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# Temperature and relative humidity trends in the northernmost region of South Africa, 1950–2016

The northernmost Limpopo Province is located in one of the warmest regions of South Africa, where the agricultural sector is prone to heat stress. The aim of this study was to explore air temperature and relative humidity trends for the region, which have implications for agricultural adaptation and management (amongst other sectors). In particular, we investigated seasonal, annual and decadal scale air temperature and relative humidity changes for the period 1950–2016. Positive temperature trends were recorded for this period, averaging +0.02 °C/year, with the strongest changes observed in mean maximum summer temperatures (+0.03 °C/year). Interannual temperature variability also increased over time, especially for the period 2010–2016, which presents probability densities of <50% for minimum temperatures. Positive relative humidity trends (+0.06%/year) were also recorded for the period 1980–2016, but proved to be the least predictable weather parameter, with probability densities of <0.5% across seasons for the study period. Considering the substantial interannual variability in temperature and relative humidity, there is clear increased risk for the agricultural sector, particularly for small-scale farmers who generally have limited capacity to adapt. Climate science focusing on the southern African region should continue to establish the impact of climate change and variability on specific small-scale farming systems and enterprises, with recommendations for strategic adaptation based on up-to-date evidence.

**Significance:**

- Heat indices have increased, and variability in temperature and relative humidity has substantially increased over recent decades.
- Changes in air temperature and relative humidity have direct and/or indirect negative effects on sectors such as agriculture, leading to reduced productivity.
- The small-scale farming sector, which contributes significantly to national food security in developing countries, is the production system most exposed and vulnerable to observed changes/extremes in temperature and relative humidity.
- There is an urgent need to build capacity of small-scale farmers for appropriate adaptation to observed changes in climate based on up-to-date evidence.

## Introduction

Globally, mean air temperatures have increased by at least 0.65 °C over the past century, while extreme rainfall events have also increased in frequency.[1-3] It is widely projected that as the earth becomes warmer, climate and weather variability will increase.[4-7] Projected temperatures for southern Africa indicate expected near-future increases at twice the global average.[8] Such changes in climate present a significant threat to food security, water resources, health and infrastructure.[2] Low-income countries are likely to be the most vulnerable to extreme climatic events due to their poor adaptive capacity in terms of finances, resources, infrastructure and expertise.[9] In particular, the small-scale farming sector, which contributes significantly to national food security in developing countries, is an exposed and vulnerable production system.[10] The situation is compounded in cases where there are limited reliable historical climate data available to establish climatic trends – a concern that holds true for most African countries.

In order to develop a sustainable adaptive capacity for target regions, and address current and future challenges presented by climate variability and/or change, it is critical to evaluate historical climate trends.[10] Process-based regional and global climate models generally have the ability to replicate large-scale climate features. However, their coarseness in spatial resolution poses challenges in providing usable information at local scales.[11,12] Region-specific historically observed climatic records, where possible, have the potential to assist ongoing climate modelling and projections, and to establish the likely impact of climate change on agricultural productivity and ultimately food security.

Several studies on historical weather and climate change have been focused at the countrywide level in South Africa[12-14], while others have been more region specific, with finer spatial detail[14-18]. For example, the study by Gbetibouo[15] on the Limpopo Basin area in northernmost South Africa provides some information on climate trends in the region. It should be noted that the study mainly focused on farmers' perceptions and adaptation to climate change and variability, rather than a detailed analysis on climate trends. A further study focused on 30 Limpopo Province catchments, analysing temperature trends for the period 1950–1999[16], and established increases in annual and seasonal temperature. However, this study did not include relative humidity, and hence was unable to establish heat indices. In the context of agricultural and human/animal thermal comfort levels, a combination of these two weather parameters (i.e. temperature and relative humidity) is important for establishing heat indices – effectively a measure of how hot it feels. Understanding of heat indices is particularly important for most resource-limited rural communities in Limpopo Province and other rural sectors of southern Africa involved in smallholder farming enterprises, many of which may already be adversely affected by extreme weather events. Evidence shows that increases in heat index trends will have far-reaching impacts on agricultural production and productivity, especially in poor communities with constrained adaptive capacity.[19,20] We thus aimed to provide an improved understanding of recent temperature and relative humidity trends in the northernmost region of the Limpopo Province, which has implications for determining heat stress. The particular focus here was on analysing seasonal and annual temperature and relative humidity trends for the period 1950–2016, and hence the computation of heat indices.

