SHORT COMMUNICATION

CHARACTERISING PAST CLIMATE CHANGE IN THE SOUTH AFRICAN SUGAR INDUSTRY: PRELIMINARY FINDINGS FOR TEMPERATURE AND RAINFALL, 1980-2024

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Abstract

Climate change, past and future, manifests as long-term changes in the annual or seasonal rainfall and air temperature values, as well as changes in their variability, for rainfall in particular. These changes pose a significant threat to agricultural systems, sugar production included. Projected future climate change and variability patterns for the South African sugar industry have been reported but, to date, little attempt has been made to characterise and quantify the real changes, in order to confirm or refute the perceived changes. This paper aims to characterise the changes in the rainfall and temperature across all the major sugarcane-producing regions of South Africa. The long-term (1980-2024) daily air temperature and rainfall records from the representative weather stations in each region were analysed by using the Climpact climate analysis tool to generate several climate change indicators. The preliminary findings showed a clear increase in the daily maximum and average temperatures for all the regions, but there was no clear trend for the minimum temperature. The rainfall analyses produced no clear trend for the annual rainfall amounts or extreme events for most of the regions, due to the high levels of inter-annual variability. Only the Midlands region showed a significant increasing trend in the annual total rainfall. The next steps in the study will be to expand the analysis to include additional study sites and to assess the impact of the increased maximum temperature and rainfall variability on sugarcane production in each region.

Keywords: Climate, temperature, rainfall, climate change, climate variability, sugarcane

Introduction

Sugarcane is grown in the eastern parts of South Africa, which receive relatively high rainfall. However, the inter-annual variability in weather (rainfall, air temperature, relative humidity and wind), as well as the cyclical variations due to the El Niño and La Niña phases of the El Niño-Southern Oscillation (ENSO), are a significant source of risk for sugarcane production, especially in the rainfed production areas, but also due to their impact on the available water resources in irrigated areas. In addition, there are risks associated with climate change, namely, the long-term changes in the annual or seasonal rainfall and temperature values and their variability.

The Intergovernmental Panel on Climate Change (IPCC) has reported rising global average temperatures, with the past few decades experiencing an accelerated warming trend (IPCC, 2023). The IPCC also reports that there is stronger evidence over the past 10 years of observed changes in climate extremes, including heatwaves, heavy rainfall events, droughts and tropical cyclones (IPCC, 2023). Climate extremes will not only have a direct impact on sugarcane production, but they will also have an impact on the Gross Domestic Product (GDP), employment in the sugar industry and foreign exchange earnings. Climate change could also result in a spatial shift in the optimal sugarcane production areas.

The projected future climate change and its impact on agricultural production, both globally and in South Africa, have been receiving increasing research attention in recent years. However, little work has been done to characterise and quantify the past climate change in the sugarcane-producing regions of South Africa, in order to confirm or to refute the perceived changes. Singels *et al.* (2005) reported a 0.75°C temperature increase and an increase in rainfall variability between 1954 and 2004 at Mt Edgecombe. Jones *et al*. (2015) reported a decreasing rainfall trend in Zululand for the period 1980-2010. Strydom and Savage (2018) found that the microclimate had changed in the KwaZulu-Natal Midlands, with an increase in the annual average air temperature being greater than the African and global observations, an increase in the relative humidity and, in some areas, a significant decrease in the rainfall. In a study in the uMngeni Catchment of KwaZulu-Natal, Strydom *et al*. (2020) noted the increased daytime temperatures and changes in the atmospheric water vapour pressure at some locations, but no significant changes in the annual rainfall totals, despite the high levels of inter-annual variability.

The valuable weather database collected and curated by SASRI over several decades provides an opportunity to investigate the past climate change. The purpose of this short communication is to report some preliminary findings of a study that aims to characterise the changes in rainfall and temperature, using historic climate data, across all the major sugarcane-producing regions of South Africa.

