Evaluating the Effect of Climate Variability on Zea Mays Productivity over Glen Research Station: South Africa

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ABSTRACT

Rainfall and temperature are one of the key environmental parameters that determine the development of a crop and livestock from one growing stage to maturity. Furthermore, temperature is critical beyond maturity but to post harvesting and storage. Rainfall is fundamental in the selection of planting dates, cultivar selection and planting density. Whereas, temperature is essential for calculation of chill and heat units for determining conducive environmental conditions for crop productivity and livestock well-being. In this study, Instat Plus statistical package is utilized to determine potential planting dates, the growing seasons, maize (Zea Mays) for different planting dates from last dekad of October to 1st dekad of January. The growing period length vary from short (less than 100), medium (above 100 days) and long term (above 120 days) varieties. The correct choice of planting time and crop type in the most important decision a farmer or a researcher can make. Taking considerations of water productivity and thermal time requirement for a selected cultivar lessons the effects of high frost risks and water shortages, which leads to soil water deficit and crop withing but encourage supporting maize growth and development. The study also looks at how heat stress jeopardizes the growth in crops, and further determine crop suitability whether to be early or late in season based on thermal times. A thorough analysis and interpretation of log-term climate data would enable the intermediaries to understand valuable knowledge for improved productivity. This paper analysed a long-term climate (1922-2020) data analysis for Glen automatic weather station, to determine climate variability and climate change possibilities, calculate heat unit and chill units. Further, develop suitable adaptation strategies relating to maize crop.

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

I. INTRODUCTION

In recent years, the propensity of weather extremes such as floods, heatwaves, droughts, and cyclones have instigated significant impacts on both the society and the environment [1], [2]. Across industries, efforts are being made to initiate and implement adaptation strategies to manage climate variability and change related risks and enhance preventative measures and adaptive capacity at district level [3]. Nonetheless, suggested preventative and strategies lack meticulous contextualization at local scale. Rural communities in South Africa and elsewhere in other developing countries are lagging behind on proactive approaches to disaster and risks reduction and management. For example, the non-existent of point specific early warning systems, lack of reliable channels of knowledge dissemination to these communities and weather station distribution across provinces is limited[4], [5].

Drought episodes and heatwaves strongly associated with the oceanic-atmospheric interactions, sea surface and El Niño Southern Oscillation [6]. Drought is referred to as a natural demonstration of climate variability and known as the top hydrometeorological hazards, since it affects a number of communities globally. Drought can lead to substantial socio-economic and environmental effects [7]. For example, in 1986-1987, 1991-1992 and 1997-1998 summer drought in southern Africa caused reduction to grain production by as much as 3 million tons, predominantly under rain-fed agricultural area. Drought and extreme temperatures together contributed to crop losses, widespread livestock mortality, water supply shortages and food insecurities [8], [9] and [10]. Other drought associated to atmospheric interactions over oceans range from typical cut-off low-pressure systems, anticyclonic conditions, and tropical, temperate troughs. However, investigations by [11] and [12], explicitly relate South Africa’s rainfall variability to the El Niño Southern Oscillation, which is an indicator of climate variability [13]-[15]. Such occurrence is linked directly to more intense and pro-longed drought. Thus, prompt semi-arid climate, such as the Free State province lead to severe dryness and becoming catastrophic in South Africa [11], [12] and [16].

Moreover, since the early 1970 the increased climate-change-induced weather variability has been witnessed throughout South Africa. These are characterized by high
inter- and intra-seasonal rainfall variability and increasing dryness [12], [17]. Within the South African context, have been confirmed the variability and inconsistencies in intra-annual, intra-seasonal, inter-annual and inter-seasonal rainfall, drought occurrences have become more frequent, intense, persistent [18], [19], causing significant socio-economic interruptions, particularly in the semi-arid areas [18], where Free State. Over the years, based on the data analyzed under discussion, the number of consecutive dry days has been increasing together with the number of daily extreme rainfall events [19]. The scenario gives the indication that, within the fewer days more rains are recorded and thus exacerbate water logging, crop damages, and eventually crop losses. According to [20], the tendency of late season rainfall onset and early seasonal rainfall cessations are also characteristic for most of South Africa, and such occurrences are expanded by the increased rainfall variability associated with climate change [15].