## Materials and methods

### *Study area*

This study focused on the northern border region of the Limpopo Province, South Africa (Figure 1). The region is located in the Vhembe District Municipality, where a large portion of its rural population resides. This semi-arid region is located in one of the warmest parts of South Africa where temperatures regularly exceed 40 °C during the warm season.[21] Mean daily maximum temperatures during summer also exceed 30 °C, and precipitation averages only ~250 mm p.a., most of which falls during summer.[21] Such climatic conditions (particularly high temperatures) regularly cause heat stress, especially in the livestock sector, thereby reducing potential productivity.[22] The Limpopo Province is one of the economically and financially poorest provinces in the country, with livelihoods in most rural villages depending on subsistence farming and casual employment. Government grants and remittances from off-site relatives contribute significantly to household incomes. Smallholder farmers produce crops and rear some livestock.

### *Data collection*

Daily temperature (1950–2016) and relative humidity (1980–2016) data for two weather stations (Macuville: data period = 1950–2014; Venetia Mine: data period = 2015–2016) in northernmost Limpopo Province were provided by the South African Weather Service. Temperature and humidity values are variable across any given landscape due to topography, land cover and external climatic inputs (e.g. airflow from surrounding regions). The values we present here are thus in *absolute* terms, only relevant to the station localities, and for the broader region serve as a more general (*relative*) indication of conditions, rather than *absolute* conditions for any given site in the province. Information was collated monthly and seasonally. Traditional seasons in South Africa are divided into summer (December – February), autumn (March – May), winter (June – August), and spring (September – November).[4] For ease of analysis, temperature data were further divided into two periods: 1950–1986 and 1980–2016.

Data were assessed to identify missing and incorrectly reported or recorded values (e.g. daily minimum temperature greater than the daily maximum temperature). Missing and/or incorrect values were then replaced using temporal interpolation techniques (hierarchical polynomial regression techniques, in particular) as described by Boissonnade et al.[23] Missing values were replaced through interpolations between observations over time (temporal interpolation). In addition, change points were identified[24] and homogenised using the quantile-matching adjustment method[25]. Using the quantile-matching method, up to 10 years' of data, before or after a change point, were used to produce reliable adjustments.[24,25] For relative humidity, zero drift in sensors was assumed.

### *Data analyses*

Temperature and relative humidity trends were determined using R software packages (lubridate and forecast)[26,27] with seasonal and trend decomposition using the locally weighted smoothing (LOESS) (STL) function. LOESS was used in regression analysis for creating a smooth line through a timeplot, thus demonstrating the relationship between variables and forecast trends. Graphs plotted from STL show four components: (1) the original data (i.e. a set of actual values); (2) a seasonal component calculated using LOESS smoothing; (3) the trend (i.e. increasing or decreasing direction in the data); and (4) the remainder representing the residual.

The total number, amplitude and intensity of heatwave days were calculated for each year. Threshold values for a heatwave were based on the average maximum temperature of the hottest month of a given year plus 5 °*C, as described by* Mbokodo et al.[28] The totals per year were only for heatwave days, where the maximum temperatures exceeded the threshold for three or more successive days, thus guaranteeing that heatwave events with a shorter duration were also detected. It is worth noting, however, that this heatwave computation ignores extremes associated with cooler months and changes in adaptation-related impacts.