Methodology

Daily maximum and minimum air temperature and rainfall data for six sites across the South African sugar belt were obtained from the SASRI weather database (https://sasri.sasa.org.za/weatherweb) for the period 1980 to 2024. Daily mean temperature was calculated as the average of the daily maximum and minimum temperature. The six sites, all with suitable long and complete datasets, were carefully selected to ensure the representation of all the major agroclimatic regions of the sugar industry. The selected sites and the regions represented were:

- Komati - Mpumalanga Lowveld, irrigated;
- Pongola – Northern Zululand, irrigated;
- Umfolozi – Zululand, partially-irrigated;
- Mount Edgecombe - North Coast, rainfed;
- Noodsberg - Midlands, rainfed; and
- Sezela – South Coast, rainfed.

Climpact (https://climpact-sci.org/) is an R-based software package that was developed for the World Meteorological Organisation (WMO) for the calculation of various climate indices associated with temperature and rainfall extremes for climate monitoring assessments (Zhang *et al*., 2011). Climpact was used to generate selected climate indices (see Table 1) for each of the six sites. These indices were deemed suitable for the study due to their relevance in agricultural applications in general and, in particular, the sugarcane-producing areas of South Africa. The data quality control functions of Climpact were used to ensure and enhance the integrity and temporal consistency of the data. The overall trend of the time series was determined in Climpact, using the Sen's slope. The P-value associated with the Sen's slope was calculated by using the Mann-Kendal test to determine whether the observed trend was significant at a confidence level of 0.05.

Results and Discussion

A total of 12 climatic indices, based on the annualised values relating to the air temperature and rainfall extremes, were used to assess climate change in the sugar industry. The findings are presented in Table 1.

Table 1. Selected Climpact air temperature- and rainfall-related indices for the six study sites. The values indicate the slope (rate of change in units/decade (based on annual records), and the units are as specified). Bold and italicised values indicate significant ($P<0.05$) rates of change

Short name	**Long name**	**Definition**	**Units** (per decade)	**Rate of Change (units per decade)**					
				KOM	**PON**	**UMF**	**MTE**	**NDS**	**SEZ**
CDD	Consecutive Dry Days	Maximum number of consecutive dry days (when PR<1.0 mm)	days	1.30	***4.44***	-1.10	1.40	-0.66	***3.40***
FD	Frost Days	Number of days when TN<0°C	days	0.00	0.00	0.00	0.00	0.00	0.00
GDD	Growing Degree Days	Annual sum of TM - n (where n is a user-defined base temperature and TM > n). Here n=10°C.	°C	***91.70***	***72.60***	***66.50***	***88.30***	***88.00***	6.30
PRTOT	Annual total wet-day PR	Sum of daily PR≥1.0 mm	mm	19.20	4.50	1.30	22.00	***46.70***	54.00
R10mm	Number of heavy rain days	Number of days when PR ≥ 10 mm	days	0.66	0.00	0.00	0.64	***1.67***	0.00
R20mm	Number of very heavy rain days	Number of days when PR ≥ 20 mm	days	0.56	0.39	0.00	0.70	0.65	0.31
TMm	Mean TM	Mean daily mean temperature	°C	***0.24***	***0.20***	***0.17***	***0.24***	***0.24***	0.02
TNm	Mean TN	Mean daily minimum temperature	°C	0.14	0.04	-0.07	0.00	***0.21***	-0.20
TNn	Min TN	Coldest daily TN	°C	0.08	0.07	-0.24	-0.17	0.07	-0.09
TXm	Mean TX	Mean daily maximum temperature	°C	***0.40***	***0.40***	***0.46***	***0.50***	***0.30***	***0.22***
TXx	Max TX	Warmest daily TX	°C	***0.71***	***0.48***	***0.95***	***0.60***	***0.66***	***0.88***
TXge38	TX of at least 38°C	Number of days when TX ≥ 38°C	days	***3.30***	***0.60***	***1.20***	0.00	0.00	0.00

TX = maximum air temperature, TN = minimum air temperature, TM = mean air temperature, PR = precipitation (rainfall). KOM = Komatipoort, PON = Pongola, UMF = Umfolozi, MTE = Mount Edgecombe, NDS = Noodsberg, SEZ = Sezela