A continuous use of weather forecasting and climate prediction knowledge when engaged in decision making and agro-advisory formulation remains the integral feature [5], [14], [21], [22]. Climate variability, trends, patterns, weather forecast and climate prediction for better agricultural water resource management, tactical and operational decision making is of paramount importance given the occurrences of extremes [3], [5], [23], [24]. On semi-arid areas, water is unquestionably the foremost environmental constraint [25], [26] and the Glen automatic weather station is located at a cold semi-arid area.

Moreover, temperature plays significant role from physiological, chemical, and biological processes of plants [27]. From the agrometeorological perspective, the occurrence of different phenological events throughout the growing planting season is due to the effect of temperature on plant growth which can easily be elucidated using accumulated heat units [5], [28], [29]. According to [30], growing degree days are founded on the concept that the real time to attain a phenological stage is linearly related to temperature in the range between base temperature and optimum temperature. Whereas, the heat unit concept adopts the fact that a direct and linear relationship between growth and temperature is expedient for the valuation of yield potential of a crop in different weather conditions. It has also been observed by many crop growth and development studies, an increase in temperature by 1°C or 2°C resulted in about 20% to 25% decrease in grain yield. The effect of temperature on phenology and yield of crop plants can be studied under field conditions through accumulated heat unit [28], [29], [31], [32].

Based on the seasonal yield predictions and observation, in semi-arid areas of South Africa, maize (Zea mays) grain yield hardly reaches 1 ton/ha under rain-fed conditions, compared to 5 ton/ha under controlled research station where supplementary irrigation and proper soil fertilization is provided. High variability in rainfall event and amounts with high evaporative demand result to constraints in crop growth and yield decline [26], [33]. The meteorological dry spell exceeding 10 days during critical crop growth stages, during approximate flowering and early grain filling stage affect the final yield [34]. Soil water retention differ for different soil types, maize on sandy soils is four times severely affected to maize on clay soils during critical growth stages [31]. Resource poor farmers are immensely impacted by meteorological parameter since extreme weather conditions has devastating effects on crop productivity. For example, Maize (Zea mays L.) is the supreme productive food crop and a stable food in Africa and other parts of the world [35]. Zea Mays verities are the stable food of many who reside within the borders of the Free State province and across South Africa. Reduction in productivity of these particular crops may result to severe food insecurity, keeping into consideration that other agricultural enterprises may be harshly affected [36], [37]. A sowing season of up to 120 days in the semi-arid areas, has the potential evapotranspiration which ranges from 650-950 mm October to March which is a summer growing season. Relating to seasonal rainfalls, it is often lower than the amount of evapotranspiration and rains are highly unevenly distributed. The annual rainfall in semi-arid areas varies from 400-600 mm. The rainfall exceeds the potential evapotranspiration with daily levels that can reach 8 mm day-1, with the possibility of decreasing the aridity index [38].

Agro-climatological parameters are the key factor toward determining, crop suitability and agricultural adaptation strategies [24], [39]. Toward ensuring food security, the agricultural industry contribute to the production of highly nutritious and safe for consumption products and produced at high yields. Adaptation of scientific and indigenous knowledge has high impact toward improved yields [36]. Moreover, adoption of local viable technologies that support improved soil productivity [40], [41], [21] by increasing the depth, fertility, soil water content and physical properties of the upper soil layer [42]. Adoption and application of agrometeorological knowledge and its principles contribute to sustainable agricultural production systems that are dependable [5], [43]. The grander increase in agricultural produce is determined by environmental suitable agronomic practices with a consideration of climatic conditions and soil types, and further production should be based on the preferences of the local people rather than be only market driven elsewhere.

