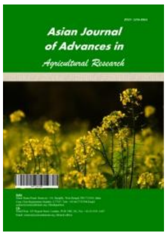

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Analysis of Rainfall and Temperature Changes and Variability over Glen Farm, South Africa

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Author's contribution

The sole author designed, analyzed, interpreted and prepared the manuscript.

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ABSTRACT

In the agricultural domain, decision-making is greatly guided by agricultural meteorology, which is the science that applies knowledge of weather and climate to qualitative and quantitative improvement in agricultural efficiency. The study area is challenged with increasing multifaceted agricultural production risks and complex agricultural ecosystems, which require analysis and understanding of local rainfall and temperature patterns. Digital technologies, such as the automatic weather station, play a pivotal role to monitor the physical environment, successively. This study engaged on a thorough analysis and interpretation of long-term rainfall and temperature data. The results would enable farmers and other users to comprehend valuable knowledge for improved productivity. The objectives of this paper were to analyse long-term climate data for Glen automatic weather station. To determine decadal climate patterns and trends, determine seasonal shifts, climate variability and climate change and quantify the frequency of the occurrence of weather extremes and develop suitable adaptation strategies relating to agronomic, phenological and physiological data necessary for crop modelling, operational evaluation and statistical analysis. The applied methods entailed Microsoft Excel and INSTAT Plus statistical software, which used to detect the interactions of environmental factors and suitable agricultural productivity. Understanding of rainfall and temperature patterns is required for agricultural management decisions, on planting date selection, crop suitability, livestock adaptation, ecosystem conservation. Agro meteorological knowledge derived from meteorological parameters,

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temperature, rainfall, wind and weather extremes, and may enhance agricultural productivity. Analysis of long-term and decadal trends in the time series indorse a sequence of alternately increasing and decreasing in mean annual rainfall and air temperature in Glen Farm.

Keywords: Agriculture; climate data; decision making; rainfall trends and patterns; weather extremes.

1. INTRODUCTION

Several studies conducted over Africa and southern Africa indicate that, the southern Africa warms, climate and weather variability will increase [1–3]. Climate variability has long exhibited challenges and stressful agricultural productivity, economic growth, community livelihoods and food security in South Africa [4][5], [6]. There are indications for increasing climate variability in southern Africa and certain areas. Some of the principal causes of increasing climate variability and climate change are a combination of external and internal factors to the climate system [4]. The agricultural fraternity has considerably been impacted by climate variability and the extreme climate evets can have intense effects on agriculture. The resource poor farmers are predominantly susceptible to climate variability because of their minimal adaptive capacity [7]. Climate variability has extensive impacts on agroecosystem and communities, which depend on them [5], [8–10]. Climate change worsen variability in rainfall and temperature, possibly increasing farmer exposure to climate related vulnerabilities including food insecurity [10]. Vulnerability denotes the propensity to be adversely affected, and includes a diversity of concepts and elements including susceptibility to detriment and lack of capacity to manage and adapt [10–12]. The Agricultural Research Council wants to play a crucial role in assisting the agricultural sector and particularly resource poor farmers, through national meteorological and hydrological services with localised adaptation strategies.

An understanding of climate variability, trends, patterns, weather forecast and climate prediction for better agricultural water resource management, tactical and operational decision making is of paramount importance [13]. South Africa is a water scarce country with increasing climate variability and change adding another facet of stress on water resources [14–16]. Increasing climate variability and high amounts of evaporative demand exacerbated by high temperatures create severe limitations for agricultural productivity [17,18]. Many studies note that as the global climate continues to warm up, the impact of such warming is likely to affect agriculture, agroecosystems and communities at different levels [4], [11]. Experts note that local specificity on climate variability and change assist identifying tailored adaptation strategies. [19]. Climate risks for agricultural production include rainfall variability, late start of rainfall season, prolonged dry/wet spells, droughts, localised flooding, rainy conditions at harvest period, heat waves, strong winds [16], [20]. Experts note that crop losses due to climate variability are a great cause for concern, at all value chain stages, as they reduce crop productivity and weaken the financial sustainability of agricultural production which eventually affect the livelihoods of communities and its contribution to Gross Domestic Product [16], [21].

Rainfall in southern Africa is characteristic of semi-arid, sub-humid and Mediterranean climate with winter rainfall in the western part, most of the country experiences summer rains. Rainfall variability is, therefore, intense in relatively short periods, whether winter or summer rain season. Other observations note that during drought, the Southern Annular Mode was positive for winter rainfall season for three consecutive years in 2015, 2016 and 2017 and was positively correlated with El Niño events [22]–[24]. The southern Africa summer rainfall is influenced by the ENSO, which indicate, dryer than normal during El Niño and wetter than normal conditions during La Niña events [25], [26]. Climate variability has been characterised by weather extremes, which are predominantly responsible for low yields, disease manifestation and insect outbreak [27]. Some studies note that little is documented about where and how crops could adapt to both increasing climate variability and change, and which impacts will distress their cultivation [28], [29]. High risks of climate variability with rainfall and temperature extremes predicted to increase in the future [5], [9], [30], [31]. Rainfall intensification, such as higher frequency of heavy rain cause immense socio-economic consequences. For instance, during the above normal rains an increased risk of respiratory in human beings, vector-borne infectious disease such as rift valley fever, water logging when roots cannot respire due to excess water in the profile [32]. Many infectious diseases are climate-sensitive and climate acting as an important driver of spatial and seasonal patterns of infections [8].

For part of southern and tropical Africa, [30] projected increases in temperature which implies an increase in the magnitude and duration of heat-waves result to increased evaporation, with consequent reduction of the amount of available soil water content. This may result in potential increased aridity in currently arid to semi-arid areas [30], [33], [34]. South Africa is susceptible to the impacts of drought and floods. A drought may be well-defined as a decrease in water availability for a given time in a particular area [35]. Most South Africa's arable land is prone to drought with 16% experiencing very severe meteorological drought, 34% severe drought and 38% moderate drought [14], [15], [36]. Rainfall data provide the opportunity to evaluate the occurrence and intensity of drought within decadal variability [34]. During 2015/16 season, a devastating drought left the South African farming community with crop failure and loss of livestock [37]. Increasing climate variability and change presents unanticipated challenges, strategies to increase adaptive capacity and minimise impacts are a necessity, since agriculture is unceasingly affected by extreme events such as floods, drought, dust storms, heatwaves, severe cold spells and heavy rainstorms.

Other studies note that, the global food system and biodiversity is in crisis. Increasing demand for food has transformed production systems globally [38], and the understanding of agro-climatological zones to determine conducive agricultural enterprises is one of the drivers and has played a major role in improving crop productivity and animal performance [17]. Agrobiodiversity, or the biodiversity of agricultural ecosystems, includes the biological aspects of human, animals and plant interactions, and predominantly determined by the given climatic conditions at a particular location [39]–[41]. Agrobiodiversity supports the preservation of the long-term sustainability of food systems, which contribute to food security. Since agricultural and food ecosystems are prominent drivers of changes in socioeconomic systems and highly related to agrometeorological parameters, most importantly rainfall onset, amount, distribution and cessation.

The study region is highly active in grain and vegetable production. For example, maize (*Zea mays L.*) is the supreme productive food crop and a stable food in Africa and other parts of the world. Wheat (*Triticum aestivum L.*) is another most essential crop species for local communities and its production has increased by 47% globally [42]. Increased agricultural yields are needed to provide food and raw food materials. Maize cropping systems under rain-fed are dominant at this farm and around Free State province and are part of the local's livelihood for provision of food, nutrition support and stover for mulching and animal feed. The greater increase in agricultural produce is determined by environmental suitable agronomic practices with a great consideration of climatic conditions and soil types. Plants in its distinct photosynthetic metabolism differ in water use and heat tolerance [43]. C3 photosynthetic metabolism plants, under high temperature conditions and relative humidity presents high photosynthetic rates but under low relative humidity it is reduced severely as a consequence of the stomatal closure [44]. Crassulacean acid metabolism (CAM) and C4 photosynthetic processes attain increased water use efficiency by concentrating CO_2 at the site of the dark reactions of photosynthesis [45]. Climate factors include increases in drought frequency and temperature, occurrence of strong winds and the effects of high level of CO_2 concentration on plant water use [46]. Frost is another limiting parameter not only for shrubs but also for all plant types [47]. There is a growing concern regarding shrubs encroachment, which may affect community and reduce the size of cultivated lands for agricultural use [48]–[50]. Shrub enlargement is associated with increasing climate variability; climate change and land use [51]. Hotter and drier conditions projected in the South African midlands can have a large impact on the composition of long-lived plant species [50], [52]. Therefore, understanding of climatic conditions of a place determines crop suitability and adaptation for a particular environment. Adaptation to climate change refers to adjustments in natural and human systems in response to actual and expected climate challenges and its effects, which impede potential opportunities [10].

Water is unquestionably a major environmental limitation and the Glen automatic weather station is located at a cold semi-arid area. The annual rainfall in semi-arid areas varies from 400-600 mm. The rainfall exceeds the potential evapotranspiration with daily levels ranging from 4-8 mm day^{-1}. Based on aridity index criteria for bioclimatic zones the climate is semi-arid range from 0.2-0.5 [53]. Depending on the seasonal predictions, in semi-arid areas in South Africa, maize grain yield hardly reaches 1 ton/ha compared to 5 ton/ha under controlled research station where supplementary irrigation and proper soil fertilisation is provided. With a concluded planting season of 75 to 120 days in the semi-arid areas, the potential evapotranspiration for the growing season ranges from about 650-950 mm for a period of six months from October to March the summer growing season. Comparing seasonal rainfalls, which ranges from 400-600 mm and evapotranspiration ranges from 650-950 mm, rains are often lower than the amount of evapotranspiration.