Maximum Temperature

The results showed a statistically significant increasing trend for all the indices relating to maximum temperature at all the study sites (Table 1). The annual absolute daily maximum temperature (TXx) showed an increasing rate range of 0.48 to 0.95°C per decade, with Umfolozi recording the highest increase. The increase in the annual mean daily maximum temperature (TXm) ranged between 0.22°C per decade (Sezela) and 0.46°C per decade (Umfolozi). There was also an increasing trend in the number of days with extreme maximum temperatures (at least 38°C, TXge38) with the potential of inducing heat stress in sugarcane in the irrigated areas. The number of days with extreme maximum temperatures increased at a rate of 1.2 days per decade for Umfolozi and 3.3 days per decade for Komatipoort, where up to 35 days per annum with extreme temperatures have occurred (2016). The years with the peak numbers of days with extreme maximum temperatures (Figure 1) coincide mostly with the El Niño phenomenon, due to the associated hot and dry conditions.

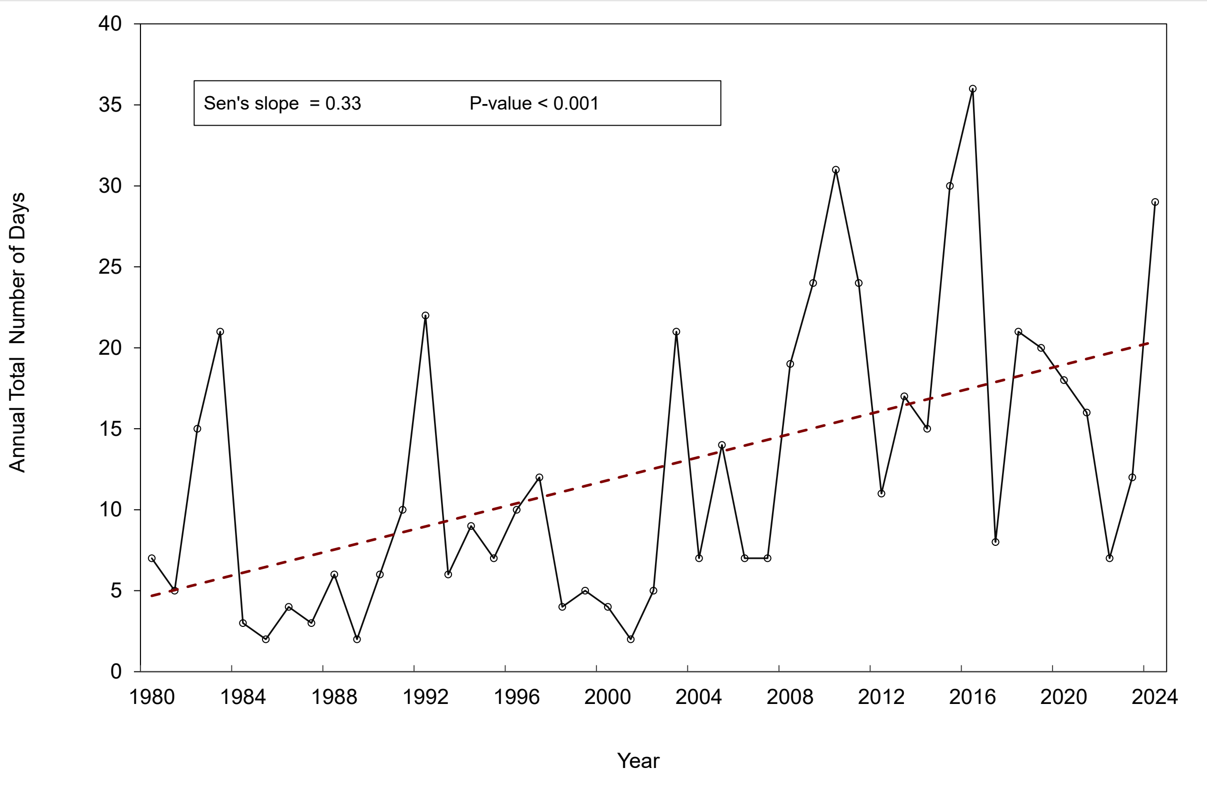

Figure 1. Annual total number of days when maximum temperature was more than 38°C at Komatipoort between 1980 and 2024. The dashed line is the Sen's slope, which represents the overall annual rate of change (increase) over that period.

