Original Research Article

Smallholder farmers' perception of agrometeorological application at municipality level: South Africa

Abstract

High dependence on rain-fed agriculture impose smallholder farmers to a plethora of climate risks which are detrimental to agroecosystems and socio-economic status. Assessment of the impact of climate variability and change at farm level is key to developing suitable agro-advisories toward mitigating climate risks. Smallholder farmers in the semi-arid areas of South Africa are most vulnerable to heightened sensitivity to extreme weather events and inadequate exposure to adaptive capacity. The increasing pressures brought in by weather events, soil degradation, loss of biodiversity, increasing population is threatening food security and sustainable livelihoods. The study conducted a reconnaissance review with smallholder farmers from selected local municipalities in KwaZulu-Natal and Free State provinces. The purpose for this analysis was to determine local climate related challenges, gaps, shocks and barriers. The survey further, identified agricultural practices, climate risks, access to climate related advisories, access to other scientific knowledge and factors hindering sustainability, stability, and profitability. We further discussed the importance of drought in situ monitoring since drought was identified as the measure limiting factor to agricultural productivity. This review challenges the existing dissemination on scientific knowledge and the accessibility of agrometeorological application to smallholder farmers. Further research seek to overcome the constraints limiting the adoption of climate smart agriculture, agrometeorological application, and minimise climatic risks and improve smallholder agricultural production.

Keywords: Smallholder farmers, climate variability and change, weather events, agroecosystems.

1. Introduction

The southern Africa is highly vulnerable to climate change, predominantly erratic rainfall, rising temperature, the intensifying occurrence of weather events, the related stressors such as floods, droughts, heat waves, wildfires, severe frost, pest invasion, disease outbreak and crop failure (Mabhaudhi, et al., 2019; Mawejje, 2016, UNGA, 2015). The high level of susceptibility is due to the dependency on climate sensitive agricultural economy, low climate smart adaptive capabilities, and the projected temperature increase of 1.5°C which will increase climate-related risks (IPCC, 2018; 2019; Niang et al., 2014). In the Sub-Saharan Africa and other African regions, agrarian practices a priority, in pursuit of strengthening food system, production of affordable food for household consumption toward food security. Over Africa, 60% active labour force are involved and employed within the agricultural sector, and 80% are smallholder agricultural producers for sustained livelihood (Balgay, et al., 2023). According to Food and Agricultural Organisation (FAO, 2012), the pronouncement indicate that in the Sub-Saharan Africa, about 80% of agrarian practices are conducted and managed by smallholder farmers.

Climate variability and change remains a worldwide limitation facing the agricultural sector, humans, livelihoods, and food security (Shirley, 2021; Mpandeli, et al., 2019; UNGA, 2015). Inconsistency in climate patterns pose a vast threat to developed and undeveloped countries, smallholder and commercial farmers as adaptive capacity is inadequate (Carelsen et al., 2021; Hendriks, 2014; Archer, et al.,2007). Therefore, addressing the impact of climate variability and change contribute to the adoption of adaptive strategies and improving agroecosystems and food security (Nyang'au, et al., 2021; FAO, 2022). The high reliance on rain-fed farming and lack of scientific knowledge adoption by smallholder farmers' favour improved vulnerability occurrence to the effects of climate change. This further aggravate the levels of crop failure, poor pastures, below normal livestock conditions, and elevated levels of poverty (Awuni, et al., 2023; Mpandeli, et al., 2015; Hardelin and Lankoski, 2015). Smallholder farmers across Africa has been credibly threatened by the effects of climate change. In South Africa, climate variation threatened food security, livelihoods and socio-economic developments, and affect the agricultural contribution to the gross domestic product. The agricultural sector contributed and expanded to 14.9% in 2020, 8.8% in 2021 and a massive upswing of 11.3% from 19.2% to 30.5% in 2022 to the country's gross domestic product (Stats SA, 2022).

Ecosystems contribute to human well-being through the direct and indirect utilisation of natural resources for optimal agricultural productivity . Preservation of human well-being necessitates sustainable and substantial food production through provisioning of optimal environmental conditions for improved food security (Rusere, et al 2023). The climatic irregularities have negatively impacted the agro-ecosystems and agricultural productivity as a resultant food risk production and sustainability to resource poor farmers (Okolie, et al., 2023; Dube et al., 2016). Redressing these negative impacts satisfactorily, the enhancement of climate smart strategies for agricultural production require thorough awareness creation for smallholder farmers to build resilience to climatic variation (Ali et al., 2017). Climate change adaptation approaches are a key toward the lessening the impact of crop failure, fruit production loss and poor livestock reproductiveness. The potential vulnerability of smallholder farmers is dependent on the resources availability, the level of adaptive knowledge applications, and adopted techniques to minimise the climate risks (Ncoyini, et al., 2022; Vogel et al., 2019).

Climate change is a widespread challenge that threatens the agroecosystems, agroforestry, the society, their livelihoods, and a vast number of nations (Burgess et al., 2022, Ghosh-Jerath et al., 2021). Agroecosystem is a cultivated ecosystem for human and environmental benefits, are the ecosystems supporting the food production systems at a given cultivated farm extent. It generally corresponding to the spatial unit of a farm and whose ecosystem functions are valued by humans in the form of agricultural produce and services (Hawton, 2000; Conway, 1987). In view of the changing climate, climate services are pivotal in assisting the agrarian sector for tactical and operational decision making (Okolie, et al., 2023; Dube et al., 2016). Furthermore, provision of localised early warning systems, deducing weather extreme events, and developing vigorous adaptation and mitigation strategies. In adapting to the climatic changes, farmers require to adopt the use of weather forecasting, seasonal predictions and implement as per recommendations on local agricultural advisories as a coping strategy. In order to understand climate risks at farm level, situational analysis and context-specific characteristic must be surveyed and contextualised (Bhattacharjee and Behera, 2018). Analysis may determine local requirements, gaps, barriers which hinder optimal agricultural productivity and sustained livelihoods. A livelihood comprises the access to natural resources, agricultural skills, decision support systems and activities required for an income generation. Sustainable livelihoods is able to cope with and recover from climate related stressors and shocks and enhance it capabilities, assets for now and in the future, while applying natural resource management (Vogel et al., 2019; Shar and Rivera, 2007).