In this study, the long-term climate data was analysed to determine the rainfall patterns and trends at a farm level. INSTAT Plus statistical software and Microsoft Excel was used to determine rainfall and temperature patterns. A number of agrometeorological studies emphasizes the direct impacts of climate change on agricultural system, such as seasonal changes in rainfall and temperature [30], [33], [54]. These changes impact agro-climatic conditions, by shifting growing seasons, planting and harvesting calendars, water availability, pest, weed and disease populations. Furthermore, by modification in evapotranspiration, photosynthesis and biomass production; and in land suitability for agricultural production. Some of the induced changes are unexpected, while others occur gradually in shifts in seasonal temperature, rainfall onset and cessation, vegetation cover and species distributions. Increasing flood risks, heat waves, pro-longed dry spells, droughts, windstorm recognised as most important agrarian threat. The increased frequency of extremes observed intensified and resulted to reduced crop production.

2. DATA AND METHODS

2.1 Study Area

Glen farm located in the south-west Free State province, in Motheo district of South Africa. The province is located between the latitudes 26.6°S and 30.7°S of the equator and 24.3°E and 29.8°E of the Greenwich meridian. The regional topography in the north-eastern and eastern parts of the Free State province is multifaceted, with low altitudes of 1.800 m, situated at an elevation of 1,395 m above sea level [36]. The region is characterised by irregular rainfall and is heavily dependent on rainfall and agriculture is the main sector. The common extremes in the region is the occurrence of droughts and floods, which is distressing agricultural productivity. The rainy season is experienced From October to March and April to September is the winter season. The region was selected to demarcate seasonal boundaries, and analyse climate variability. According to the long-term climatic data and previous studies, the area has monthly mean sunshine hours of about 319.5, 296.5 and 296.3 in November, December and January, respectively. The annual sunshine hours and annual average rainfall of about 3312.3 and 559 mm respectively in the area. The region gets the lowest July rainfall and the highest January rainfall with the coldest months being June to August the minimum temperatures can drop to below -10°C [55].

2.2 Long-Term Climate Data

Daily maximum and minimum temperature and rainfall data from 1922-2020 for one station for this study. The long-term rainfall and temperature data were obtained from the Agricultural research Council – Natural Resources and Engineering Agrometeorology and Climate Change Programme Database [55]. The station was selected based on a continuous length of records for both rainfall and temperature data to comprehend its patterns and trends at farm level and knowledge deduced from it. In this study, complete data was defined as missing less than 5 days per month.

Monitoring climate through weather station data plays a critical role in identifying and tracking trends and patterns of the extent of floods, drought, heat waves and cold spells. Long-term climate data provide a valuable historical data that explore to understand local and regional climatic conditions, climate variability status and its impact on agricultural productivity. This study focuses on one automatic weather station located at Glen College of Agriculture experimental farm. Climate data for the period 1922-2020, was extracted for the following analysis: monthly average rainfall and temperature, annual mean rainfall, total monthly rainfall, rainy days, dry spells, rainfall probability, 7-day maximum rainfall and annual temperature time series.

2.3 Long-Term Climate Data Analysis

Daily rainfall and air temperature data records from 1922 to 2020 were manually checked for errors and outliners using Microsoft Excel and

INSTAT Plus Version 3.036 statistical software [56] was also used for agronomical characterization of the rainfall. The relationship between rainfall time series and moving average to discover the long-term trend as indicated in Fig. 2. This characterisation consisted of determining the timing of the onset date and cessation of rains, length of rainy season, total seasonal rainfall and probability of dry spells. Files were then created with data as prescribed for the software Microsoft Excel was used as the primary tool for data analysis to test and understand moving average and linear regressions and the fluctuations of climate data and INSTAT V3.36 was used for validation and to sort and group the data for analysis.

Daily data was analysed as they are for consecutive dry days, consecutive wet days, the number of very heavy rainfall days, the total number of rainfall days. The temperature data was grouped as follows, Maxmax and Minmin and then integrated into monthly and annual data for other analyses. The main indicators for drought, extreme rainfall events and extreme air temperature events in this study were consecutive dry days when rainfall is < 1mm; consecutive wet days when rainfall is ≥ 1mm; very heavy rainfall when rainfall is ≥ 20mm, monthly maximum value of daily maximum air temperature and monthly minimum value of daily minimum air temperature. Understanding the cyclical nature of the dry seasons was assessed through understanding rainfall characteristics over the long-term, depending on the spatial resolution of data available in each region to ensure that the results of the study and reports were of good quality. Dry spells in this study are defined as periods of 10, 20, and 30 days or more with less than 1 mm rain that can lead to the initial stage of meteorological drought.

The daily and monthly rainfall and temperature records was analysed with Instat, selected years from 98 years climate data. The chance of rain was assessed both when the previous day was dry, i.e. the chance that a dry spell would continue, and when the previous day was rainy, i.e. the chance that a rainy spell would continue, which is known as a Markov chain [56]. The probabilities of dry spell lengths of 5, 7, 10 and 15 days during the growing season were determined from the Markov chain model to obtain an overview of dry spell risks. Dry spells lengths of 5–15 days were selected in order to accommodate both drought sensitive and drought tolerant cultivars during the growing season.

3. RESULTS AND DISCUSSION

3.1 Rainfall and Temperature Trend Cycles

The Glen farm is 4600 ha in size located proximate Modder River catchment. It is divided into various land-use practices, for crop production, animal production, natural veld, and cultivated pastures. The farm has multiple soil types which are, Bonheim form; Swartland form; Glenrosa form and Valsrivier form. Various cops have been successfully planted on these fields under dry land and supplementary irrigation. The key agricultural produce include maize, legume, lucerne, sorghum, a variety of vegetables produced on land and under hydroponics systems and livestock [57]. Relative to other experimental farms, Glen has different ecotypes, hosts a number of research trials and intensification farming for commercialisation and consumption by the community, and has high share of its economic output dependent upon natural resources and formal capacity building for high learning specialists on agricultural related disciplines[57], [58].

Data relating to the state of the atmospheric environment include observations of rainfall, air temperature, solar radiation, sunshine, wind speed and direction [55]. Rainfall data was analysed to identify the onset and cessation of rainfall at the Glen weather station using INSTAT Plus statistical package to determine rainfall patterns and trends for this particular station. Glen location is characterised by four seasons, spring, summer, autumn and winter. Monthly average rainfall and temperature differ from month to month with the highest recordings from November to March (Fig. 1). Experiencing relatively severe cold temperatures in winter and mild to hot temperatures in summer months, with significant inter-annual variabilities. Long-term average dry season (May to September) minimum and maximum temperatures are 0°C and 19.6°C respectively, whereas wet season average temperatures are slightly higher, 11.8°C and 30.8°C (Fig. 1).

Rainfall records are, however, much more variable, indicating significant inter-annual and seasonal variabilities. Just 2 years of Glen’s 1021.3mm of rainfall has historically fallen within the wet season and about 60% years recorded above 500 mm, which is above annual rainfall average. However, as presented in Fig. 2, significant inter-annual variations occur in both dry and wet seasons, with total annual rainfall variating from as much as 1000 mm down to as little as 300 mm. Drought occur in semi-arid areas of South Africa and neighbouring countries, during the El Niño-Southern Oscillation (ENSO) events, bringing hot and drier conditions and La Nina brings cooler and wetter conditions, ([5]).