Plants in its discrete photosynthetic metabolism vary in water use efficiency and heat tolerance [18], [44], [45]. Maize varieties are the stable food in the Free State province and produced with success in this region. Publications developed in 1910, indicate that the Free State province in 1909 produced beyond 2 million bags (50 kg) of maize and had the largest export trade in maize of any province in the Free State [46]. Based on the provincial statistics in 2017/18, the Free State produced 3990 bags (50kg) of maize [47]. Comparing maize production in 1909 and 2017, a highly significant decrease is evident. Maize cropping systems remain dominant within Free State mostly under rain-fed agriculture which is one of the livelihood sources to provide food and nutrition support. However, the hotter and drier conditions projected in the South African midlands can have a huge impact on crop productivity [31], [42], [48]. Climate factors include increase in drought frequency and temperature, occurrence of storm winds and the effects of high level of CO2 concentration on plant water use [49], [50]. Frost is another limiting parameter when occur unexpectedly [51]. However, most of studies relating to weather extremes and its

DOI: http://dx.doi.org/10.24018/ejfood.2021.3.3.313
Vol 3 | Issue 3 | June 2021
impact focus on broader scale, overlooking its impact at a localized level.

This study evaluated the latitudinal trends of rainfall, heatwaves, drought and wet/dry spell and related disasters prone to this area, to furnish guide on the formulation tailored agro-advisories and context-specific adaptation strategies suitable for the Free State. It assessed decadal climate patterns and trends, the possibility of seasonal shifts, climate variability, climate change and climate change adaptation practices of farmers. Such developed knowledge plays a crucial role for ecological and sustainable development at a district level to maintain socio-ecological systems. This agrometeorological generated knowledge beneficial for the improvement of local livelihoods. Agriculture is very active in the Free State and most locals rely on natural resources and agriculture for income generation, this categorize them to be highly vulnerable to climate variability and change. Thus, encourage knowledge developers in the field of weather/climate and agricultural scientists to develop adaptation strategies and disseminate for timeously implementation according to improved tactical and operational decision making. These initiatives respond to policy by acknowledging and achieving the Sustainable Development Goals, particularly on reducing poverty, zero hunger, reduced inequality and more importantly climate action.

II. DATA AND METHODS

A. Study Area

The area of the study covers the Free State province (Fig. 1), a province that governs Bloemfontein, Thaba-Nchu and Botshabelo which falls under Mangaung Metro Municipalities and another prominent town in the region. Free State province is located between the latitudes 26.6°S and 30.7°S of the equator and the distances 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. The Glen automatic weather station is located in Motheo District and identifies as 30144 station number, it is situated at an elevation of 1,395 m above the sea level. The province is administratively divided into five districts which are, Motheo district, Xhariep district, Fezile Dabi district, Lejweleputswa district and Thabo Mofutsanyane district (Fig. 1). According to the long-term climatic data indicate that, 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. The region gets the lowest July rainfall and the highest January rainfall with the coldest months being June and July.

B. Climate Data Acquisition

The findings of the nature and trends of rainfall and air temperature happenings was accomplished through an analysis of daily, monthly, and annual rainfall data from Glen weather station long-term climate data. Agrometeorological 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. The climate data was sourced from the Agricultural Research Council-Natural Resource Management & Agricultural Engineering (ARC-NRE) in South Africa. Long-term climate data over the period 1922-2020 data analysis for Glen automatic weather station. Analysis determined and developed suitable adaptation strategies relating to agronomic, phenological and physiological data necessary for crop modelling, operational evaluation, and statistical analysis.

C. Climate Data Analysis

The long-term rainfall and temperature data recorded from 1922 to 2020 were obtained from Glen climatic station in Free State, which is maintained and monitored by ARC-NRE. The data were manually and thoroughly checked for any errors, outliers and temporal inconsistency using Microsoft Excel and INSTAT Plus 3.036. Microsoft Excel was utilized to determine the statistical relationship, such as, averages, correlations, regressions, and deviations. The moving averages (MA) was used to indicate the values below and above the trend line. INSTAT V3.036 was used for data sorting, validation and grouping for analysis. INSTAT (3.036) statistical software [52] was also used for agronomical characterization of the rainfall. This characterization consisted of determining the timing of the onset date and cessation of rains, length of rainy season, total

Fig. 1. South African map and ARC-SCW weather station distribution in the Free State.
seasonal rainfall, and probability of dry spells. Rainfall daily data were analyzed to quantify consecutive dry (a day with rainfall < 1 mm) and wet days (a day with rainfall ≥ 1 mm, a very heavy day with rainfall ≥ 20 mm) the total number of rainfall days, MaxTmax (monthly air temperature maximum from daily values) and MinTmin (monthly minimum air temperature from daily values) and were integrated into monthly and annual data for further analysis. In this study, dry spells are well-defined as periods of 10, 20, and 30 days or more with less than 1 mm rain that can consequence to the initial stage of meteorological drought. Microsoft Excel was used to compute the normal regression statistics, trend analysis and significance of these trends.