The purpose of this investigation hopes to identify the needs of the farmers by using smallholder level data to examine vulnerability to changing climate, and agricultural practices. Lack of access to weather and climate knowledge is number one barrier to improved decision making toward high agricultural production. Thus, adoption of a precautionary approach at smallholder farmer level, may result to informed decision. The reason being that, farmer requirements differ based on agricultural practices and the environmental conditions, in terms of appropriate policies to adapt since vulnerability to changing climate are region specific. For illustration, central Free State Lejweleputswa district communities in semi-arid areas may be more susceptible to veld fires, droughts, cold spells and dust storms, while communities in KwaZulu-Natal Umzinyathi districts may be disposed to floods. Consequently, the study seeks to identify agricultural practices, climate risks, access to climate related advisories and factors hindering sustainability, stability, and profitability. The study further hopes to develop recommend for adequate policies for different regions, since the level of vulnerability vary from each other. This study seeks to equally contribute to the growing pools of knowledge about application of weather and climate knowledge for informed decision making. Moreover, this research equally provides an important knowledge to agricultural practitioners who desire an empirical scientific article regarding climate risk and agrometeorological applications. Despite the principal role smallholder farmers in in both regions play in the agricultural production cycle, their perceptions on climate variability and change knowledge is limited. To seal existing gaps, this study aims at satisfactorily explore farmers' perceptions of climate variability and change; and adaptation measures adopted to enhance their resilience towards weather extremes and climate change.

2. Materials and Methodology

2.1 Description of Study Area

The study was conducted in the Free State and KwaZulu-Natal provinces of South Africa at selected municipal districts, which is Lejweleputswa and UMzinyathi municipal districts, respectively. Data collection was sampled amongst the smallholder farmers with the assistance of Agricultural Advisors. Lejweleputswa District Municipality is one of the five districts of the Free State province. It is located in the north-western part of the Free State Province and is approximately 32,287 square kilometres in area. Lejweleputswa borders Northwest Province to the north-west and North Cape Province to the west. Lejweleputswa consists of five local communities such as Masilonyana, Tokologo, Tswelopele, Mathjabeng and Nala (Figure 1).

With an annual population growth rate of 1.5% per year, the district has a population of 634,462 in 2019. That is 22% of the total population of the Free State Province (LDM, 2017-2022). The district municipality receives an annual rainfall ranging from 400 to 560 mm and average temperature of 20°C. Agriculture in the district is largely rain-fed, with less than 10% of arable land being irrigated. The most suitable produced crop are maize wheat, barley, sunflowers, potatoes, and vegetables.

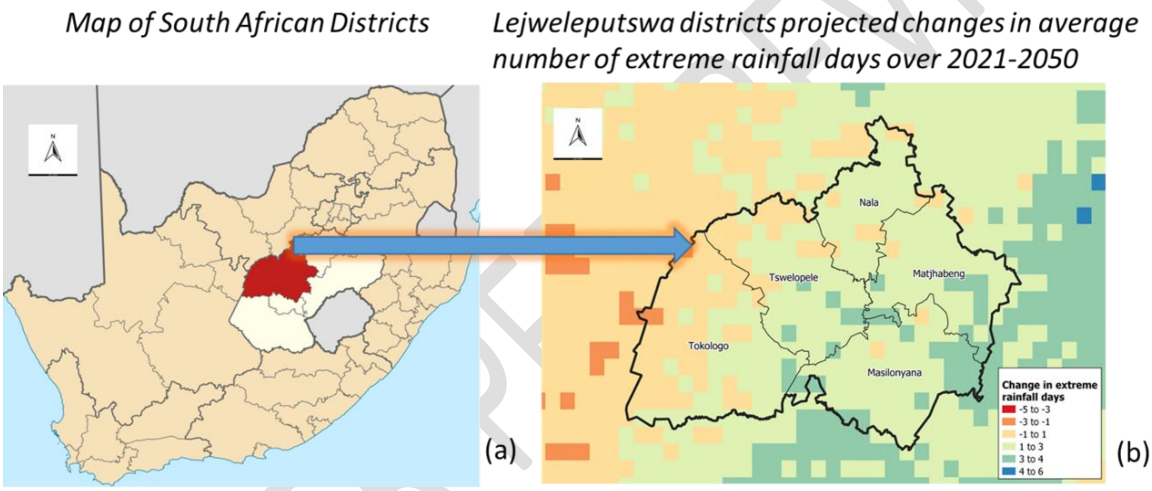

Figure 1*: A map showing the South African districts, Lejweleputswa district, its local municipalities indicating change in extreme rainfall days (CSIR, 2019).*

The Umzinyathi district municipality is located in the central north of KwaZulu-Natal province, with an estimated population of 510 337, and area size of 8,589 km^2 (Brigid *et al*., 2013). The district consists of four local municipalities, namely, Msinga, Umvoti, Nquthu and Endumeni, however, the study sampled participants from Umvoti and Msinga local municipalities (Figure 2). Umzinyathi district experiences very cold winters and mild summers with an average annual temperature ranging from of 15-20°C, which is generally suitable for agricultural production (Umzinyathi Municipality, 2016). Average annual rainfall ranges from 600 mm to 1200 mm, indicating potential for rain-fed agriculture.

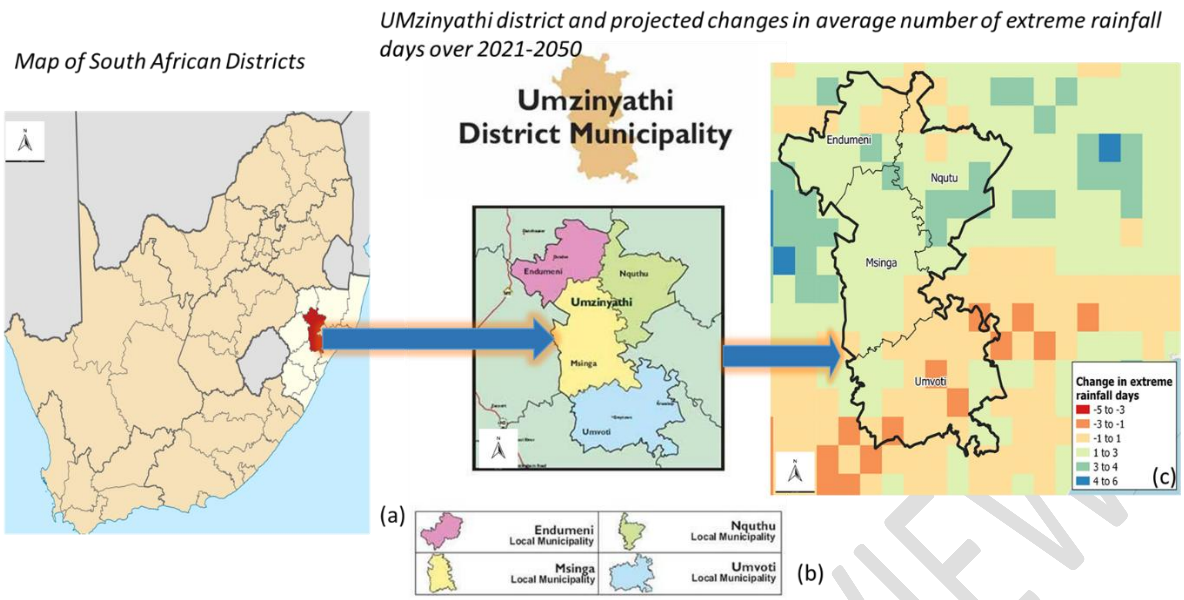

Figure 2: *: A map showing the South African districts, UMzinyathi district, its local municipalities indicating change in extreme rainfall days (CSIR, 2019).*