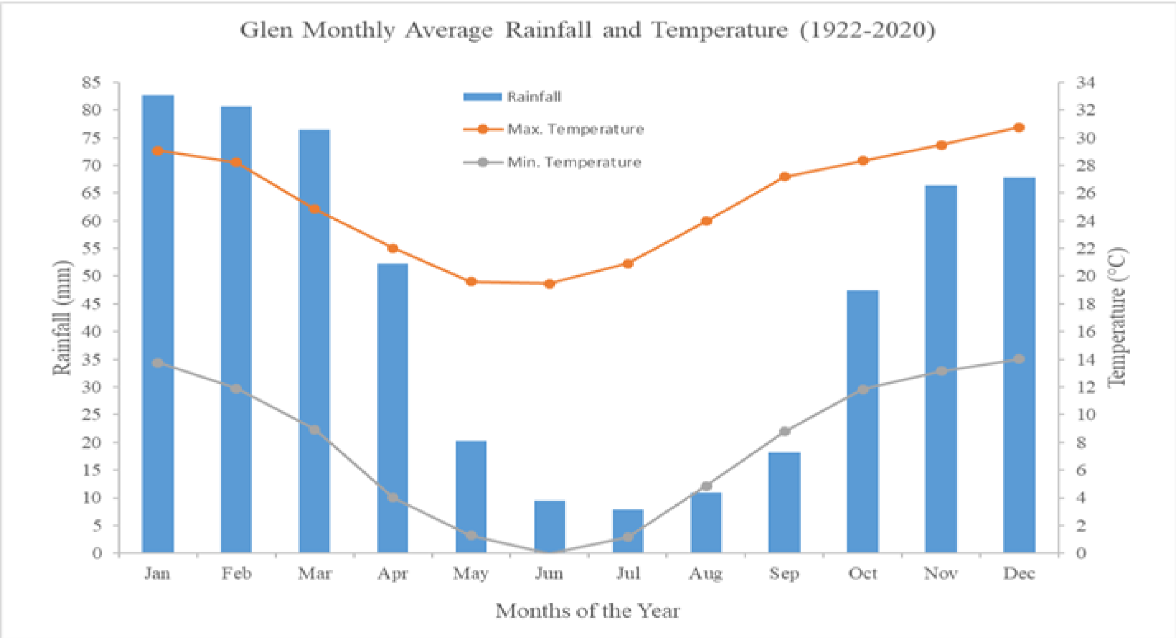

Fig. 1. Glen monthly average rainfall and temperature long-term averages

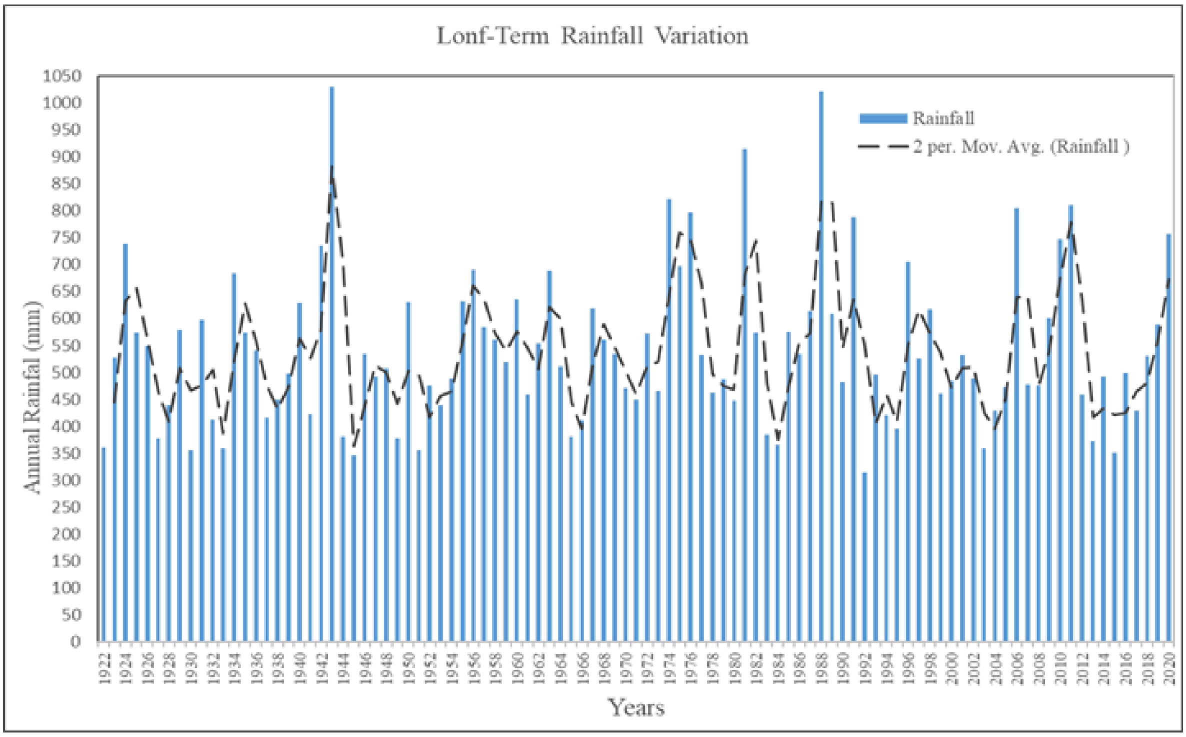

Fig. 2. Annual rainfall variation for Glen farm

Droughts in this study area occur every 3 to 6 year period and they cause severe effects for crop yields and livestock health. Fig. 3 shows the occurrence of El Niño (warming) and La Niña (cooling) events in the study area[23], [26], [59]. Graphic scrutiny recommends that events are associated with low rainfall (to mention a few, 1922, 1925/26, 1932/33, 1944/45, 1951, 1969/70, 1983/84, 1991/92, 2003/04, 2012/13, 2015/16) and the La Niña events to high rainfall (for instance 1924/25, 1942/44, 1949/50, 1974/75, 1975/76, 1987/88, 2010/11, for example). Noticed variability correlates intensely to the ENSO Index, with annual average rainfall during El Niño events being 30% - 50% lower than that occurring during La Niña years (Fig. 2 and Fig. 3). Additional, noticeably different patterns are evident in long-term rainfall averages when distinguished grounded on ENSO position.

There are varieties of methods that can be explored in order to quantify the rainfall events. INSTAT plus statistical package use box-plot method to determine the event of rainfall. Box plot is a form of summary of a given dataset, which includes, the minimum and the maximum, interquartile range, the computation and the median as described below. The median is the middle data ranked as the measure for central tendency of data and the same as 50th percentile of data, demonstrated as the red line in Fig. 4. The inter quartile range represent the middle 50% of the ranked data, drawn from 25th lower quartile and 75th upper quartile value percentile. The whiskers are drawn as vertical lines extending outward from the ends of the box, representing maximum and minimum rainfall amounts (Fig. 4). For instance, January median was about 60mm, with 25th percentile at 50mm and 75th percentile at about 100mm of rainfall (Fig. 4). November to April month demonstrate the lower quartile value was above 30mm with the higher quartile value above 100mm (Fig. 4). The maximum at 90th percentile from November to March at above 180mm of rainfall.

The used climate data indicate oddities, since a minimum of 0 mm was observed in some years on rainy season months November, December, March and April. March and April rains ranged from 0mm to about 210 mm, November from 0 mm to over 200 mm and December ranged from 2 mm to over 180 mm. The rainfall records confirm there was no rain in April 1932, March 1943, 1953, 2011 and March 2017 received 3mm as prolonged dry spells were observed, which is significantly affect agricultural efficiency. Rainfall trends in this study area indicate that the rainy season start in mid-December month to early April (Fig. 4). Furthermore, in this study area floods are prone to occur mostly in January, February and March (Fig. 4), but on other year drought episodes occurred during the same months. Monthly rainfall trends cycles show a consistent pattern from October-April but a steady decrease from May-July and a distinct increase from thereon approaching the spring-summer season (Fig. 4). The decrease and lack of rainfall during autumn-winter months contribute to prolonged dry spells and drought periods between cessation and onset of rains[24], [34], [35]. Observations specify that general rainfall cycles and trends in rainfall patterns are certainly inconsistent due to climate variability. These trends are skewed towards even drier than normal conditions, particularly during September-November. Such inconsistencies indicate that the study area experience inter-seasonal and intra-seasonal rainfall fluctuations.

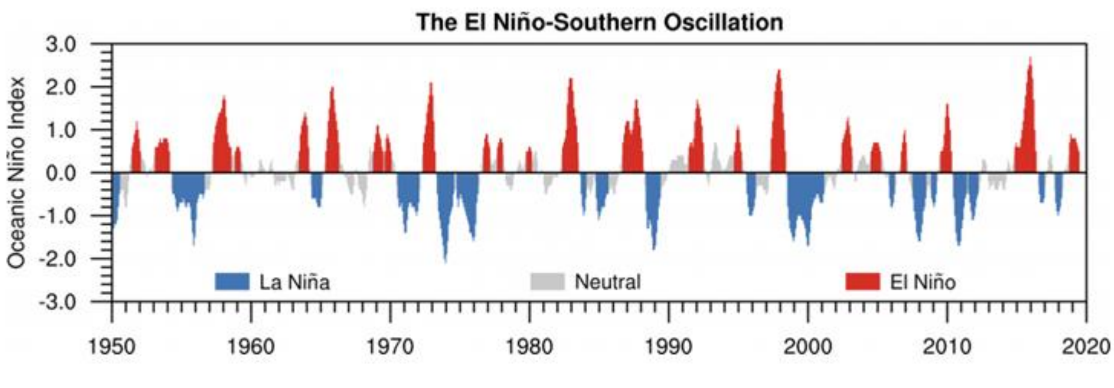

Fig. 3. Time series of the El Niño-Southern Oscillation based on the Oceanic Niño Index (https://origin.cpc.ncep.noaa.gov/products/analysis_monitoring).

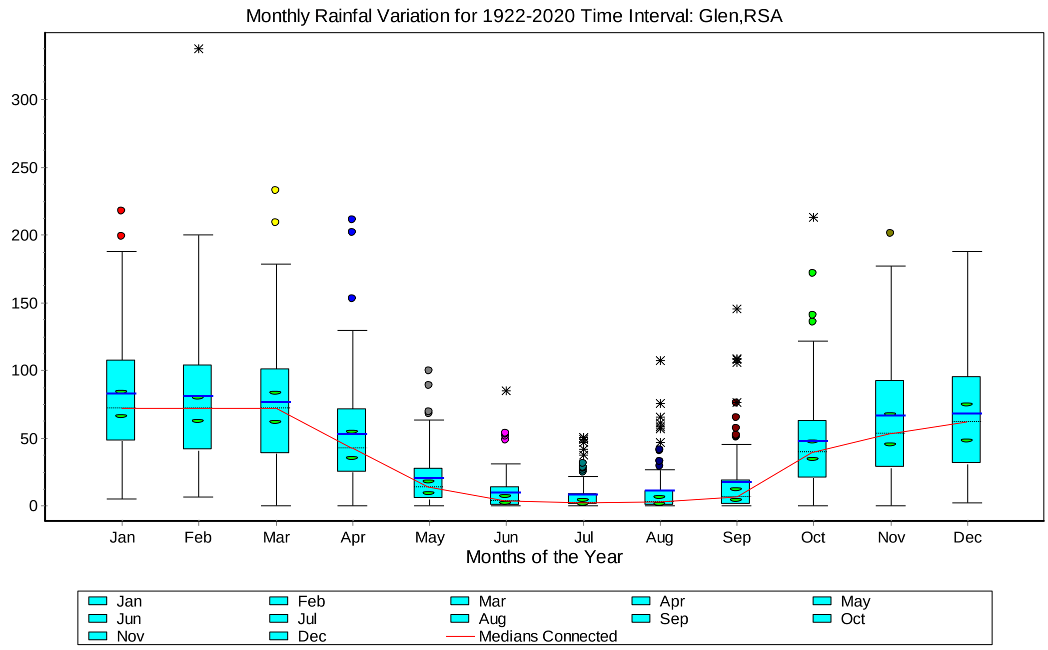

Fig. 4. Monthly rainfall variation for Glen Weather Station for 98 years

Annual variability in rainfall days and the observable impacts of ENSO phases on the total rainfall days in this region. Within a period of 98 years, the annual rainfall ranged from 315.1mm to 1021.3 mm in 1992 and 1988, respectively. The boxplot horizontal lines indicate rainfall value means grouped by month, which indicate rainfall, will start to decrease from May and reach its lowest point in September. Rainfall climb again from October and reach its peak from January to March. Therefore, the dry season assigned from May to September and the rainy season on October to April which determined to be the suitable planting season, but cautious in planting date selection and sequential planting can be advisable to maximise agricultural output.