D. Glen Area Soil Classification

The distribution of South Africa’s soils is mapped as land types of 1:250 000. A land type is a map unit with uniform macro-climate, typical terrain morphology and a characteristic soil distribution pattern in the landscape [53]. In the Free State, the factors which have played a dominant role in soil formation are parental material and climate. Glen is a farm of approximately 4600 ha in size; it is divided into various land-use practices, for crop production, animal production, natural veld, and cultivated pastures. The farm has multiple soil types suitable for the land use practices. On the pasture camps are four classified soil types which are:

1) Bonheim form (Melanic A horizon up to about 40 cm with some Vertic properties, Pedocutanic B horizon, Unspecified/Saprolite (has been laying for a long-time weathering).

2) Swartland form (Orthic A horizon from 0 to about 20 cm, Pedocutanic B horizon from about 20 to 40 cm, Saprolite from about 40 to 120 cm).

3) Glenrosa form (Orthic A horizon, Lithocutanic B horizon, the depths of the horizons are not confirmed yet). On the cultivated pasture fields.

4) Valsrivier form (Orthic A horizon, Pedocutanic B horizon, unconsolidated material without signs of wetness horizon, depths of horizons not yet confirmed).

The crop production fields were classified as Hutton form (Orthic A horizon, Red Apedal B horizon, depths of horizons not yet confirmed). Various cops have been successfully planted on these fields under dry land and supplementary irrigation.

III. RESULTS AND DISCUSSIONS

A. Annual Rainfall Trends

The Free State province has a moderate annual, seasonal, and monthly rainfall variability and differ across and within the different climatic regions. The eastern part of the Free State has a high annual, seasonal, and monthly variability comparing to the western part of the province. Rainfall varies greatly from the eastern to the western, this is also influenced by the dissimilarities in the landscape. This weather station shows that some years had highest mean annual rainfall of above 1000 mm other years had below 400 mm (Fig. 2). The high variability in inter-seasonal and intra-seasonal, indicate the exposure of this station to dry spells, mostly during spring, autumn and winter season most especially during the climatological months. During spring to summer months, wet spell is prevalent in this region.

The mean annual rainfall in the station ranged from 315.1 mm in 1992 to 1021, 3 mm in 1988 and 1029.5 in 1943. The difference between the highest and lowest recorded mean annual rainfall was 714.4 mm. Approximately about 16.33% of years received recorded mean annual rainfall of below 400 mm. Years that ranged between 400 mm and 600 mm mean annual rainfall was recorded at 59.18% with 25.51% years that recorded mean annual rainfall of above 600 mm. Most interestingly, one in fifty years the mean annual average was recorded above 1000 mm and six in 98 years the mean annual rainfall recorded above 800 mm. Some of these rainfall deviations are entirely linked to El Niño Southern Oscillation events and some associate with hydro-meteorological extremes. The moving average (MA) was utilized to indicate the data trend more clearly and to highlight the values which are above and below the trends (Fig. 2), whereby the filtering effects depends on N and 2 years of MA was used. Moving average is expressed as follows:

\[ MA=1/N \sum_{i=1}^{N} D_t \]

where

\( D_t \) is the actual value at time;

\( N \) is the number of periods in the Mas.

B. Monthly Rainfall Trend

Monthly rainfall trends-cycles demonstrate a distinctive steady decrease from January to March, April to May; June to July and a steady increase from September thereon as the yearly cycles approach the spring-summer season (Fig. 3 and 4). This trend-cycle is unique for this region and also show the monthly mean less than 90 mm. January to February the only months with the highest mean rainfall above 80 mm and June to July, the least recorded months. The moving average indicate September, October to November above the trend line. Additionally, Fig. 3 and 4 show the mean monthly rain days, indicating January to March with highest rainy days and June, July and August have the lowest rain days. Noticeably, the scarcity of rainfall during autumn to winter months reveals and expose this region to be prone to prolonged dry spells and drought events between rainfall onset and cessation.
in this region.