2.2. Sampling Methods and Data Collection

A sampling procedure to select smallholder farmers was guided by the inclusion of district agricultural advisors as the gatekeepers for agricultural community. Qualitative data was collected by the adoption of closed ended and open-ended questions in a form of a structured questionnaire. Seven focused group discussions were held in all selected local municipalities. These discussions comprised of district agricultural advisors, smallholder farmers and the researchers. Amongst the groups there was a fair amount of women and youth representation. To ascertain the status of the agricultural status, use of earth observation and agrometeorological products, key informants interviews were also conducted. The key informants interviewed were agricultural practitioners from the Free State Department of Agriculture and Rural Development, Officials from the municipality, and agro-dealers. A number of 129 smallholder farmers participated in this investigatory study respectively from all selected areas, between July and August in 2022.

2.3 Data analysis

Descriptive statistical analysis was conducted by the utilization of Microsoft Excel which was further supplemented by the use of SPSS software to test the reliability of the information gathered from the questionnaires. Application of these statistical tools was endorsed to determine the socio-economic characteristics, farmer's perceptions on agricultural production status, agrometeorological applications, the level of support from agricultural practitioners and factors hindering sustainability and profitability.

2.4 Ethical Considerations

The approval to conduct research and collect data from the respondents at selected places was obtained from Human Sciences Research Council, Developmental capable Ethical State, South Africa. Ethics clearance was issued by Research Ethics Committee Protocol No REC 2/22/06/22, on the project titled: Earth Observation and Disruptive Economics: Developing Smart Tools for Value Enhancement for Small Scale Food Production. The permission to conduct this research was granted prior data collection and engagement with the respondents.

3. Results and Discussions

3.1 Demographics and Socio-economic characteristics

In seven local municipality, a total number of 129 smallholder farmers selected with the guidance of the district agricultural advisors, this is a category of farmers who are capable to produce for household consumption and markets, and generation an income and subsequently generating revenue continuously from their agribusinesses, which form a source of income for the family. These farmers have the prospective competency to expand agricultural operations to become commercial farmers, with the provision of comprehensive support ranging from, required technical skills, scientific knowledge, financial, and agribusiness managerial skills.

Out of 129 smallholder farmers sampled, 41, 57% were female while 58, 43% were male. The age ranged from 20 to 77 and both with an average of 50.16 years. A significant difference between female and male was recognized at 5% significant level (p=0.01). The male respondents were higher than the female. Whilst, per municipality it was observed that males respondents outweighed over females among most farmers in Masilonyana by 91%, Tokologo by 89%, and Matjhabeng by 73% municipalities, with female smallholder farmers being more prevalent than male farmers in Tswelopele by 77% , Msinga by 55%, and Mvoti by 55%. Nala Municipality obtained equal number of smallholder farmers in terms of gender. The observed significant difference was attributed to smallholder farmers in selected areas dominated by livestock farmers who are mainly leading within this category. The high male dominance was attributed by males who retired from local mining works, commercial farmers and engaged into agribusiness activities. The farmer's educational status differed from all municipalities, for instance, in Masilonyana, Tokologo and Mvoti municipalities have educational status above grade 12, while in Nala, Matjhabeng and Msinga most farmers had grades 8-12. In Tswelopele municipality, most farmers had grades 4-7 education, in other municipalities there were 25% fewer farmers with grades 4-7 education. In sampled municipalities, 95% respondents were fulltime farmers and about 5% have agribusiness while earning income from other means. The analysis indicate, the marital status of respondents 57, 14% of the respondents were married, 21% unmarried, 6.14% divorced, 12,43% widow and 3,29% unspecified (Figure 3). This indicates a stable marriage situation and well-structured family units in the selected areas. Decision making on land use and agricultural enterprise selection were not gender biased, female respondents' demonstrated independency in decision making and involvement in different value chain stages.

The average family size of the respondents comprised of five members, with most households ranging from five and seven members. The respondents in Mvoti, Msinga, Tswelopele, Nala, and Masilonyana had the farm size ranging from 1-100 hectares, while in Tokologo, Nala, Matjhabeng, and Mvoti the farm size owned by the respondents were about 400 hectares. Most respondents in Masilonyana, Matjhabeng, Tokologo and Msinga had a farm sizes ranging from 100-200 hectares. The average farming experience was 21, 87 years, since some respondents indicated to have been involved in agricultural activities at a young age. The more years of experience in agricultural practice has a high influence on continuous engagement in agribusiness. The more widespread farming interest and experience makes farmers participate intensively in adaptation measures to enhance resilience in the changing climate (Nyang'au, et al., 2021; Alhassan, et al., 2019).