3.2 Rainfall Patterns

Time series and trend analysis plots mean rainfall variability and number of rainy days for Glen (Fig. 4). Most rainy days are in January, February, March, November and December. On average, January is the most rainy month and July the least rainy month. The average annual amount of rainy days is 71 days per annum (Fig. 5). The annual rainfall varies from year to year with the number of rainy days decreased from season to season and decade to decade[4], [13], [60]. The rainfall intensity increased is January, February and March in the last decades.

The reality, South Africa faced its disproportionate drought in 2015 traced back since 1983 and 1984, which recorded 384.9 mm and 365.2 mm, respectively. Worst drought observed in 1992, 2003, 2013 and 2015 recorded 315.1 mm, 360.1 mm, 373.4 mm and 350.9 mm, correspondingly (Fig. 2 and 5). This severe drought endorsed to the amalgamation of events, such as regular climate dynamics, Elniño episode and climate change. According to weather station records, 1992 and 2015 was the driest years in the past two decades and since recording of rainfall started in 1922 (Fig. 5). The average national rainfall in 2015 was approximately 400 mm in comparison to the long-term average of above 600 mm. As can be seen from Fig. 2 and 5, below average rainfall was recorded in four or more consecutive years, the other two periods being from 1930 to 1933 and from 1944 to 1949.

The concentration of mean rainfall across the period understudy ranged from 26.23 mm in 1992 to 85.79 mm, 85.11 mm in 1943 and 1988, respectively. In the last decade from 2010 to 2010, the highest concentration mean rainfall recorded 62.24 mm in 2009 and the lowest recorded 29.24 mm in 2015. The linear regression for both mean rainfall and number of rainy days indicate a distinct increase, indicating positive trend of irregular rainfall pattern and the number of rainy days (Fig. 5).

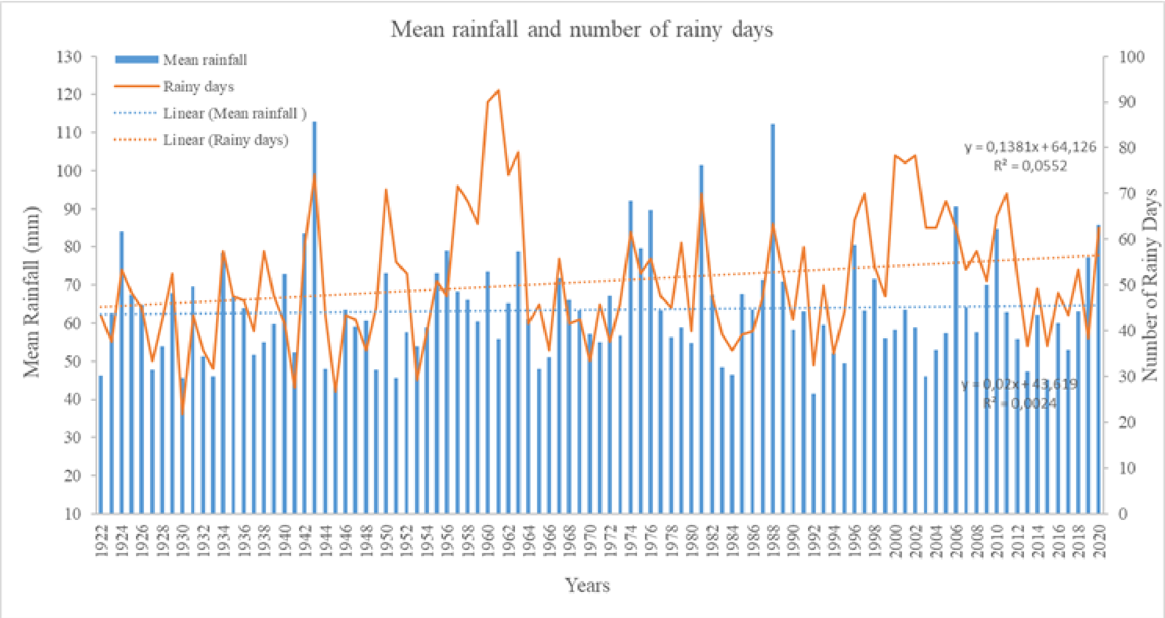

Fig. 5. Annual mean rainfall and rainy days at Glen experimental farm for 1922-2020

Zooming in to March month for each year to determine rainfall totals and the number of rainy days (Fig. 6). March is one of the months receiving the highest rains in this study area. Fig. 6, indicates the amount of rains recorded in March for each year since 1922 to 2020. During this month, the highest rainfall amount exceeded 200mm in 1925, 1948, occurred in association to La Niña event and the least recorded was 0 mm in 1953, which was triggered by the Elniño phenomenon, as represented in Fig. 3. More rains may shower within few days and result to floods and even crop damages. March month was selected to ascertain total rains and number of rainy days, since under study area most crops reach critical stage of water requirement. Absence of rains in March result in total crop failure since most crops during this period are reaching the maturity phase[14], [20]. Water deficit result to flower shedding and reduced yield. Illustration in (Fig. 6), indicate rainfall fluctuations from year to year for a specific month, thus indicate cautiousness for on farm decision making. Climate knowledge is mainly significant to achieve optimal agricultural outputs[4], [14], [20], [57], [61].

3.3 Rainfall Extremes

Rainfall data at selected site were used to calculate annual rainfall totals, monthly rainfall, number of rainy and dry days. About 65% of the Glen, farming is rain dependent, complex and vulnerable. Rain intra-seasonal variability has been deepened due to increase in frequency and intensity of the extreme rainfall and weather events, such as floods and drought episodes. Rainfall is the crucial input for agriculture but has erratic behaviour in terms of amount and distribution. For best agricultural commodity turnout, a detailed study on rainfall patterns and trends is vital. Rainfall variability in time and space influences the agricultural productivity and sustainability of households and locality. Duration of the number of days without rains within the planting season require intervention techniques to retain soil water content and the crop well-being [19], [29], [62].

The higher occurrence of consecutive dry days recorded in June, July, August and September affirms dry winter season, prolonged dry spells, meteorological and agricultural drought in the study area. Prolonged dry days contribute to different types of droughts, from meteorological, agricultural, hydrological and eventually to socio-economical drought [36]. Intensification of rainfall extremes observed during 2010-2020 comparing previous decades, with drought occurrence intensifying in the last thirty years[7], [63], [64].

For the comparison of the wet and dry spells 2007 and 2017 years was selected based on its distinctive difference in rainfal distribution from month to month (Fig. 7 and Fig. 8). The recorded annual rainfall for 2007 was 477.21 mm with

2017 at 429.53 mm, the two years obtained a difference of 47.7 mm. Year 2017 recorded monthly rainfall ranging from 0 mm to 1.52 mm from June to September, whereas, 2007 recorded monthly rainfall ranging from 0.8 mm to 57.0 mm from June to September. Therefore, a significant defference in wet and dry spell interval was experienced.

Rainfall amount and distribution as represented in Fig. 7, show rainy and dry days throughout the year. Onset, distribution and cessation of a rainy season retains the key to agricultural preplanning. The first 20 days in 2007, rainfall accumulation amounted to 6.1 mm (Fig. 7), whereas, 2017 accumulated to 89.66 mm. From the 5th to 14th January 2007 and 14th to 23rd January 2017 (Fig. 8), a 10 day dry spell occured, indicationg a severe dry condition which may lead to delayed planting or crop failure triggered by water deficit unless supplimentary irrgation is provided. Good rains occurred in in day 269 on the 26th September, therefore, early planting was advisable with guidance from weather forecast and climate predictions (Fig. 7)[65]. This year indicate one very dry year with unfavourable agricultural productivity unless preventative measures and technologies are adopted to improve agricultural productivity.

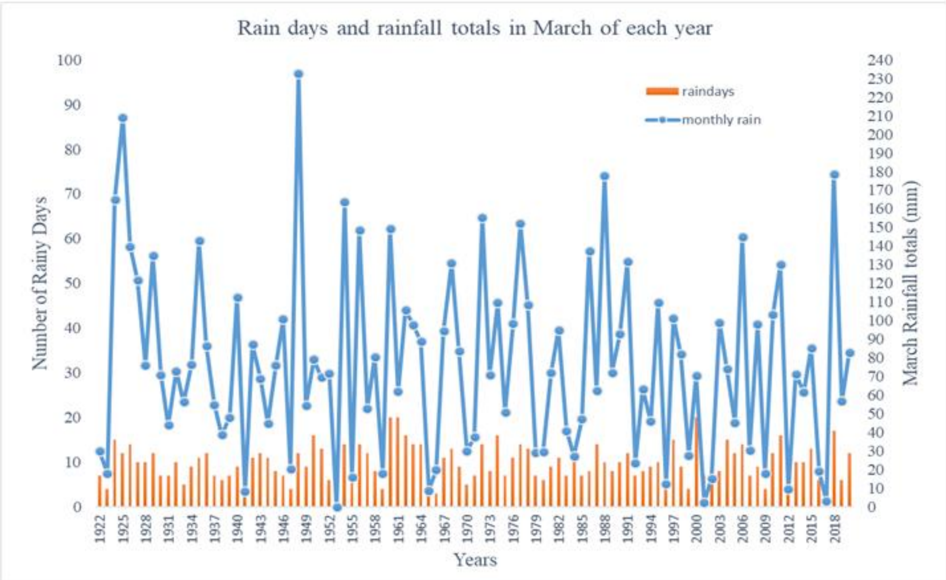

Fig. 6. March rainfall totals and the number of rain days for Glen

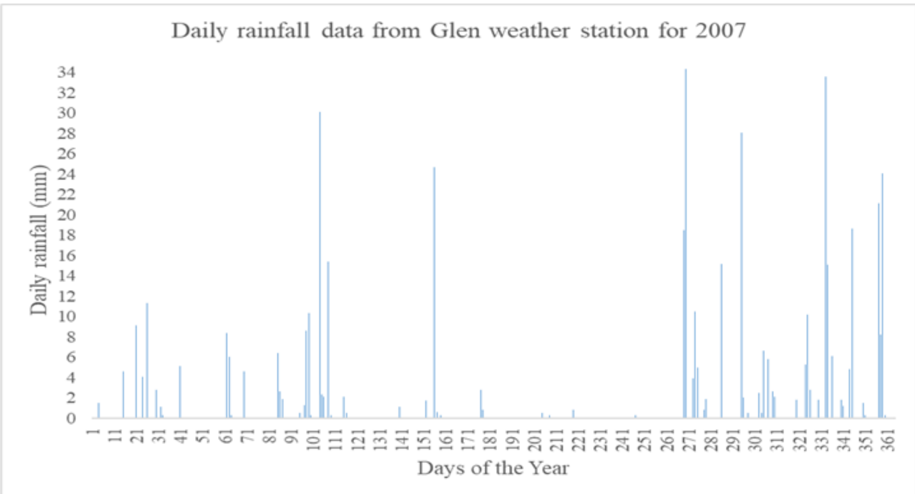

Fig. 7. Daily rainfall data and dry spell for year 2007

In comparison to year 2017 (Fig. 8), the first 13 days of January indicate good rainy season which accumulated 95.8mm. A total amount of 169.4mm recorded in February, with March rains recorded at 3mm and April at 48.5mm. This scenario suggect early planting of short crop cultivar. Rainfall variability is a prime cause of agricultural failure, but with understanding of adaptation strategies which are aligned with suitable agricultural commodities, losses are minimised.[28], [60].