The increasing trend of maximum temperatures resulted in an increase in the daily mean temperatures (TMm) across all the sites, with the highest rate of increase of 0.24°C per decade was observed at Noodsberg, Komatipoort and Mount Edgecombe. Consequently, the growing degree days (base 10°C) (GDD) showed a significant increasing trend for all the sites, ranging from 63- to 92-degree-days per decade. This has potentially wide implications for sugarcane production, both positive and negative. Higher temperatures promote a faster growth rate, which potentially increases radiation interception and results in better yields (Jones *et al.,* 2015). However, they could also result in increased water stress and related risks during periods of inadequate soil water availability, in both rainfed and irrigated areas. Cane quality could also be affected negatively, due to increased vegetative growth under warmer conditions when soil water is not limiting (Singels *et al.,* 2005). Higher temperatures may potentially result in shorter harvesting cycles, e.g. in the Midlands, but they could also pose increased pest and disease pressure.

These results confirm and add to the evidence of a climate that is becoming more extreme and at similar magnitudes to the values reported by others (Nayamuth, 2005; IPCC 2023; Strydom *et al*. 2020) with respect to average and maximum temperatures. Singels *et al* (2023) projected temperature increases of about 2°C, with little spatial variation across the South African sugar industry, for the 2046-2065 time-period (relative to the 1971-1990 baseline period), with uncertainty around the rainfall projections.

Minimum Temperature

There was no definite trend for the minimum temperature (TNm and TNn), including the related indices, like frost days (FD), across all the sites. The average (TNm) and absolute (TNn) annual minimum temperatures decreased slightly at three sites (Umfolozi, Mount Edgecombe and Sezela) and increased at the other three sites. However, all these trends were not significant, except for Noodsberg, where the data suggested a significant increase in the mean daily minimum temperature at a rate of 0.21°C per decade. Less severe minimum temperatures would be expected to have a positive effect on germination, seedling development, ratoonability and yield (Sanghera, 2020). The increasing trend of the minimum temperature for Mount Edgecombe, reported by Singels *et al*. (2005), could not be confirmed in this study. The minimum temperature data across all six sites showed high levels of inter-annual variability, but with no significant trend.

Rainfall

No significant trend was observed for the annual total rainfall (PRTOT) for all sites, except for Noodsberg. Other rainfall-related indices, like the days with extreme rainfall, also showed no significant changes at most sites (Table 1). An analysis of the rainfall data by month and season did not indicate any noticeable shift in the rainfall seasonality either. The only exception was Noodsberg, where the annual total rainfall showed a significant increasing rate of nearly 47 mm per decade (Figure 2), coupled with an increasing trend for the number of rainfall events, recording at least 10 mm (R10 mm). On the other hand, four of the sites showed an increasing number of days without rainfall, with Pongola and Sezela having a significantly-increasing rate of consecutive dry days per year (CDD) at 4.4 and 3.4 days per decade, respectively.