Rainfall cycles and trends are evidently inconsistent resulting to climate variability and even climate change as confirmed by other studies conducted from other climatological zones within South Africa [28]. Nevertheless, the trends are skewed to toward even drier conditions from April to August.

The resulting boxplots in Fig. 4, indicate the minimum values of 0mm observed in March, April, November, and December. Thus, show the occurrence of oddities and the possibilities that other years recorded no rains in these rainy months for this region, unlike the scenario observed in January and February. The rainfall in other years during March and April ranged from 0 mm to over 210 mm, in November from 0mm to over 200 mm and in December ranged from 2 mm to over 180 mm. The daily rainfall assures no rain occurrence in April 1932, March 1943, 1953, 2011 and March 2017 received 3mm, which is irrelevant for agricultural purposes. Unmistakably, the rainy season start in about December month to early April (Fig. 3 and Fig. 4). The flood occurrences are predisposed January, February, and March (Table 1, Fig. 3 and 4). For example, annual rainfall inconsistencies, 377.8mm of rains that occurred within 50 rain days were observed in 1927 and the highest amount of rains occurred within 73 days which amounted of 578.1 mm in 1929.

The representation of wet, dry, and normal rainfall years is indicated in Table I, show the scenarios and the selection of worst and best years. Year 1992 being the driest, normal year seen in 1964 and the wettest years in 1943 and 1988. Based on the representation in Table I and Fig. 3 and Fig. 4 rainfall onset occur from October to April which for summer planting season.

However, rainfall onset was delayed in other years, for example, 2015 and 1948 due to prolonged dry spell and drought events. The onset of rains defined as the first occurrence after when the rainfall accumulated over the previous 10 days is at least 25 mm and no dry spells of more than 9 days in the following 20 days was used as a successful planting date, adapted from [54] On the other hand, the end of the rainy season was obtained by looking for the last day on which the cumulative 25 mm over 10 days occurred.

![Fig. 3. Mean monthly rainfall (trend-cycles) and mean rain days for Glen 98 year’s data.](image)

![Fig. 4. Monthly rainfall variation for Glen Weather Station for 98 years.](image)

| TABLE I. MONTHLY RAINFALL FROM 9 SPECIAL YEARS SHOWING EXTREME AND NORMAL YEARS |
|-----------------|----------|---------|-------|-------|-------|-------|-------|-------|-------|-------|
| Month           | Jan     | Feb     | Mar    | Apr    | May    | Jun    | Jul    | Aug    | Sep    | Oct    |
| Year            | 1992    | 1945    | 2015   | 1948   | 1964   | 1959   | 1981   | 1988   | 1943   | All    |
| Jan             | 18.8    | 62.0    | 49.5   | 102.2  | 18.0   | 66.6   | 188.1  | 40.7   | 71.4   | 617    |
| Feb             | 8.3     | 74.6    | 79.2   | 51.8   | 46.6   | 61.8   | 199.9  | 337.8  | 68.9   | 929    |
| Mar             | 23.6    | 75.9    | 85.3   | 232.8  | 88.7   | 31.9   | 72.1   | 178.0  | 0.0    | 788    |
| Apr             | 22.9    | 12.4    | 21.1   | 47.0   | 25.2   | 39.5   | 26.5   | 111.7  | 0.0    | 607    |
| May             | 0.0     | 4.6     | 16.8   | 17.1   | 4.9    | 34.0   | 30.6   | 12.5   | 270.9  | 209    |
| Jun             | 0.0     | 0.0     | 24.6   | 0.0    | 51.0   | 0.6    | 12.7   | 18.1   | 88.8   | 107    |
| Jul             | 22.3    | 3.8     | 11.2   | 0.0    | 0.0    | 0.6    | 0.0    | 2.0    | 0.0    | 91     |
| Aug             | 0.0     | 0.0     | 7.1    | 0.0    | 2.0    | 0.0    | 0.0    | 0.0    | 49.0   | 107    |
| Sep             | 30.1    | 0.0     | 27.7   | 0.0    | 6.0    | 0.0    | 39.5   | 44.5   | 49.0   | 913    |
| Oct             | 161.0   | 4.3     | 26.2   | 0.0    | 94.1   | 0.0    | 23.4   | 44.5   | 61.5   | 527    |
| Nov             | 28.1    | 65.5    | 26.2   | 0.0    | 99.8   | 0.0    | 22.4   | 44.5   | 121.3  | 695    |
| Dec             | 315     | 42.6    | 2.0    | 0.0    | 74.2   | 0.0    | 22.4   | 44.5   | 171.9  | 651    |
| All             | 315     | 42.6    | 351    | 507    | 111    | 511    | 915    | 1021   | 1030   | 5514   |