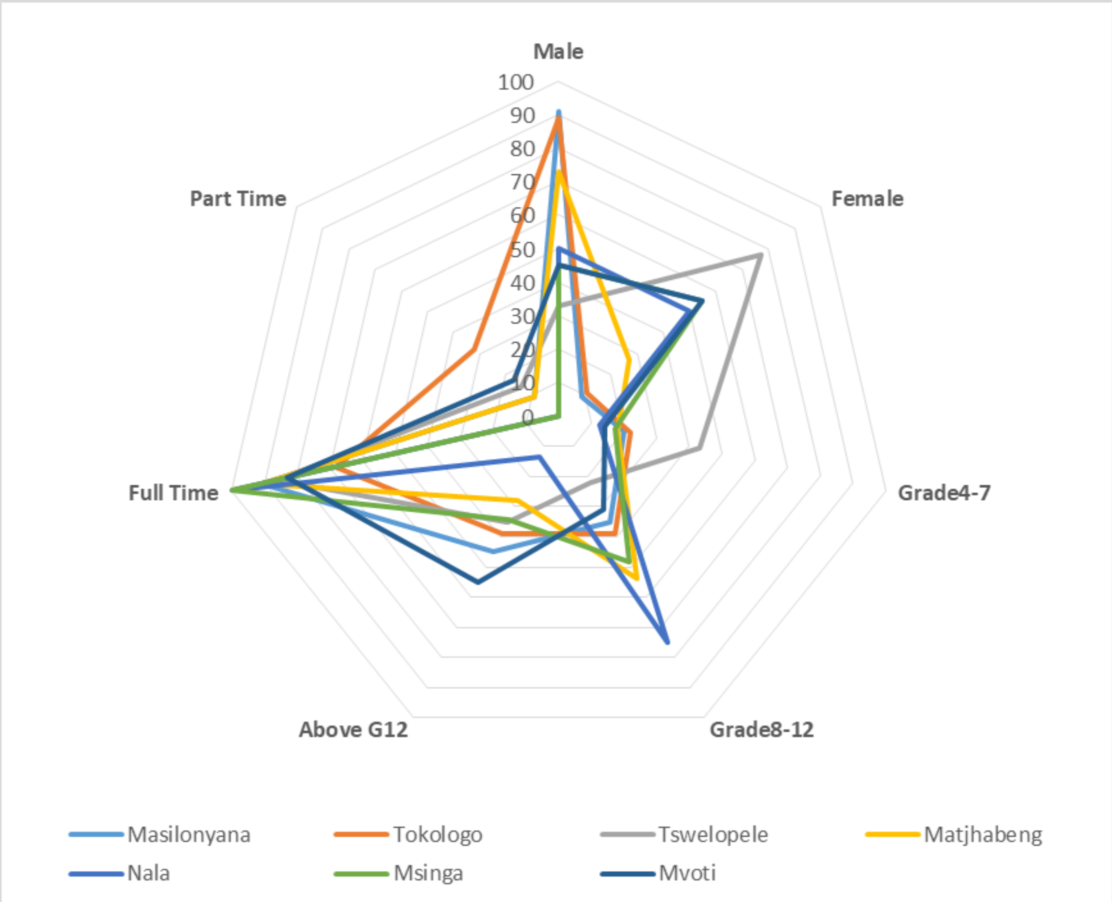

Figure 3. Demographic characteristics of smallholder farmers in selected municipalities

3.2 Farmers perceptions on climate variability and change

Smallholder farmers remain vulnerable to extreme weather events, especially flooding, drought, heatwaves, hailstorms, and severe cold conditions. Smallholder farmers are diverse in their farming needs and challenges encountered and widely differ according socio-economics standards. A high level of education id assumed to have a significant impact and influence to the adoption of agrometeorological application to minimise climate related risks. Knowledge equipped farmers possess the capability include climate and agricultural smart practices to maximise perceived and realised resilience against climate variability and change at a given agroecosystem (Carelsen, et al., 2021). Amongst the respondents, 55% practiced mixed farming, toward ensuring biodiversity and food security, 27% were solely involved in livestock production, and 18% were sole crop producers (Figure 4).

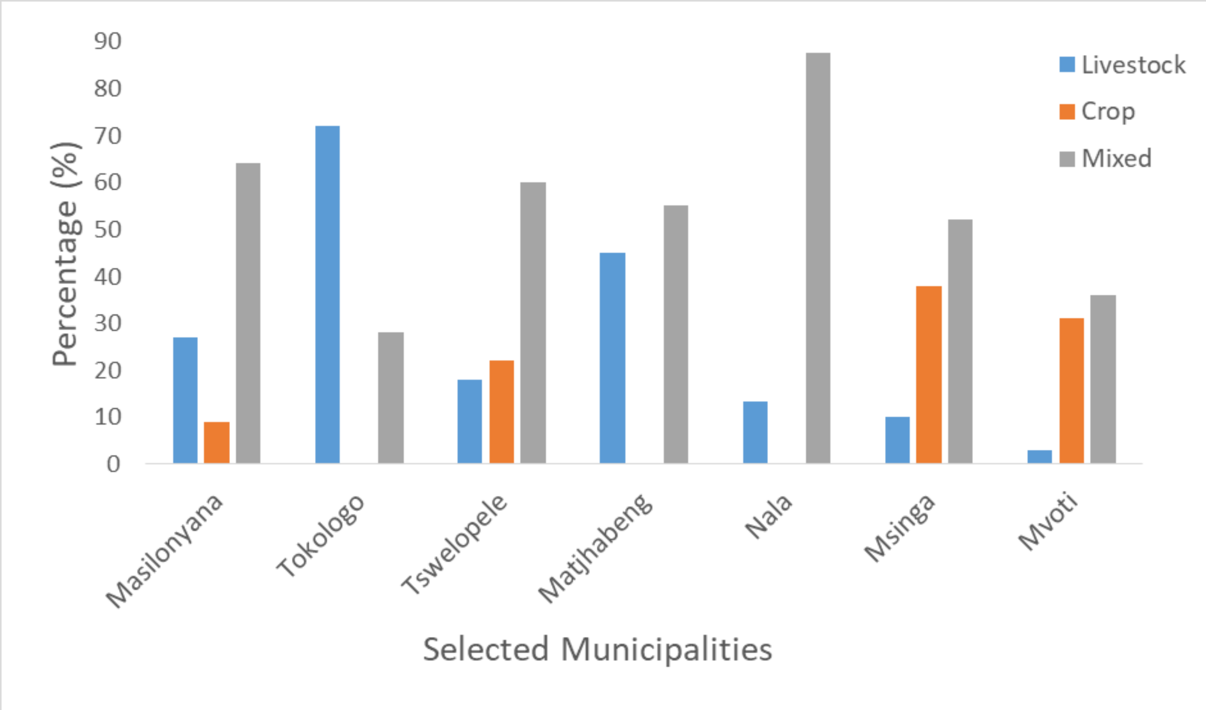

Figure 4. Farmers' agricultural enterprises in selected municipalities

According to focus group discussions, it was determined, that substantial proportion of the respondents with higher level of education were most likely to adopt weather forecasting, climate prediction, climate smart agriculture and integrated pest and disease management practices and make informed decisions. Furthermore, relatively farmers with higher education level incorporated technologies and scientific knowledge toward enhancement of climate change adaptation. For example, some smallholder farmers have weather-climate-agricultural related cell phone application used to guide on operational and tactical decision making. Out of sampled respondents, 64,75% adopted and practised climate smart agriculture technologies such as, intercropping, mulching, mixed farming and crop rotation, while 35,25% of them did not specify any incorporation of technologies. Adoption of agrometeorological applications, enables smallholder farmers to have access to weather forecast, seasonal prediction, innovations, crop suitability, crop types, crop cultivars and varieties and other climate change adaptation strategies (Obi and Maya, 2021; FAO, 2010). However, the smallholder farmer's perceptions on the accuracy and reliability of weather forecast and seasonal prediction differed from farmer to farmer and municipalities. Out of sampled municipalities, Masilonyana, Matjhabeng and Msinga professed a high level of accuracy and reliability, with 71, 42%, 80% and 62,5%, respectively. Amongst the selected respondents, 73,57%

farmers use the application of indigenous knowledge indicators and systems for informed decision making. As hypothesised that farmers with high level of education had better understanding and interpretation of weather forecasts and seasonal predictions for the implementation of agricultural activities.

