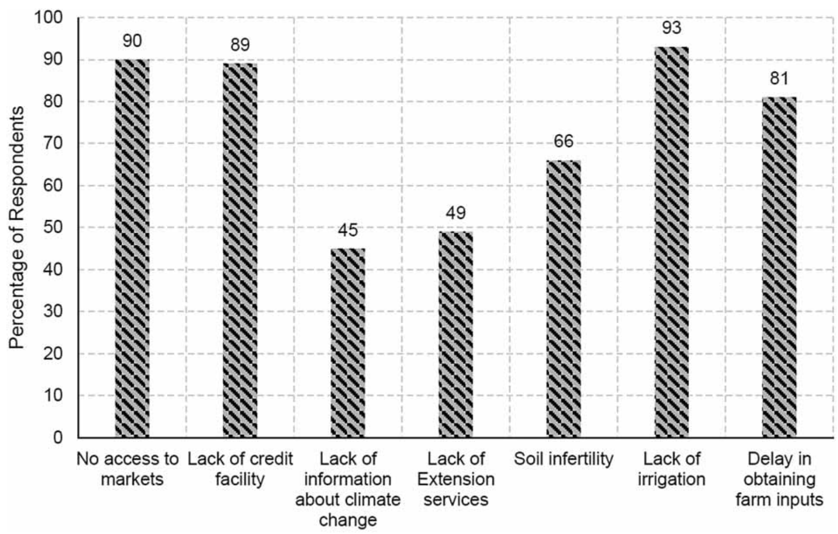


Figure 6 | Barriers to adaptation. Factors limiting smallholder farmers from responding to climate change in the study area. *Source*: Field Survey Data 2019.

The application of the Mann–Kendall trend test in this study confirms farmers' perception of climate change, as the analysis of trend supports farmers' notion of warmer temperature, decreased precipitation as well as shift in the start of rain during the planting season. The model is assumed to be the best fit for this study, as it has been used in other similar studies in South Africa to evaluate climate change trend in various agro-ecological zones (Ndlovu & Demlie 2020; Nyikadzino *et al.* 2020).

While farmers in the catchment observed the changes in climatic conditions of their area, not all of them take up remedial actions in response to these changes, due to barriers resulting from limited information about climate change and plausible adaptation options, financial constraints, lack of extension services and delayed farm inputs, among others. These barriers are, however, not unique to farmers in the Olifants catchment, as similar studies conducted by Gbetibouo (2009), Oduniyi *et al.* (2019a, 2019b) and Chikosi *et al.* (2019) in Limpopo Province, South Africa also reported similar barriers.

Patently, the extent to which smallholder farmers in the catchment can effectively respond to the impact of climate change depends to a large extent on their adaptive capacity. According to Akanbi *et al.* (2021), the adaptive capacity of smallholder farmers is considered to be low compared to the commercial farmers. The reason could be that the commercial farmers have a well-structured and planned farming system and are able to access finances to adopt new technology in response to climate change; although smallholder farmers actively participate in approaches that could reduce the impacts of climate change on their production. Some of these approaches are either influenced by their age or farming experience. The over- or underutilization of some of these approaches without prior knowledge of their environmental consequences can lead to maladaptation, thereby increasing the vulnerability of farmers. Work *et al.* (2019) in their study described maladaptation as action or inaction taken that may result in increased vulnerability of climate change, increased adverse climate-related risks or reduce current and future welfare. The possibilities of maladaptation are particularly evident among smallholder farmers in the study area. For instance, the majority of farmers in this study adopted the use of chemical fertilizers to increase soil nutrients and improve crop yield. The over-application and persistent use of chemical fertilizer can result in the pollution of groundwater sources and leaching. Leaching is not only hazardous to groundwater source but also to the health of subsoil, where these chemicals react with clay to create hard layers of soil known as hardpan. Therefore, the over-application of chemical fertilizer jeopardizes the health of water and soil (Fadina & Barjolle 2018). Following the increasing risk of crop losses resulting from climate change, more sustainable practices, such as the use of organic manure, planting of nitrogen-fixing crops and the cultivation of cover crops, can help in improving soil nutrients and consequently reduce maladaptation. Other adaptation measures employed by farmers were changing planting dates in response to the delay in the onsets of rain. Farmers reported that they will only plant when they experience the first onset of rain. However, this approach could reduce the amount of yield loss, but crop such as maize is greatly affected by temperature. According to Mangani *et al.* (2019), temperature above 30 °C negatively affects the yield of maize crop, while temperature below 10 °C halts all development activities. Delaying planting date means planting during periods when temperatures are high. With the projected increase in future temperatures for the catchment, this could result in further increasing the vulnerability of crops if the adaptive measure is not supplemented with other measures such as the use of appropriate crop varieties with shorter growing period as well as the use of drought-resistant varieties.

CONCLUSION

The findings from this study show that the Olifants catchment is certain to experience a long-term change in climatic condition, as temperature increases with decreasing precipitation. Results from our assessment show that smallholder farmers are generally aware of the changes happening in the area. Although the majority of the farmers could not give a clear explanation of what climate change is all about, their description of climate change was based on their observation of increased temperature extreme, decreased rainfall duration and intensity and shift in the timing of rainfall. Their perception of climate change was in accordance with the analysed observed temperature and rainfall data. Most farmers who have perceived these changes are adjusting their farming practice to cope with the impact. However, only a few farmers who were aware of these changes and their impact did not adapt, due to poor access to credit facilities, shortfall in extension services, lack of climate information, market and farm inputs. It is therefore imperative for government to provide smallholder farmers with flexible and affordable credit facilities in order to embark on a more efficient adaptation response to climate change. Enhancing smallholder farmers' awareness of the potential benefit associated with climate change adaptation is essential for policy intervention measures.

In line with the findings of this study, there is a need for the adoption of adaptation technologies capable of reducing the adverse impact of climate change on both agriculture and livelihoods of smallholder farmers. Policy must also promote on-farm level adaptation through effective participation of farmers in the development and implementation of relevant and appropriate adaption measures. In addition, any intervention that promotes the implementation of adaptation response to climate change should consider specific factors relevant to the nature of practices. Since adaptation practice is resource-intensive, it may not be easily implemented by smallholder farmers given their financial constraints. To scale up the adaptive capacity of these farmers, there is a need for an integrated and smooth coordination of various sectors such as public organization, private and non-governmental organizations in providing necessary assistance to smallholder farmers.

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DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

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