3.4 Rainfall and Water Balance

Water is the most essential component for plant life. Plants absorb soil water content from the soil through their root system to maintain a favourable hydraulic balance. The absorbed water transports nutrients to other parts of the plants. The soil water balance depends on the capability of water from rainfall or irrigation to infiltrate soil through the surface and be stored in the soil profile. Water drainage out of the root zone by the forces of gravity, runoff of water that does not enter the soil surface, water lost from the surface by evaporation and water absorbed by plant roots and used in transpiration. Soil water balance relate to the water added through rainfall or irrigation and lost through evapotranspiration, runoff and drainage. If soil water balance is higher than rains and reached the saturation level, runoff occur soil profile has no capability of water storage. Where rain was higher than water balance, the water infiltration rate is higher for reserving water within the soil profile. For example, Fig. 9 exhibit the simulation of rains and water balance fluctuations throughout the year. Water balance was higher compared to the the rains in the last part of the year, and poor rains observed at the beginning of the planting season with possible prolonged dry spells[17].

A time-series plot given in Fig. 10(a), illustrate the largest daily extreme observed in year 1976 and 1988 with about 96 mm of daily rainfall. Other extremes recorded above 80 mm per day were 86.9, 85, 83 and 80.9 in 1960, 1996, 1998 and 2006 respectively. A number of 23 in 86 years, show that 26.7% recorded a value over 60 mm. About 70% of years recorded above 40 mm (Fig. 10 (b), Glen area had no years recorded rainfall daily maximum exceeding 100 mm.

A propability plot, show 80% chances of receiving an amount of about 67.04 mm in the study area (Fig. 10 (b). The maximum daily rainfall of receiving 50.5mm is in 50% probability and about 35.04 mm received in 20% of the years. The model estimate the best sowing date on the 31st October for early planting under good and above-normal seasonal rains. Other potential planting dates around the 14th November, 30th November, 1st week of December, 27th December and 1st week of January provided informed decision on crop type and cultivar selection.

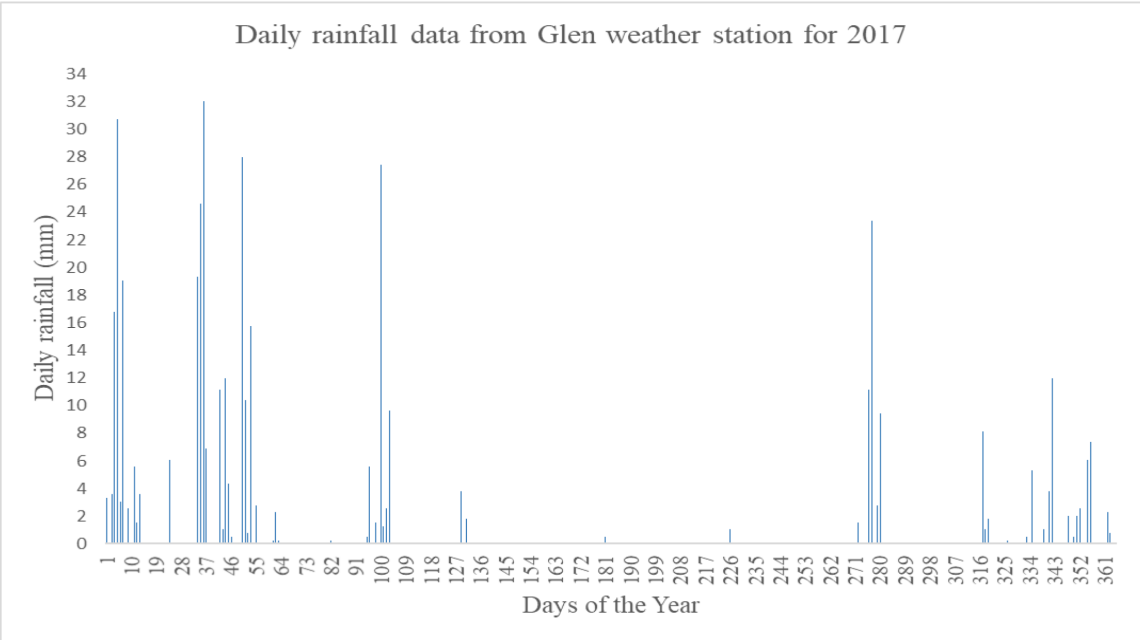

Fig. 8. Daily rainfall data and dry spell lengths for year 2017

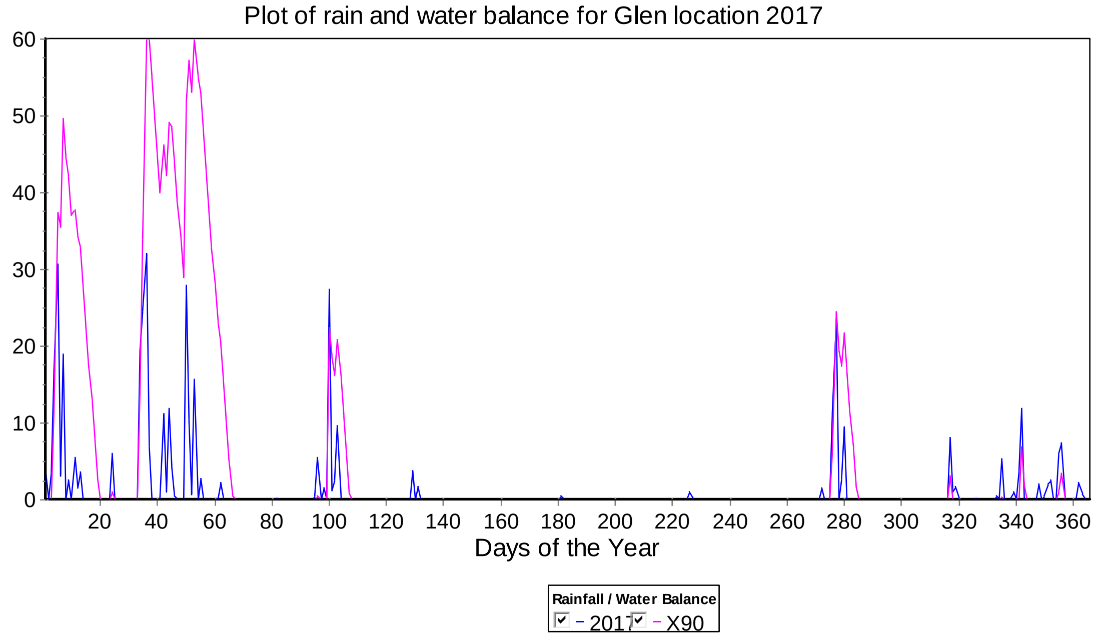

Fig. 9. Rainfall and water balance for Glen 2017

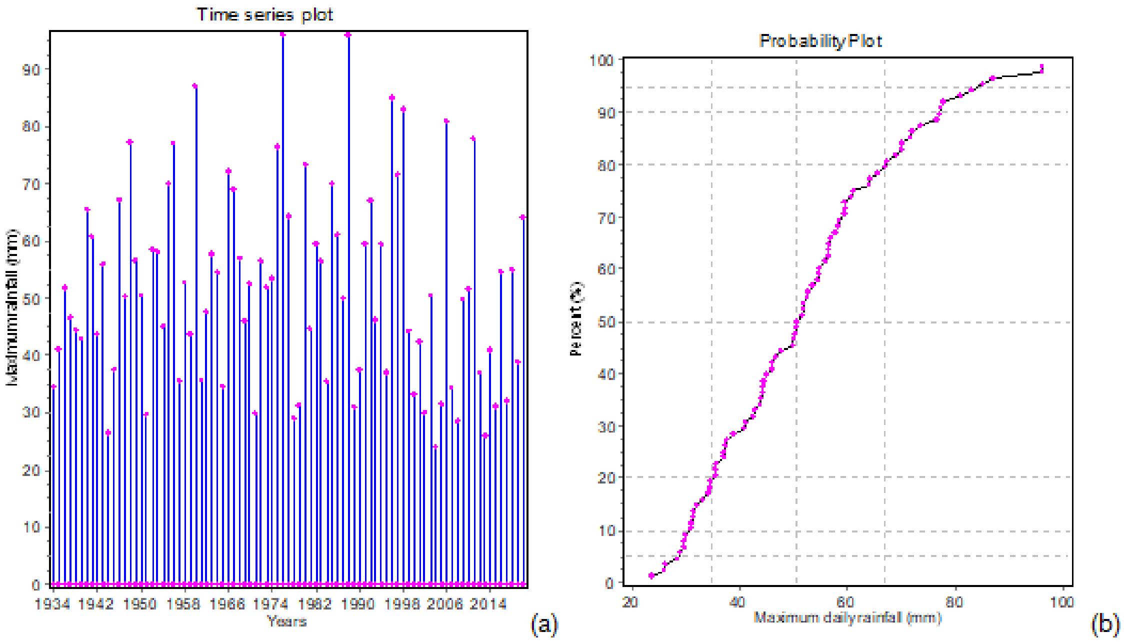

Fig. 10. Maximum daily rainfall (a) time series and (b) propability plot

The largest recorded 7-day total was 178.1 mm in 1988 (Fig. 11(a)), occurred during the La Niña phase in which severe floods were experienced in the study area and South Africa at large. In six occurrences, 7-day maximum exceeded 80 mm but below 100 mm of rainfall and 80% of the years received below 67.04 mm and 50% years recorded less than 51.6mm. Based on this knowledge development of tailor-made advisories on the length of the season and determining the planting dates is vital[4], [57], [66]. The 7-day maximum rainfall plot protrays essential knowledge for sowing date selection (Fig. 11 (b). Therefore, Fig. 1; Fig. 4 and Fig. 11 (a) and (b) validate the planting season for the study area starting from October to April. The rainy day records an average rainfall exceeding 10mm and above 15 mm a heavy rainfall event and a very heavy rainfall event exceeds 25 mm.