The suitable climate smart agriculture practice to adopt and improve resilience to the changing climate, should be according to the improving crops water use efficiency. Thus require leaf area optimization, improvement of the roots dynamics, leaf area index, and soil water conservation (Mbava, et al., 2020). Smallholder farmers used timelines and indicated the occurrence of weather conditions and identified indicators of climate variability and change within their local municipalities and area of practice. The respondents perceived a late onset of rains over time with 89%, poor rainfall distribution with 65%, a decreased rainfall amount with 79, 8% and 58% noting late rainfall cessation (Figure 5). The results further indicate most smallholder farmers perceived shorter rainfall season occurrence than the normal with 88,2% and perceived rainfall seasonal shift with 93,4%. A significant number of smallholder farmers indicate a great concern on very poor rainfall distribution, with 31,5% noting normal rainfall occurrence and 2% citing insignificant change within seasonal rainfall distribution. The changes in rainfall onset and cessation resulted in delayed planting dates, prolonged dry spells, poor crop production and the seasonal planting was observed to be shorter than normal conditions (Figure 5).

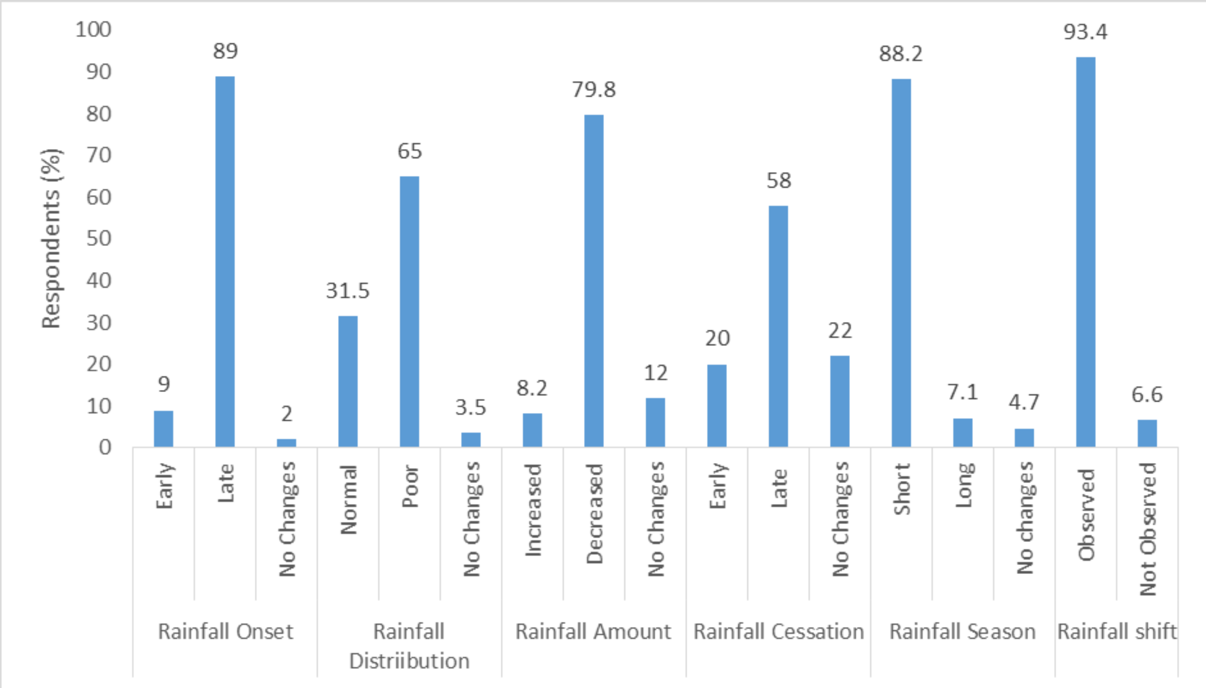

Figure 5. Smallholder farmers' perception of rainfall changes in selected municipalities

Smallholder farmers are highly disposed to potential consequences of adverse weather conditions, like severe cold, drought, flooding, are liable to adopt adaptive effects. Amongst these weather events, severe cold effects are a result to crop frost burns, while drought result to water scarcity. Historical rainfall trends from agrometeorological weather station revealed, decadal climate variability. The rainfall analysis revealed that there was declining trends in the total annual rainfall for the last 30 years. The average annual decrease was recognised with the rainfall covariance of variation of 13,88% (Figure 6). The covariance of variation signifies moderate rainfall variation within the period for a particular location. Thus confirms the observation by farmers who reported a decline in rainfall over selected municipalities. These findings are consistent with studies conducted across South Africa (Sian, et al., 2021; Fauchereau, et al., 2003). Additionally, smallholder farmer observations are consistent with historical climate data analysis, indicating changes in climate and decrease in rainfall.