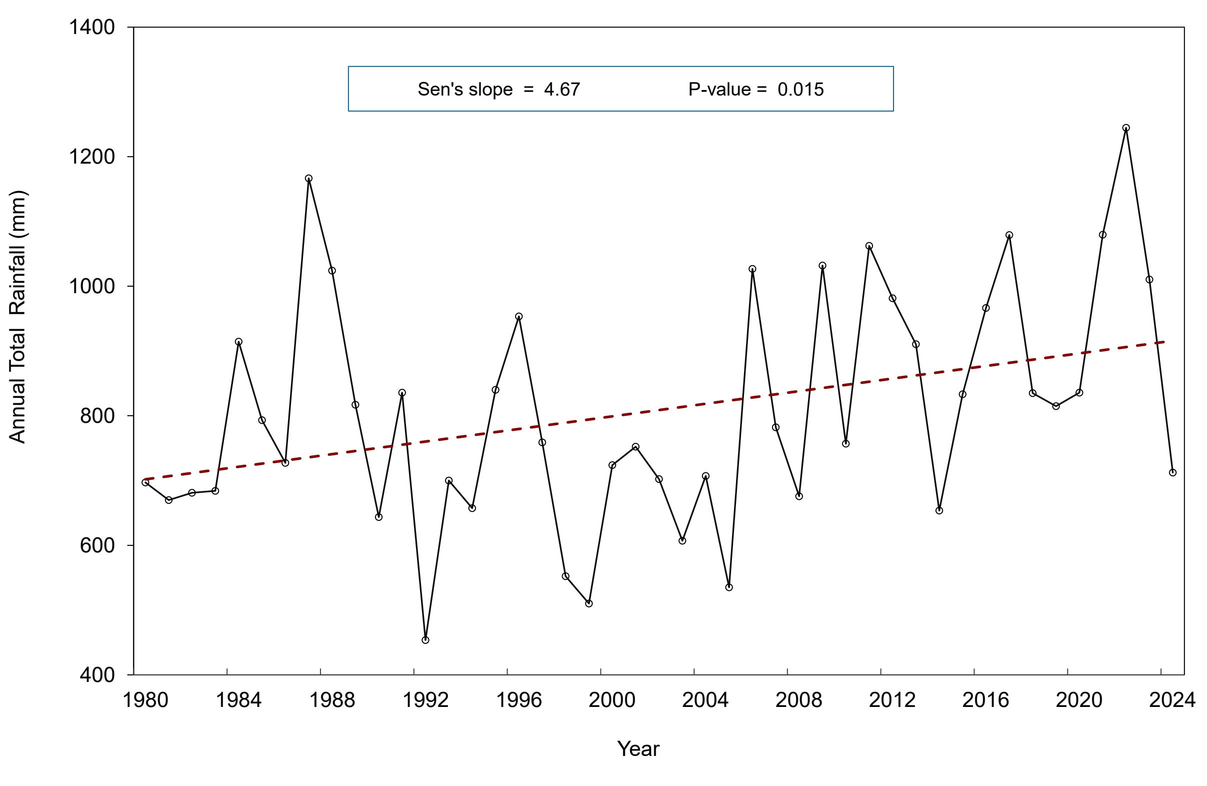

Figure 2. Annual total rainfall for Noodsberg between 1980 and 2024, for daily rainfall events of at least 1.0 mm (PRTOT). The dashed line is the Sen's slope, which represents the overall annual rate of change (increase) over that period.

Overall, the rainfall data also showed a high inter-annual variability, which is often linked to the ENSO phenomena (high during La Niña conditions and low under El Niño conditions), and which is in line with the previous findings by Singels *et al*. (2005) and Strydom *et al.* (2020). Jones *et al*. (2015) reported small changes in the projected annual rainfall at the three sites investigated and commented that there were considerable variations in the rainfall trends between different projections.

The increasing number of consecutive dry days for Pongola and Sezela indicate an increased risk of lower yields related to water availability, especially in rainfed crops. An analysis of the trends in the sub-daily rainfall intensity would be useful for informing the design and implementation of erosion and runoff control structures.

Conclusions

Across all the study sites, an increase in the daily maximum and average temperature and all the related extreme heat indices was the clearest and most significant trend established in this study. The associated increase in the growing degree days may have implications for sugarcane maturity, while also posing pest and disease threats, e.g. in the Midlands. There was no evidence of trends in cold weather extremes across all the study sites. The study results suggest that rainfall is becoming more variable, with more large events and more consecutive dry days, in general, but there was no noticeable trend in the annual total rainfall, except for the Midlands, where increasing annual totals were observed at Noodsberg. The northern irrigated areas, while getting warmer, are not really getting wetter, which raises concern over the irrigation water demand and availability in future, due to the elevated crop water use. In the rainfed and cooler areas, higher temperatures may promote more vigorous growth, but they will also increase the risk and severity of water stress during periods of drought. This study will be extended to more sites across the industry, in order to help assess the related impacts on sugarcane production and quality.

Future Work

Work is underway to increase the number of study sites, in order to ensure that all parts of the industry are adequately represented and, where possible, to corroborate the regional trends. Thereafter, climate-driven parameters, such as the potential and simulated evapotranspiration from sugarcane production, thermal discomfort and fire danger indices, will also be analysed. Finally, the impact of climate change on sugarcane production in South Africa over the same period will be analysed to evaluate the trends in production.

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