3.5 Temperature Data Analysis

The mean annual temperature trends based on linear regression analysis are presented in Fig. 12. As a result, an increasing trend has been noticed in the original long-term data on both minimum and maximum temperature from 1922-2020. The increasing trend exhibited by the trend line (Fig. 12) is obvious with a positive linear equation that there was increase in temperature recorded at this weather station. The average maximum temperature ranged from 25°C to 29°C with the average minimum temperature ranging from 8°C to 11°C. An increase of about 1.2°C was observed. Based on the selected station, maximum and minimum showed a significant trend with spatial and seasonal differences for maximum temperature in the main rainy season.

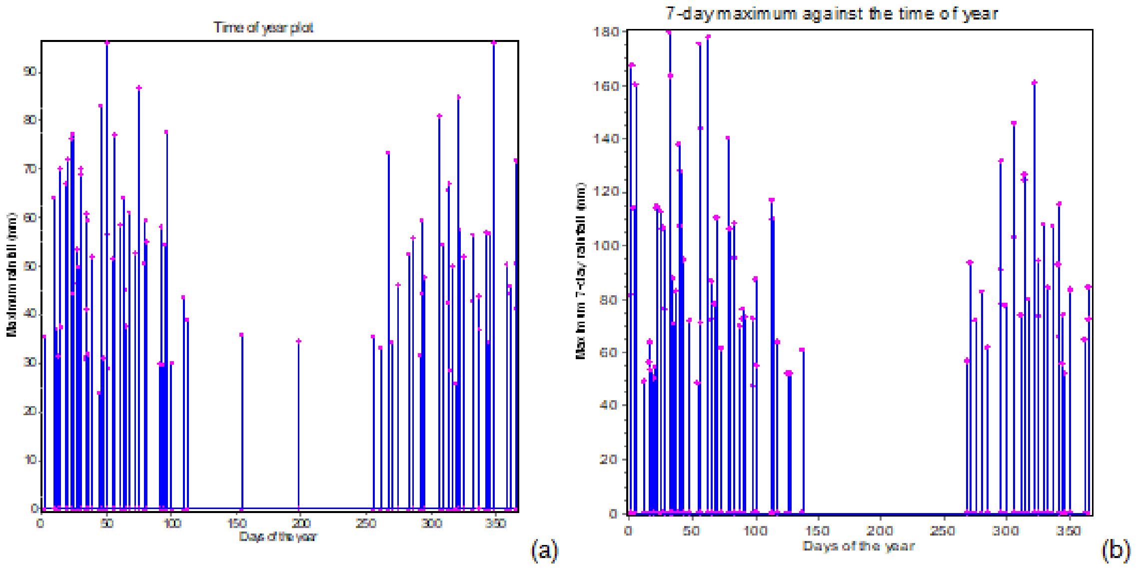

Fig. 11. Maximum rainfall (a) sowing time of the year and (b) 7-day maximum rainfall plot

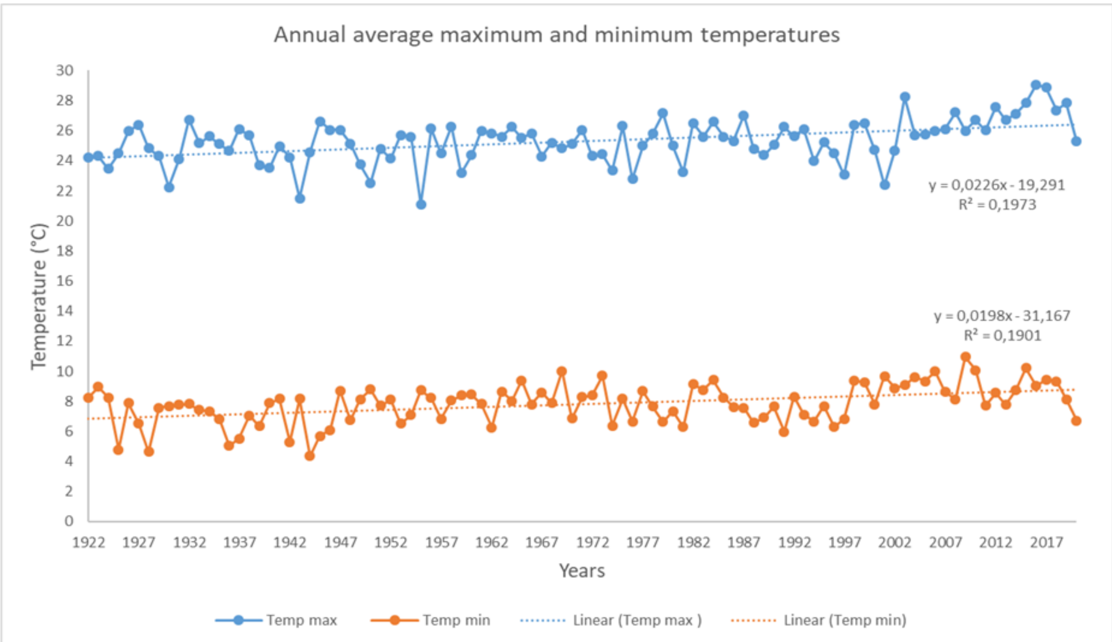

Fig. 12. Annual temperature series (1922-2020)

Knowledge on trends in temperatures provide critical insight the limits that cause distinct but sub-lethal responses on agricultural commodities, for example the shedding of tomato plant at below 5°C, the fastest growth of maize roots and shoots at 30°C, temperatures of -2°C injured the leaves of unhardened winter wheat plants and -4°C was lethal. Plant growth and development entirely related to critical temperature values from germination to the fall of seasonal temperature, rainfall amount, soil water balance, day length patterns and their interactive effects.

In the study area, the first frost date occurred on the 11th April. The hottest months start from November, December and January (Fig. 13) with above 40°C maximum temperatures in some years. May to August record the lowest minimum temperature in this weather station. The recorded threshold of the lowest temperature range from 0°C to -11.7°C (Fig. 13 and Fig. 14). A frost day is characterised by the minimum temperature of less or equal to 0°C. The cold spells occurring in September and October months, play a critical role on planting date selection. Thus planting in October and September result into delayed seed emergence and seedlings recovery phase, and the probability of prolonged dry spells is imminent. On agricultural decision making temperature and rainfall trends plays a primary role toward crop suitability, planting date selection, planting densities, crop and cultivar selection.

The upper and lower fences represent temprature values more than 75th and less than 25th percentile. The interquartile range, is a useful measure of variation. The maximum teperature plot shows that 50% of the data points between 25th and 75th percentile were within the range of 34°C and 39°C. 25% below 34°C and 25% above 39% with the median of 36°C (Fig. 14). The minimum temperature range from 6°C and 11°C with the median of 7°C and the outlier of -10°C in January. The minimum temperature observed in July is 11.1°C with the upper fence at 0°C and a median of -5°C (Fig. 14). In January to March and October the minimum temperatures ranged from -5°C and 0°C. But observation indicate June, July and August with minimum temperatures dropped below -10°C, the coldest months in the study area. The highest maximum temperatures recorded in September to March was 40°C, with January record maximum at 42°C.

Based on climate change model projections, temperature are getting warmer in the southern Africa and the worldwide [30], [31], [67], [68]. The daily temperature from 1922 to 2020 indicate that last decade 2000 to 2020 is warmer comparing to the other decades earlier in years. Warmer temperatures may result to poor agricultural