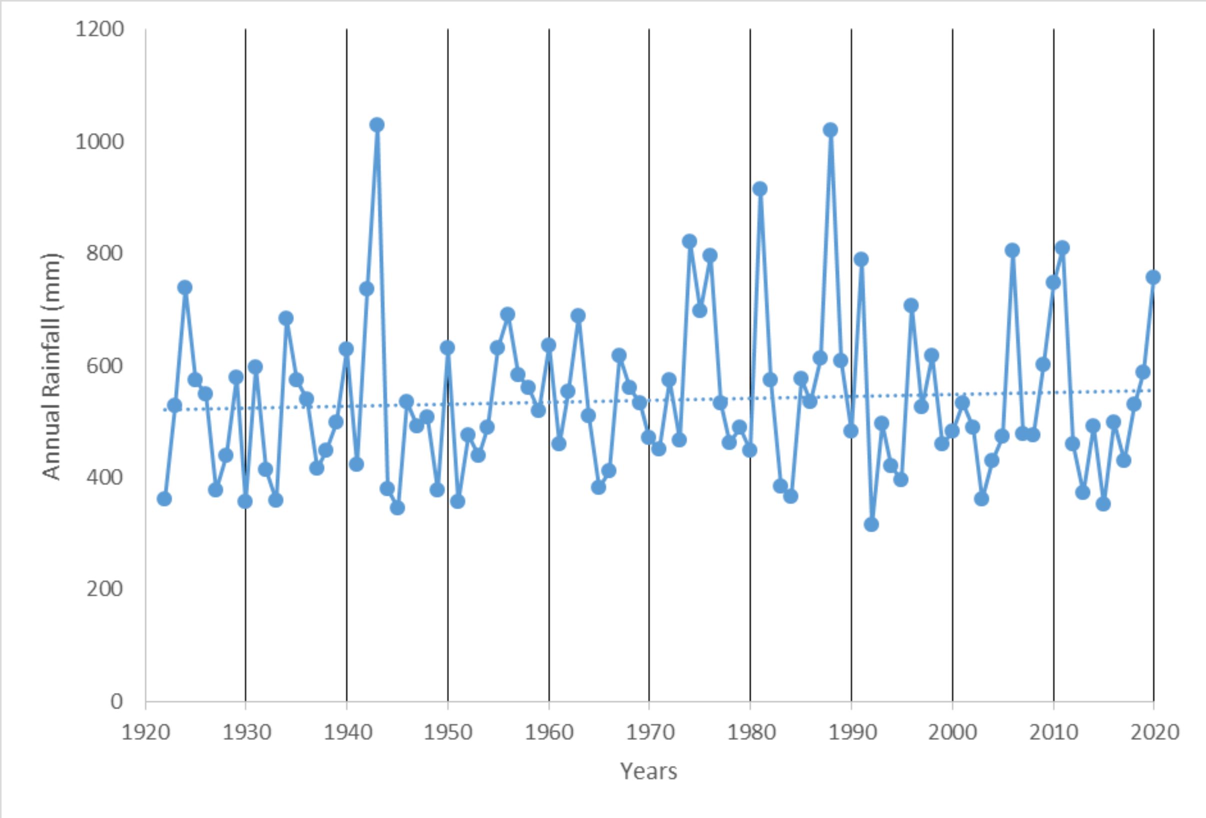

Figure 6. Trend of the total annual rainfall in Glen College of Agriculture: 1922-2020

The temperature was observed to have increased over the summer season and decreased during the winter season over years. The summer seasons are perceived to be warmers by 86%, the winter season have become colder by 14%. The occurrence of increased temperatures resulted to heatwaves, high rate of evapotranspiration and the drying of crops leading to crop failure. The temperature data indicated a gradual decadal increase in the minimum and maximum average temperature. These findings conclude the results that regardless of the recorded increase, a noticeable variation in maximum and minimum temperatures over a period of decades and years.

The occurrence of extreme weather events at farm level, smallholder farmers witnessed an increase number of seasons with continuous decrease in crop productivity leading to crop failure. The agribusiness has been perceived by many farmers as a risky business, for the following reasons, poor agroecosystems, high cost of inputs, changes in livelihoods, increase pest-disease outbreaks and poor crop quality. These occurrences are resultant to food insecurity and poverty in its all aspects.

Out of the sampled smallholder farmers, it was indicated that agricultural advisors visits has a positive effect on the performance of farmers, since required knowledge was furnished to make fundamental decisions. Respondents indicated that field visitation by agricultural advisors during the growing season on daily bases with 52, 29%, 5.3% once a season and 42,14% advisors. Key informants interviews, indicated that smallholder farmers are well-informed on climate variability, change and the use of indigenous knowledge for agrarian decision making. Smallholder farmers are aware of agrometeorological application and have adopted a number of climate smart agriculture, such as, preservation of agroecosystems, water conservation practices, agroforestry and mulching. Respondents who has high access to agricultural advisors and other expertise had better crop production and implemented intervention measures toward climate change resilience.

3.3 Factors hindering agricultural profitability

Smallholder farmers are vulnerable to the impacts of weather extremes, climate variability and change because of lack of capacity to establish suitable coping strategies to obtain a viable living. As the changing climate effects in irregular rainfall patterns, smallholder farmers continue to face threats and shocks to food security and sustainable livelihoods. Climate data analysis indicates that over the last three decades, climate change has intensified the recurrence of meteorological and agricultural droughts. Out of sampled smallholder farmers, factors hindering profitability mentioned were as follows, water scarcity, lack of land, lack of scientific agricultural knowledge, lack of mechanisation and resources, and access to finance (Figure 7). Among sampled smallholder famers, 43,57% mentioned the issue of water scarcity which is the main limitation to productive agriculture. Since most smallholder farmers operate under rain-fed agriculture and has to cope with erratic rainfall, high evaporative demand, poor soil nutrient status, marginal soils and recurrent droughts with subsequent production failures. To improve agricultural productivity and crop yields farmers require skills to minimize risks imposed by environmental variables.

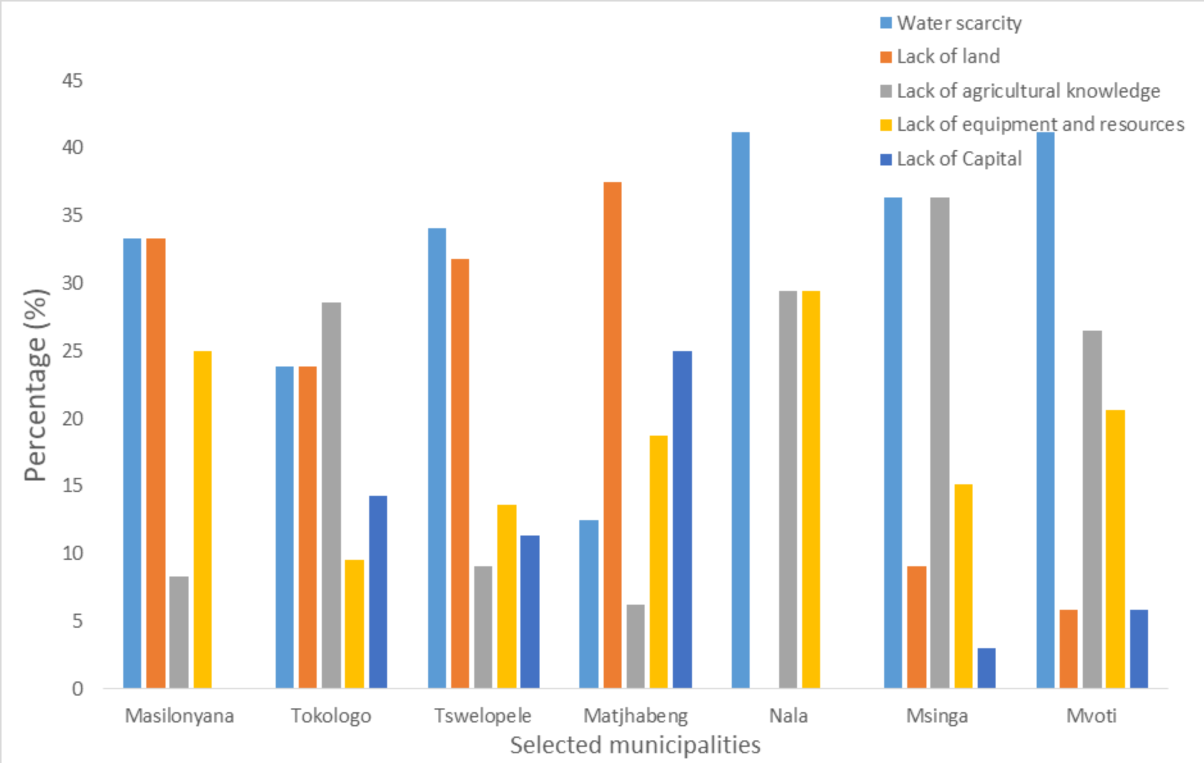

Figure 7. Some limitations to agricultural profitability experienced by smallholder farmers