DOI: http://dx.doi.org/10.24018/ejfood.2021.3.3.313
C. Annual Number of Rainy Days

The Glen weather station, total number of rainfall days per annum proved to be highly inconstant. The station experienced a steady increase in annual rainfall days from 1964 to 2020. A sharp increase as the outliers are observed from 1957 to 1963, indicate the La Niña year, which explains the above-average rainfall experienced in this region (Fig. 5 and Fig. 7). The other outliers are observed in 2000, 2001 and 2002, which are confirmed to be La Niña years [55]). Year 1961 recorded the highest number of rainy days of 121 and 1930 at the lowest of 36 days. The region experienced the upward trend in total annual rainfall days with the R² of 0.0512 which indicate the steady increase rainy days (Fig. 5). Interestingly, this upward trend is supported by a steady increase in the number of rainfall days. These occurrences indicate extreme rainfall annual variability (Fig. 2, Fig. 5 and Fig. 7). Furthermore, Fig. 7, show March rainfall variability for all the years and the sum of rainy days. Year 1982 and 1987 amounted to 67 rainy days with the in between years recorded below 67. Year 2013 had 54 rain days and 2015 and 2016 with 55 rainfall days per annum, these years was associated with an El Niño event, which further confirms the annual variability in rainfall days and the influences of ENSO phases on the total rainfall days in this region.

Total monthly rainfall days was calculated and indicate monthly rainfall variability (Fig. 6). January month saw the highest number of rainy days which amounted to 1002, with July month recorded 166. The summer months from November to March show a higher number of rainy days which ranged from 761 to 1002 and the winter months ranged from 166 to 391. Thus serve to confirm climate variability and the long dry spells that occur during the winter season in this region.

D. Dry Spell Length Analysis

Consecutive dry days of 1 to 10 days indicate an indication of a weak dry spell period; a medium-strength dry spell between 11 and 20 and above 21 days is categorized as a strong dry spell. Consecutive dry days over the period of 31 days, as observed in Glen weather station (Fig. 8), signify prolonged dry spell periods which agricultural and meteorological drought event within a season. During this season and based on the consecutive dry days, agricultural drought and meteorological drought are a regular event of dry and cold season (Fig. 8 and Fig. 9). Up to about 90 consecutive dry days can be observed in the Free State (Fig. 8), and in some parts of the province even more numbers can be observed.
Some years experienced early rainfall onset starting from mid-October and late onset experienced late December to early January. Dry years displayed annual rainfall far below average annual rainfall in year 1922, 2007, 2015 to mention a few and observed data showed drought occurrence intensifying in the last thirty years. During 2018/19 planting season, prolonged dry spell, which last for up to 28 days had the severe effects in this region. For example, rainfall onset was delayed to early February, which resulted farmers to plant short season cultivars. The average rainfall received for December 2018 was 0.70 mm and the maximum temperature ranged from 30 °C to 40 °C, which lead to higher evapotranspiration rate. Another example, severe drought event in 2015/2016 and 2018/2019 resulted to severe impact on crop production, animal husbandry and human health. Prolonged dry spells or drought events in rain-fed production consequent to crop failure and food insecurity.

An example of longer length dry spell periods is seen in year 2017, March received only 3mm and such occurrence impeded crop growth and development under rain-fed crops, which led to crop failure. It is apparent this location experience rainfall inconsistencies which lead to severe impact on agricultural productivity in the absence of weather forecast and climate prediction for informed decision making.