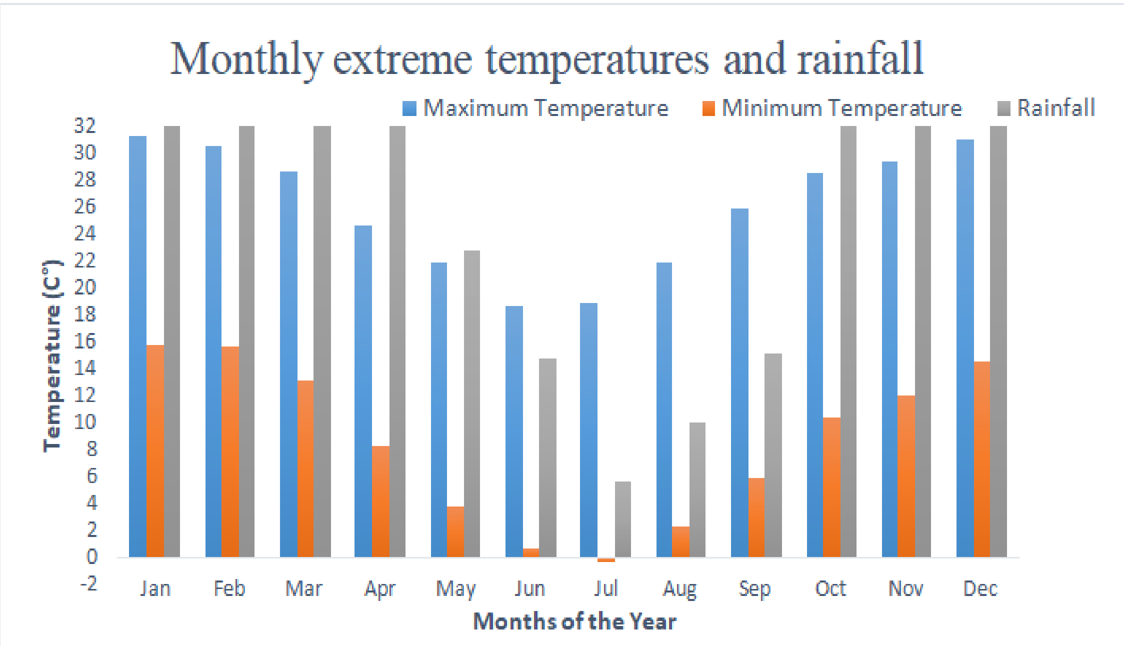

Fig. 13. Monthly rainfall, maximum and minimum temperatures for Glen station

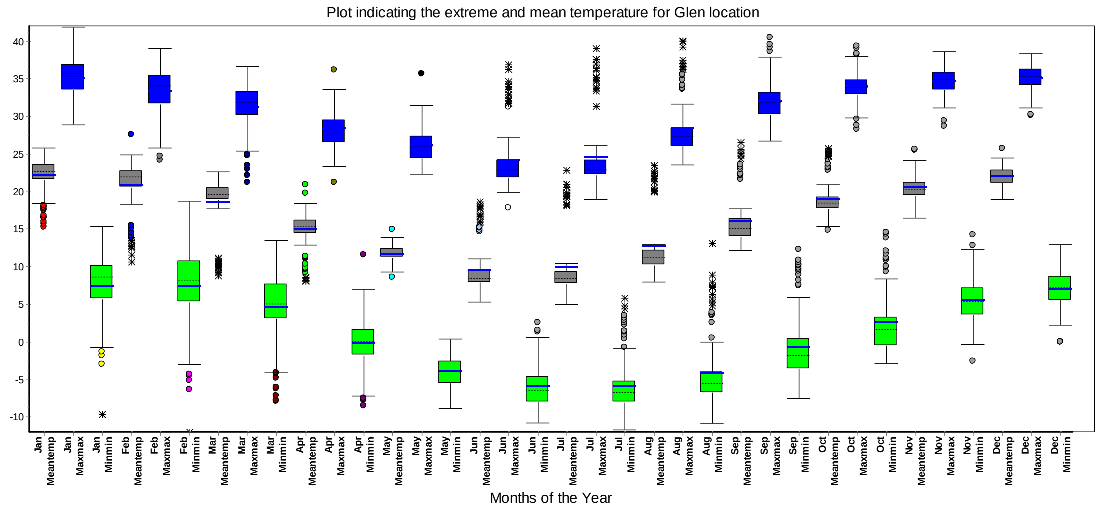

Fig. 14. Boxplots for monthly minimum, average and maximum temperatures with outliers

productive since other agricultural enterprises require cold temperatures for growth and development the process called vernalisation [67]–[69]. The analysed climate data indicate the climate variability the increase of extreme events in the period of 30 years indicate the occurrence of climate change as recorded in the study area.

4. CONCLUSIONS

Using the long-term rainfall and temperature, the study has shared insight on the rainfall and temperature patterns in Glen Farm, South Africa. In consistent with previous studies which reported rising temperatures, intensification of weather extremes and rainfall onset shifts in South Africa and elsewhere. The trend in temperature has consequence on agricultural activities, in semi-arid areas. Increasing temperature affect evapotranspiration, reduce surface and soil water balance and may lead to drought and water scarcity, which cause crop yield reduction and livestock mortality.

This study found significant rainfall inter-annual and seasonal variabilities. The annual rainfall variation ranged from 300 mm to above 1000 mm. The monthly maximum 90th percentile was recorded above 180 mm from November to March. Rainfall intensified from January to March from 2010 to 2020, indicating irregular rainfall patterns and decreased number of rainy days. The study area is 65% rainfall dependent for agricultural activities. Rain intra-seasonal variability has been deepened due to increase in frequency and intensity of extreme rainfall and weather events, such as floods and drought episodes. Dry spell duration ranged from 5 to 30 days, which may inhibit crop growth and development. Therefore, rising temperature and rainfall scarcity affect contribution of agriculture to poverty reduction, food security, livelihood and poor economic development.

Rainfall irregularities in the study area inflict severe threats to agricultural productivity, thereby reducing income generation and affecting household livelihoods. To counterbalance the impacts of weather extremes, rainfall irregularities on agricultural activities, adoption of climate-smart techniques, such as use of drought resistant and early maturing crops may be recommended. Moreover, crop and livestock diversification and crop-livestock integration may serve as significant strategies to reduce climate variability and change impact. Therefore, policy makers must facilitate the adoption of climate related knowledge for improved decision-making and ensure the availability and provision of accurate and reliable early warning systems.

COMPETING INTERESTS

Author has declared that no competing interests exist.

REFERENCES

1. Engelbrecht FA, et al. Downscaling last glacial maximum climate over southern Africa. Quaternary Science Reviews. 2019;226. DOI: 10.1016/j.quascirev.2019.105879

2. Gasse F, Chalié F, Vincens A, Williams MAJ, Williamson D. Climatic patterns in equatorial and southern Africa from 30,000 to 10,000 years ago reconstructed from terrestrial and near-shore proxy data. Quaternary Science Reviews. 2008;27:25–26.
DOI: 10.1016/j.quascirev.2008.08.027.
3. Nicholson S. The nature of rainfall variability over Africa on time scales of decades to millenia," Global and Planetary Change. 2000;26;1–3.
DOI: 10.1016/S0921-8181(00)00040-0.
4. Salinger MJ, Stigter CJ, Das HP. Agrometeorological adaptation strategies to increasing climate variability and climate change. Agricultural and Forest Meteorology. 2000;103:1–2.
DOI: 10.1016/S0168-1923(00)00110-6.
5. Thornton PK, Ericksen PJ, Herrero M, Challinor AJ. Climate variability and vulnerability to climate change: a review. Global Change Biology. 2014;20;11.
DOI: 10.1111/gcb.12581
6. Flatø M, Muttarak R, Pelser A. Women, weather, and woes: The triangular dynamics of female-headed households, economic vulnerability, and climate variability in South Africa. World Development. 2017;90.
DOI: 10.1016/j.worlddev.2016.08.015.
7. Ademe D, Ziatchik BF, Tesfaye K, Simane B, Alemayehu G, Adgo E. Climate trends and variability at adaptation scale: Patterns and perceptions in an agricultural region of the Ethiopian Highlands," Weather and Climate Extremes. 2020;29.
DOI: 10.1016/j.wace.2020.100263.
8. Thomson MC, Mason SJ. Climate information for public health action. Rout ledge Studies in Environment and Health Rout ledge. Studies in Environment and Health;2019.
9. Intergovernmental Panel on Climate Change. Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. England; 2012.
10. Intergovernmental Panel on Climate Change. Climate change 2014–Impacts, adaptation and vulnerability: Regional aspects; 2014.
11. Apraku JF, Morton, Apraku-Gyampoh B. Climate change and small-scale agriculture in Africa: does indigenous knowledge matter? Insights from Kenya and South Africa. Scientific African;2021.
DOI: 10.1016/j.sciaf.2021.e00821.
12. Todorović M, Jovanović N. Climate Change and Agriculture," in Encyclopedia of Water, Wiley; 2019.
DOI: 10.1002/9781119300762.wsts0177.
13. Mahmood R, Jia S, Zhu W. Analysis of climate variability, trends, and prediction in the most active parts of the Lake Chad basin, Africa. Scientific Reports. 2019;9(1).
DOI: 10.1038/s41598-019-42811-9.
14. Jordaan YT, Bahta, Phatudi-Mphahlele B. Ecological vulnerability indicators to drought: Case of communal farmers in Eastern Cape, South Africa. Jàmbá: Journal of Disaster Risk Studie.2019;11(1).
DOI: 10.4102/jamba.v11i1.591.
15. Jordaan H, et al. Determining the water footprints of selected field and forage crops, and derived products in South Africa. Bloemfontein; 2019.
16. Theron SN, Archer E, Midgley SJE, Walker S. Agricultural perspectives on the 2015-2018 Western Cape drought, South Africa: Characteristics and spatial variability in the core wheat growing regions. Agricultural and Forest Meteorology. 2021;304–305
DOI: 10.1016/j.agrformet.2021.108405.
17. Barron J, Rockström J, Gichuki F, Hatibu N. Dry spell analysis and maize yields for two semi-arid locations in east Africa," Agricultural and Forest Meteorology. 2003;117:1–2.
DOI: 10.1016/S0168-1923(03)00037-6.
18. Botai C, Botai J, de Wit J, Ncongwane K, Adeola A. Drought characteristics over the Western cape province, South Africa. Water. 2017;9(11).
DOI: 10.3390/w9110876.
19. Nkomwa EC, Joshua MK, Ngongondo C, Monjerezi M, Chipungu F. Assessing indigenous knowledge systems and climate change adaptation strategies in agriculture: A case study of Chagaka Village, Chikhwawa, Southern Malawi. Physics and Chemistry of the Earth, Parts A/B/C. 2014;67–69.
DOI: 10.1016/j.pce.2013.10.002.
20. Midgley S, Methner N. Climate adaptation readiness for agriculture: drought lessons from the western cape, South Africa. Cape Town; 2016.
21. Wehrli K, Guillod BP, Hauser M, Leclair M, Seneviratne SI. Identifying Key Driving Processes of Major Recent Heat Waves," Journal of Geophysical Research: Atmospheres. 2019;124(22).
DOI: 10.1029/2019JD030635.