Drought occurrence was listed as a major limitation in all municipalities, as it results to soil water deficiency and eventually to crop failure. Thus, drought monitoring through long-term rainfall data analysis and its indicators assist decision makers by understanding it onset, development, duration and cessation. The impact of prolonged dry spells has devastating effects to agricultural productivity. When smallholder farmer were provided with small scale drought monitoring systems, these were centered around localized environmental variables, which are minimum and maximum temperature, rainfall water capacity on reservoirs. The variables were used in the form of irregularities from climatological average conditions to determine drought and its type (Figure 8). Another measure of drought in situ measurement was to observe water stress signs on crops. Local surface observations provide information about drought effects on the vegetation, since the actual soil water content available at plant root level is responsible for crop growth. Droughts are driven by lack of rainfall and a high atmospheric evaporative demand. Drought can be classified into four categories, which are meteorological, agricultural, hydrological and socio-economic drought. These categories are defined depending on the duration, development and intensity.

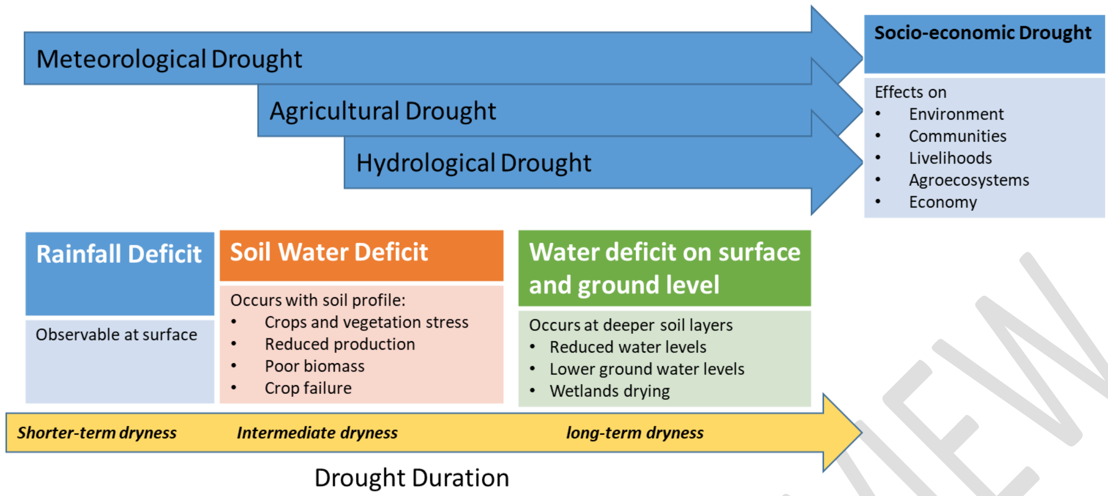

Figure 8. Drought types with its major triggers and impacts (Crocetti, et al., 2020)

Conclusions

The overall objective of this study has been to assess the views, knowledge and challenges with regard to weather extreme impacts, climate variability and change effects to agriculture and various adaptation strategies for improved agricultural production. The level of climate variability and change awareness was high and smallholder farmers indicated the effect of the changing climate on agriculture, erratic rainfall, drought occurrence, poor crop production, increased water scarcity and increased pests and diseases outbreaks. Smallholder farmers in these selected municipalities adopted different adaptation strategies to mitigate the negative effect of extreme weather conditions, such as climate smart agriculture and the use of weather forecasting and climate predictions. However, smallholder farmers need structured trainings, awareness creation, through research and advisory services. Drought occurrence was listed as the main limiting factor to agricultural performance.

Drought events in the semi-arid areas of South Africa have guided knowledge generators to actively engage with smallholder farmers in minimizing climatic risks and educate famers on suitable intervention measures. There is an urgent need to provide advanced monitoring of drought and its impacts on agriculture by agricultural researchers and advisors. Provision of agrometeorological applications and advisories, such as weather forecasting, climate prediction, and agricultural scenarios, earth observation maps, soil water content conditions, is needed for agricultural advisory for informed decision making. Forecast of weather extreme impacts on agricultural productivity products require proper interpretation to the level of its users.

This investigation contributes to conversation about the dissemination of knowledge to the rightful owner toward improves livelihoods, vibrant agribusiness, climate-smart agriculture, agrometeorological applications and food security. The data was limited to the selected municipalities, thus tailored advisories has to be developed restricted to these municipalities and extensive data has to be obtainable to address relevant climate related matters per location.

.

REFERENCES

Alhassan, H., Kawka, PA., and Adzwala, W. 2019. Farmer's choice of adaptation strategies to climate change and variability in arid region of Ghana. *Review of Agricultural and Applied Economics*. 22 (1) pp. 32-40.

Ali, SA., Liu, Y., Ishaq, M., Shah, T., Ilyas, A., and Din, IU. 2017. Climate change and its impact on the yield of major food crops: Evidence from Pakistan. Foods. 6 (6) pp. 39. https://doi.org/10.3390/foods6060039

Archer, E., Mukhala, E., Walker, S., Dilley, K., and Masamvu, K. 2007. Sustaining agricultural production and food security in Southern Africa: an improved role for climate prediction? *Climate Change*. 83 (3) pp. 287-300.

Balgah, RA., Benjamin, EO., Kemingsi, JN., and Buchenriender, G. 2023. COVID-19 impact on agriculture and food security in Africa. A systematic review and meta-analysis. *World Development Perspectives*. 31 pp. 100523. https://doi.org/10.1016/j.wdp.2023.100523

Brigid, L., Mangqalaza, H., Ngwenya, M., Bodenstein, B., Ramoroka, K., Har, T. and Jacobs, P. 2013. Mapping Innovation for Rural Development in Umzinyathi District Municipality. South Africa: Human Science Research Council.