The largest daily extreme was seen in 1976 and 1988 and both amounted to about 96mm. Other extremes recorded above 80mm per day were observed in 1960, 1996, 1998 and 2006 which recorded 86.9 mm. 85 mm, 83 mm and 80.9 mm, respectively. Just about 23 in 86years had a value over 60 mm which counts of only 26.7%. Just over half years had a value of more than 40 mm which count to about 70%.

This region indicate 80% probability of receiving 67.04 mm. The annual maximum exceed 67.04 mm on one year in 5, simple meaning the the five-year return period. The maximum daily was less than 30.5 mm in 50% of the years and less than 35.04 mm was received in less than 20% of the years. The model estimate that the best sowing date is the 31 December for early planting in good rainfall years. Mid-November, late-November, early December, early December, first and last week of January are the best planting dates provided crop type and cultivars are taken into considerations.

E. Temperature Data Analysis

Field experiences and climate studies has provided scientific evidence of the Earth progressively getting warmer [14]. The province is situated inland of South Africa. It is typically warm, with extreme heat in summer and extremely cold temperatures during autumn to winter seasons in winter (Fig. 9 and Fig. 10). More extreme intra-day, intra-seasonal and inter-seasonal air temperature variations were observed. The province is characterised by warm to sizzling summers, heatwave, wind storms, wildfires and winters are severely cold with occurrence of black forst. Fig. 10 displayed a slight downward trend on minimum temperature. The decrease in night air temperatures and a significant increase in day-time air temperatures specify distinct air temperature variations in this region, and thus contribute to low soil regime temperature and the low specific heat capacity of the soil. Daily air temperature variations with decreased wet days and mean annual rainfall, consequence to dry spells and drought.

In this region, January to November the minimum temperatures could drop below zero. January to March and October have minimum temperatures ranged from -5 °C and 0 °C. During the coldest months June, July and August minimum temperatures can drop to below -10 °C. The highest maximum temperatures are distinct between September and March, but only January recorded the highest maximum above 40 °C. The highest recorded maximum temperature was 42 °C (Fig. 9 and Fig. 10).

Temperature is one of the most important climatic parameters as it is a determinant of plant and animal growth and survival. Moreover, crops, livestock, stored products, packaging of products, pests and diseases are all affected by the temperature conditions. Temperature is a primary factor affecting the rate of plant development. High air temperature reduces the growth of shoots which affect root growth. Understanding of temperatures assure identification of critical temperatures which are the limits that cause distinct but sub-lethal responses, 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 are 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.

![Fig. 8. Daily rainfall distribution and dry spell lengths indication for year 2017.](image-url)
F. Maize Crop Production

The average maize yield for Glen Experimental Farm from 2006 to 2020 was 3.78 tons ha⁻¹. The seasonal yield ranged from 1.98 7tons ha⁻¹ to 5.44 7tons ha⁻¹. The highest maize yield was achieved 2006, 2008, 2013 and 2020. The trend indicates a slightly and insignificant increase in crop yield with R² of 0.0043. The Free State average maize yield was recorded at 3.8 tons ha⁻¹. (Fig. 11). An indication of maize yield pattern and seasonal rainfall trends shown in Fig. 11. The crop yield pattern indicates, the correlation between seasonal rainfall and maize crop yield. During the drier season the yield was lower comparing the seasons that obtained higher seasonal rainfall (Fig. 11). Maize production is economically viable if the production exceeds 3.6 7 tons ha⁻¹. The yield average obtained from this study indicate the average yield for this region is within the expected amount. The crop coefficient (Kc) as the ratio of crop evapotranspiration (ETc) over Evaporation (ETo). The Kc coefficient approach integrates crop characteristics and averaged effects of evaporation from the soil. The Kc values for initial, crop development, mid-season, and late stages crop development, ranged from 0.40-6., 0.70-0.80,1.1-1.21 and 0.50-0.66 (b).