Probability density plots, calculated using R software package ggplot2[29], were tested for significance at the 95% confidence level, and used to establish variability of temperature and relative humidity across the seasons and decades under study. Density plots provide a relative likelihood of these random variables falling within a particular range of values. The heat index (incorporating air temperature and relative humidity) was calculated using weathermetrics[30]. Maximum daily air temperatures and minimum relative humidity were used to determine the heat index. Weathermetrics' heat.index creates a numeric vector of heat index values from numeric vectors of air temperature and either relative humidity or dew point temperature. In calculating the heat index in R using the weathermetrics package, the following code was used:

heat.index (t = NA, dp = c(), rh = c(), temperature.metric = 'celsius', output.metric = celsius),

where t is numeric vector of air temperatures; rh is numeric vector of relative humidity (in %); temperature.metric is the character string indicating the temperature metric of air temperature and dew point temperature (possible values are 'celsius'); and output.metric is the character string indicating the metric into which heat index should be calculated (possible values are 'celsius').

Weathermetrics calculations for heat index are based on the National Weather Service Hydrometeorological Prediction Center Web Team Heat Index Calculator.[31] Results from weathermetrics were validated by the RClimdex version 1.9[32] software calculations on warm days (TX90p) and warm spell duration indicator (WSDI). TX90p shows the percentage of days when maximum temperature (TX) is greater than the 90th percentile centred on a 5-day window, while WSDI highlights the annual count of days with at least 6 consecutive days when TX is greater than the 90th percentile.

## Results

### *Temperature trends*

Time series graphs show positive trends in temperature, with averages marked for each month over the 1950–2016 period (see Figures 2–4). Rates of minimum, mean and maximum temperature increases were similar (+0.02 °C/year) for the study period. However, summer maximum temperatures recorded the highest rate of increase (+0.03 °C/year) compared to other seasons and other temperature parameters (i.e. average and minimum). Seasonal and trend decomposition of temperatures show that mean maximum temperatures ranged between 28 °C and 33 °C (see Supplementary figure 1), average temperatures ranged from 21 °C to 25 °C (see Supplementary figure 2), and mean minimum temperatures from 14 °C to 18 °C (see Supplementary figure 3). The absolute highest and lowest recorded temperatures were during the summer of 1992 (45.2 °C) and winter of 1972 (-3.8 °C), respectively (see Table 1).

Strongest positive warming trends are observed for the past three and a half decades (i.e. from 1980–2016). For instance, mean annual maximum temperatures increased at a rate of +0.02 °C/year between 1950 and 1986, but substantially increased to +0.03 °C/year for the period 1980–2016.


**Figure 1:** The study area: Northernmost Limpopo Province, South Africa.

The rate at which mean annual temperatures have increased, has remained similar over time: 0.02 °C/year over the period 1980–2016, compared to 0.02 °C/year for the period 1950–1986. None of the warming trends (i.e. for the periods 1950–2016, 1950–1986 or 1980–2016) were statistically significant at the 95% confidence level.

### *Heatwave trends*

The value for determining the threshold for a heatwave in northernmost Limpopo Province was 38.9 ºC (i.e. 33.9 ºC+5 ºC). All heatwaves occurred during the summer season. The rate of increase in the number of heatwave occurrences per annum is +0.07 days/year for the study period (see Figure 5). The frequency of heatwaves for the period 1950–1986 was ~1.5/year, which then increased substantially to ~3.1/year for the period 1980–2016. Further, the mean duration of heatwaves increased during the last three decades (mean = 5.9 days) over that of the previous decades (mean = 4.6 days).