Burges, AJ., Cano, MEC., and Parkes, B. 2022. The deployment of intercropping and agroforestry as adaptation to climate change. *Crop and Environment*. 1 (2) pp. 145-160. https://doi.org/10.1016/j.crope.2022.05.001

Carelsen, CPR., Ncube, B., and Fanadzo, M. 2021. Classification and characterization of smallholder farmers in South Africa: a brief review. *South African Journal of Agricultural Extension*. 49(2): 97-106.

Conway, GR. 1987. The properties of agroecosystems. *Agricultural Systems*. 24 (2). pp. 95-117. https://doi.org/10.1016/0308-521X(87)90056-4

Crocetti, L., Forkel, M., Fischer, M., Jurecka, F., grlj, A., Salientining, A., Trnka, M., Anderson, M., Ng, W., Kokaj, Z., Bucur, A., and Dorigo, W. 2020. Earth Observation for agricultural drought monitoring in the Pannonian Basin (southeastern Europe): current state and future directions. Regional Environmental Change. 20 (123). https://doi.org/10.1007/s10113-020-01710-w

CSIR. 2019. ‘Green Book | Adapting South African Settlements to Climate Change’. Green Book | Adapting South African Settlements to Climate Change. 2019. www.greenbook.co.za.
Dube, T., Moyo, P., and Nyathi, D. 2016. The impact of climate change on agro-ecological based livelihoods in Africa: a review. *Journal of Sustainable Development*. 9 (1) pp. 256-267.
FAO, 2012. Smallholder and family farmers. Sustainability Pathways.
FAO. 2010. Climate-Smart Agriculture: Policies, Practices and Financing for Food Security, Adaptation and Mitigation; FAO: Rome, Italy.
Fauchereau, N., Trzaska, S., Rouault, M., and Richard, Y. 2003. Rainfall Variability and Changes in Southern Africa during the 20th Century in the Global Warming Context. *Natural Hazards*. 29 pp 139-154.
Fredriksson, L., Rizon, M., Davidova, S., and Bailey, A., 2021. Smallholder Farms in Bulgaria and Their Contributions to Food and Social Security. *Sustainability*. 14 (14) pp. 7635; https://doi.org/10.3390/su13147635
Ghosh-Jerath, S., Kapoor, R., Ghosh., Singh, U., Downs, AS., and Fanzo, J. 2021. Pathways of climate change impact on agroforestry, food consumption pattern, and dietary diversity among indigenous subsistence farmers of Sauria Paharia tribal community of India: a mixed methods study. *Frontier Sustainable Food Systems*. 5 pp. 174. https://doi.org/10.1016/j.crope.2022.05.001
Hardelin, L and Lankoski, J. 2015. Climate change, water and agriculture: challenges and adaptation strategies. *EuroChoices*. 14 (2) pp. 10-15.
Hawtin, G.C., 2000. Genetic diversity and food security. UNESCO Courier, pp. 27−29. http://www.unesco.org/courier/2000_05/uk/doss23.htm (viewed 05.09.23)
Mabhaudhi, T., Chimonyo, S., Hlahla, S., Massawe, F., Mayes, S., Nhamo, L., and Modi, AT. 2019. Prospects of orphan crops in climate change. *Planta*, 250(3): 695-708.
Mawejje, J., 2016. Food prices, energy and climate shocks in Uganda. *Agricultural and Food*, 4(1).
Mbava, N., Mutema, M., Zengeni, R. 2020. Factors affecting crop water use efficiency: a worldwide meta-analysis. *Agricultural Water Management*, pp. 228, art. 105878 [11 p.]. ISSN 0378-3774.
Mphandeli, S., Nesamvuni, E and Maponya, P. 2015. Adapting to the impacts of drought by smallholder farmers in Sekhukhune District in Limpopo province, South Africa. Journal of Agricultural Science. 7 (2) pp. 115-124.
Ncoyini, Z., Savage, MJ., and Strydom, S., 2022. Limited access and use of climate information by small-scale sugarcane farmers in South Africa: a case study. Climate Services. 26 pp. 100285.
Niang, I., Ruppel, OC., Abdabro, MA., Essel, A., Lennard, C., Padgham, J., and Urquhart, P. 2014. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA (2014), pp. 199-1265.
Nyang’au, JO., Mohamed, JH., Mango, N., Makate, C., and Wangei, AN. 2021. Smallholder farmers’ perception of climate change and adoption of climate smart agriculture practices in Masaba South Sub-county, Kisii, Kenya. *Heliyon*. 7 (4) pp. 203-219.

Obi, A., and Maya, O. 2021. Innovative Climate-Smart Agriculture Practices in the Smallholder Farming System of South Africa. Sustainability. 13 (12) pp. 6848. https://doi.org/10.3390/su13126848
Okolie, CC., Danso-Abbeam, G., and Ogundeji, A. 2023. Livelihood vulnerability to the changing climate: the experiences of smallholder farming households in the Free State Province, South Africa. *Climate Services*. 20 pp. 100371. https://doi.org/10.1016/j.cliser.2023.100371
Rusere, F., Hunter, L., Collinson, M., and Twine, W. 2023. Nexus between summer climate variability and household food security in rural Mpumalanga Province, South Africa. *Environmental Development*, 47 100892. https://doi.org/10.1016/j.envdev.2023.100892
Shah, KU., and Rivera, JE. 2007. Export processing zones and corporate environmental performance in emerging economies: The case of the oil, gas, and chemical sectors of Trinidad and Tobago. Policy Science. 40 (4) pp. 265-285.
Shirley, R., 2021. Energy for food, livelihoods, and resilience: An integrated development agenda for Africa. *One Earth*, 4(4) pp. 478-481.
Sian, K., Wang, J., Ayugi, BO., Nooni, IK., and Ongoma, V. 2021. Multi-Decadal Variability and Future Changes in Precipitation over Southern Africa. Atmosphere. 12 (6) pp. 742. https://doi.org/10.3390/atmos12060742
Stats SA, 2022. Agricultural Preliminary Survey. https://www.statssa.gov.za/publications/P1101/P11012021.pdf, Viewed on the 31 August 2023.
Umzinyathi District Municipality. 2016. ENVIRONMENTAL MANAGEMENT FRAMEWORK: STATUS QUO REPORT.
UNGA, 2015. Transforming Our World: the 2030 Agenda for Sustainable Development. Resolution Adopted by the General Assembly (UNGA), United Nations, New York, USA.
Vogel, C., Steynor, A., and Manyuchi, A., 2019. Climate services in Africa: re-imagining an inclusive, robust and sustainable service. Climate Services. 15. pp. 100107.