The planting dates were selected based on the rainfall probabilities for the region, 14-day weather forecast and regional climate prediction, whether the predicted rains would be above-normal, normal, or below normal. The planting dates were identified from, last October dekad 3rd, 2nd November, last December dekad and 1st January dekad. During the planting season were dry spells were observed supplementary irrigation was established to avoid crop failure and improve soil water content. Planting season 2011/12 and 2015/16 was the most affected, the seasonal rains ranged from 257.7 mm and 259,1 mm, this planting season was associated with drought events in the province. Field management measures are critical mostly during drought events to retain soil water content and minimize the rate of evapotranspiration toward optimizing the turgidity of crops.
The results indicated the highest crop canopy was about 80% obtained at 80 days after planting (Fig. 12(a)), with a leaf area index of 4.8 for maize late planted cultivar under rainfed. The best planting dates were observed to be in mid-November, mid-December, and most preferable early January to minimize the occurrence of prolonged dry spells and increase planting density for economically viable yield. Degree days are critical for determining the length of the season and the suitable planting dates to improve the yields.

Understanding of rainfall and air temperature trends and its features is essential for planning as well as formulating strategies for area-specific adaptation. This study also contributed on the implementation of United Nation’s Sustainable Development Goals (SDGs) and developed recommendations that could be implemented when formulating local adaptation strategies toward the improvement of the environment and the livelihood of the societies. Timely dissemination of knowledge on adaptation strategies could guide the communities to take necessary preventative measures and minimize disasters. For example, decrease in the number of rainfall days, lead to shorter planting season, and lack of water and thus infringe the right to clean water for agricultural production. But increasing in time and night temperature, could affect crop growth and physiology, to alleviate poverty water storage, irrigation and adoption of climate smart agriculture are the preeminent recommendations. Poverty alleviation programmes in the Free State are grounded on selling the final products to the community as fresh maize on the cob, dry maize for livestock feed and selling dry maize to the millers for maize meal. All these final maize products are sold for generation income.

IV. CONCLUSIONS

The study area is located in a semi-arid Agroclimatological Zone with the annual rainfall of 559 mm. The highest rains occur in January with the lowest rains in July and the coldest months being June and July. The study area constitutes of three soil types, namely, Bonheim, Swartland, Glenrosa and Valsrivier which are under pasture camps and under crop production Hutton soil form.

The climate data indicate the highest mean annual rainfall amounted to 102.3 mm in 1988 and 1029.5 mm in 1943 with the lowest at 315.1 mm in 1992. The high variability in inter-seasonal and intra-seasonal, indicate the exposure to dry spells, in spring, autumn and winter season. This region experiences wet spell in spring and summer month.

One in fifty years an annual average was recorded above 1000 mm and six in eight years at 800 mm. The rainy season starts late December to early April and floods are susceptible from January to March. Sequential planting may start as early as October to April for summer crops. January had the highest number of rainy days comparing to other months. Prolonged dry spells of more than 31 days were observed at Glen automatic weather stations. The largest daily extreme was seen in 1976 and 1988 and both amounted to about 96 mm. The region is characterised with more extreme intra-day, intra-seasonal and inter-seasonal air temperature variations.

Findings in the study indicated that, maize yield average was about 3.78 tons ha⁻¹. The suitable planting dates were identified from, last October decade 3rd, 2nd November, last December decade and 1st January decade. The maize growing seasonal rainfall ranged from 257.7 mm and 745.5 mm, with the crop coefficient Kc ranging from 0.5 to 1.28. Comparing to other studies, Kc can vary from one region to another. These Kc variations are influenced by environmental conditions, variety selection and crop developmental stages. Furthermore, agrometeorological parameters result to Kc variation, elevated air temperature, water vapour pressure deficit during the growing season that trigger leaf stomatal closure which impeded the plant from full potential transpiration.

We recommend that the crop producers incorporate weather forecast, climate prediction, climate smart knowledge and technologies, preventative measures and early warning systems minimize the extent of risk. This study area was selected because of the active crop production and other agricultural enterprises. However, special training on agrometeorological applications should be arranged for the local farmers and extension intermediaries within the region.

Dynamic trends and characteristics of both rainfall and air temperature regimes for this region must be understood from context-specific perspectives to address challenges brought by climate variability and change to improve agricultural produce and food security.

ACKNOWLEDGMENT

The National Research Foundation financially supported this research.
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