22. Reason CJC, Rouault M. Links between the Antarctic Oscillation and winter rainfall over western South Africa. Geophysical Research Letters. 2005;32(7). DOI: 10.1029/2005GL022419.
23. Philippon N, Rouault M, Richard Y, Favre A. The influence of ENSO on winter rainfall in South Africa," International Journal of Climatology. 2012;32(15). DOI: 10.1002/joc.3403.
24. Archer E, Landman W, Malherbe J, Tadross M, Pretorius S. South Africa's winter rainfall region drought: A region in transition?. Climate Risk Management. 2019;25. DOI: 10.1016/j.crm.2019.100188.
25. Mason SJ. El Niño, climate change, and Southern African climate. Environmetrics. 2001;12(4). DOI: 10.1002/env.476.
26. Kane RP. Periodicities, ENSO effects and trends of some South African rainfall series : an update. South African Journal of Science. 2009;105(5).
27. Sacolo SJ, Mkhandi SH. Assessment of the potential of rainwater harvesting for maize production in the Lubombo plateau. Physics and Chemistry of the Earth, Parts A/B/C; 2020. DOI: 10.1016/j.pce.2020.102935.
28. González-Orozco CE, Porcel M, Alzate Velásquez DF, Orduz-Rodríguez JO. Extreme climate variability weakens a major tropical agricultural hub. Ecological Indicators. 2020;111. DOI: 10.1016/j.ecolind.2019.106015.
29. Porter JR, Howden M, Smith P. Considering agriculture in IPCC assessments. Nature Climate Change. 2017;7(10). DOI: 10.1038/nclimate3404.
30. Engelbrecht F, et al. Projections of rapidly rising surface temperatures over Africa under low mitigation. Environmental Research Letters. 2015;10(8). DOI: 10.1088/1748-9326/10/8/085004.
31. Bathiany S, Dakos V, Scheffer M, Lenton TM. Climate models predict increasing temperature variability in poor countries. Science Advances. 2018;4 (5). DOI: 10.1126/sciadv.aar5809.
32. Ojo OI, Ochieng GM, Otieno FAO. Assessment of water logging and salinity problems in South Africa: an overview of Vaal harts irrigation scheme. Water and Water and Society. 2011;153.
33. Maure G, et al. The southern African climate under 1.5◦C and 2◦C of global warming as simulated by CORDEX regional climate models. Environmental Research Lettters. 2017;13:1–9.
34. Malherbe J, Dieppos B, Maluleke P, Van Stander M, Pillay DI. South African droughts and decadal variability. Natural Harzards. 2016;80:657–681.
35. Vogel C, Koch I, van Zyl K. A persistent truth'—Reflections on drought risk management in Southern Africa. Weather, Climate, and Society. 2010;2(1). DOI: 10.1175/2009WCAS1017.1.
36. Orimoloye R, Ololade OO, Belle JA. Satellite-based application in drought disaster assessment using terra MOD13Q1 data across free state province, South Africa. Journal of Environmental Management. 2021;285. DOI: 10.1016/j.jenvman.2021.112112.
37. Zuma-Netshiukhwi G, Mphandeli S. The capabilities of interdisciplinary approach to strengthening farmers' resilience to climate variability and change. International Journal of Research in Agriculture and Forestry. 2019;6:18–25.
38. Shepherd M, Turner JA, Small B, Wheeler D. Priorities for science to overcome hurdles thwarting the full promise of the 'digital agriculture' revolution. Journal of the Science of Food and Agriculture. 2020;100(14). DOI: 10.1002/jsfa.9346.
39. Leclerc C, Coppens d'Eeckenbrugge G. Social Organization of Crop Genetic Diversity. The G × E × S Interaction Model. Diversity. 2011;4(1). DOI: 10.3390/d4010001.
40. Zimmerer KS, et al. The biodiversity of food and agriculture (Agrobiodiversity) in the anthropocene: Research advances and conceptual framework. Anthropocene. 2019;25. DOI: 10.1016/j.ancene.2019.100192.
41. Baumann MD. Agrobiodiversity's caring material practices as a symbolic frame for environmental governance in Colombia's southern Tolima. Geoforum; 2021. DOI: 10.1016/j.geoforum.2021.01.002.
42. MA M, et al. In situ measurements of winter wheat diurnal changes in photosynthesis and environmental factors reveal new insight into photosynthesis improvement by super-high-yield cultivation. Journal of Integrative Agriculture. 2021;20(2).

DOI: 10.1016/S2095-3119(20)63554-7

43. Hartzell S, Bartlett MS, Porporato A. Unified representation of the C3, C4, and CAM photosynthetic pathways with the Photo3 model. Ecological Modelling. 2018;384.
DOI: 10.1016/j.ecolmodel.2018.06.012.
44. Falasca SL, Ulberich AC, Ulberich E. Developing an agro-climatic zoning model to determine potential production areas for castor bean (*Ricinus communis* L.). Industrial Crops and Products. 2012;40.
DOI: 10.1016/j.indcrop.2012.02.044.
45. Bartlett MS, Vico G, Porporato A. Coupled carbon and water fluxes in CAM photosynthesis: modeling quantification of water use efficiency and productivity. Plant and Soil. 2014;383:1–2.
DOI: 10.1007/s11104-014-2064-2.
46. Bond WJ, Midgley GF. Carbon dioxide and the uneasy interactions of trees and savannah grasses," Philosophical Transactions of the Royal Society B: Biological Sciences. 2012;367:1588.
DOI: 10.1098/rstb.2011.0182.
47. Joeng H, Byun S, Kim D, Lee K. Frost growth mechanism and its behaviour under ultra-low temperature conditions. International Journal of Heat and Mass Transfer 169:120941. 2021;169:12009412-undefined,.
48. Smit GN. "An approach to tree thinning to structure southern African savannas for long-term restoration from bush encroachment. Journal of Environmental Management. 2004;71(2).
DOI: 10.1016/j.jenvman.2004.02.005.
49. Masubelele ML, Hoffman MT, Bond WJ, Gambiza J. A 50 year study shows grass cover has increased in shrublands of semi-arid South Africa. Journal of Arid Environments. 2014;104:43–51.
50. Rutherford MC, Powrie LW, Husted LB. Plant diversity consequences of a herbivore-driven biome switch from Grassland to Nama-Karoo shrub steppe in South Africa. Applied Vegetation Science. 2012;15(1).
DOI: 10.1111/j.1654-109X.2011.01160.x.
51. Munson SM, Webb RH, Belnap J, Andrew Hubbard J, Swann DE, Rutman S. Forecasting climate change impacts to plant community composition in the <scp>S</scp> onoran <scp>D</scp> esert region. Global Change Biology. 2012;18(3).
DOI: 10.1111/j.1365-2486.2011.02598.x.
52. Giller KE, Hijbeek R, Andersson JA, Sumberg J. Regenerative Agriculture: An agronomic perspective. Outlook on Agriculture. 2021;50(1).
DOI: 10.1177/0030727021998063.
53. Colantoni et al. "Soil aridity under climate change and implications for agriculture in Italy. Applied Mathematical Sciences. 2015;9.
DOI: 10.12988/ams.2015.52112.
54. Wright Y, et al. Major climate change-induced risks to human health in South Africa," Environmental Research. 2021;196.
DOI: 10.1016/j.envres.2021.110973.
55. Agricultural Research Council. Agromet-Climate Database. Soil, Climate and Water, Agricultural Research Council, 600 Belvedere, Arcadia, Pretoria, South Africa;2018.
56. Stern R, Rijks D, Dale I, Knock J. Instat Climate Guide." University of Reading, England; 2006.
57. Zuma-Netshiukhwi G. The use of operational weather and climate information in farmer decision making, Exemplified for the South-Western Free State, South Africa; 2012.
58. MacMillan EJ. The production of maize in the province of the Free State. Transvaal Agricultural Journal. 1910;9(33).
59. Null J. CCM "El Niño and La Niña Years and Intensities;2021
Available:https://ggweather.com/enso/oni.htm, Mar..
60. Ndlovu M, Clulow AD, Savage MJ, Nhamo L, Magidi J, Mabhaudhi T. An Assessment of the Impacts of Climate Variability and Change in KwaZulu-Natal Province, South Africa. Atmosphere. 2021;12 (4).
DOI: 10.3390/atmos12040427
61. Lyon B. Southern Africa summer drought and heat waves: Observations and coupled model behavior. Journal of Climate. 2009;22(22).
DOI: 10.1175/2009JCLI3101.1
62. Sivakumar M. Climate prediction and agriculture: current status and future challenges," Climate Research. 2006;33.
DOI: 10.3354/cr033003.
63. Hales S. Impacts on health of climate extremes. Climate Change and Human Health: Risks and Responses. 2003;79–102.
64. Mpandeli S, et al. Assessing climate change and adaptive capacity at local

scale using observed and remotely sensed data. Weather and Climate Extremes. 2019;26.
DOI: 10.1016/j.wace.2019.100240

65. Thornton P, Fawcett R, Galvin K, Boone R, Hudson J, Vogel C. Evaluating management options that use climate forecasts: modelling livestock production systems in the semi-arid zone of South Africa," Climate Research. 2004; 26.
DOI: 10.3354/cr026033.
66. Stigter K. Agrometeorological Services under a Changing Climate: Old Wine in New Bags," Bulletin. 2008;57(2).
67. van der Walt J, Fitchett JM. Extreme Temperature Events (ETEs) in South Africa: a review. South African Geographical Journal; 2021.
DOI: 10.1080/03736245.2021.1907219.
68. Jeong H, Byun S, Kim DR, Lee KS. Frost growth mechanism and its behavior under ultra-low temperature conditions. International Journal of Heat and Mass Transfer. 2021;169.
DOI:10.1016/j.ijheatmasstransfer.2021.120941.
69. Jeong H, Byun S, Kim DR, Lee KS. Frost growth mechanism and its behavior under ultra-low temperature conditions. International Journal of Heat and Mass Transfer. 2021;169.
DOI:10.1016/j.ijheatmasstransfer.2021.120941.

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