The annual heatwave amplitude (1950–2016) during periods associated with a heatwave in northernmost Limpopo Province is presented in Figure 6. The lowest (40.1 ºC) heatwave amplitude was recorded in December of 1988, while the highest (45.2 ºC) was in December of 1992. Generally, heatwave amplitude increased significantly ($p=0.04$) over the study period. The intensity of heatwaves (i.e. average temperature with which the heatwave threshold was exceeded per year, taking all heatwaves for that year into account [see Figure 7]) also increased significantly ($p=0.04$) over the period 1950–2016. Table 2 shows heatwave trends in terms of change in heatwave amplitude and intensity of heatwaves.

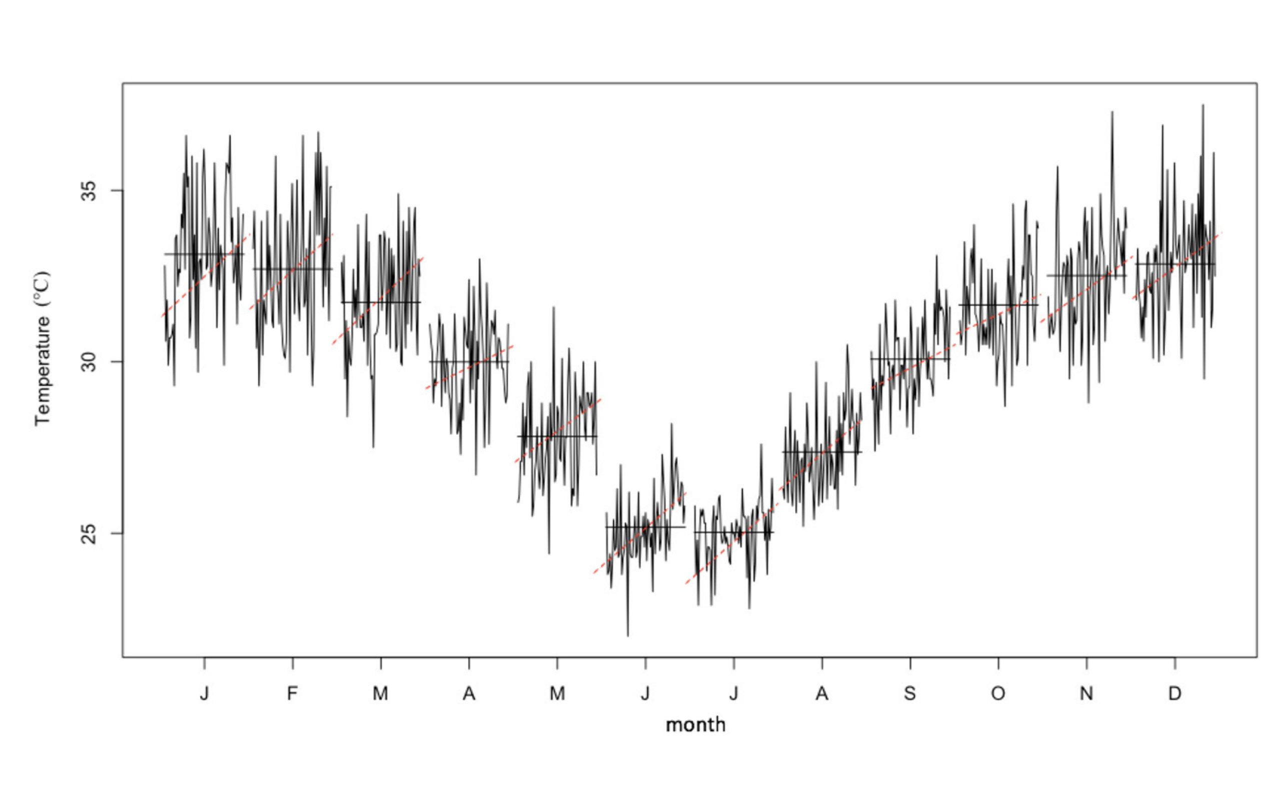


**Figure 2:** Mean monthly maximum temperatures for northernmost Limpopo Province, 1950–2016. Horizontal lines represent monthly mean values and red dotted lines represent trend lines.

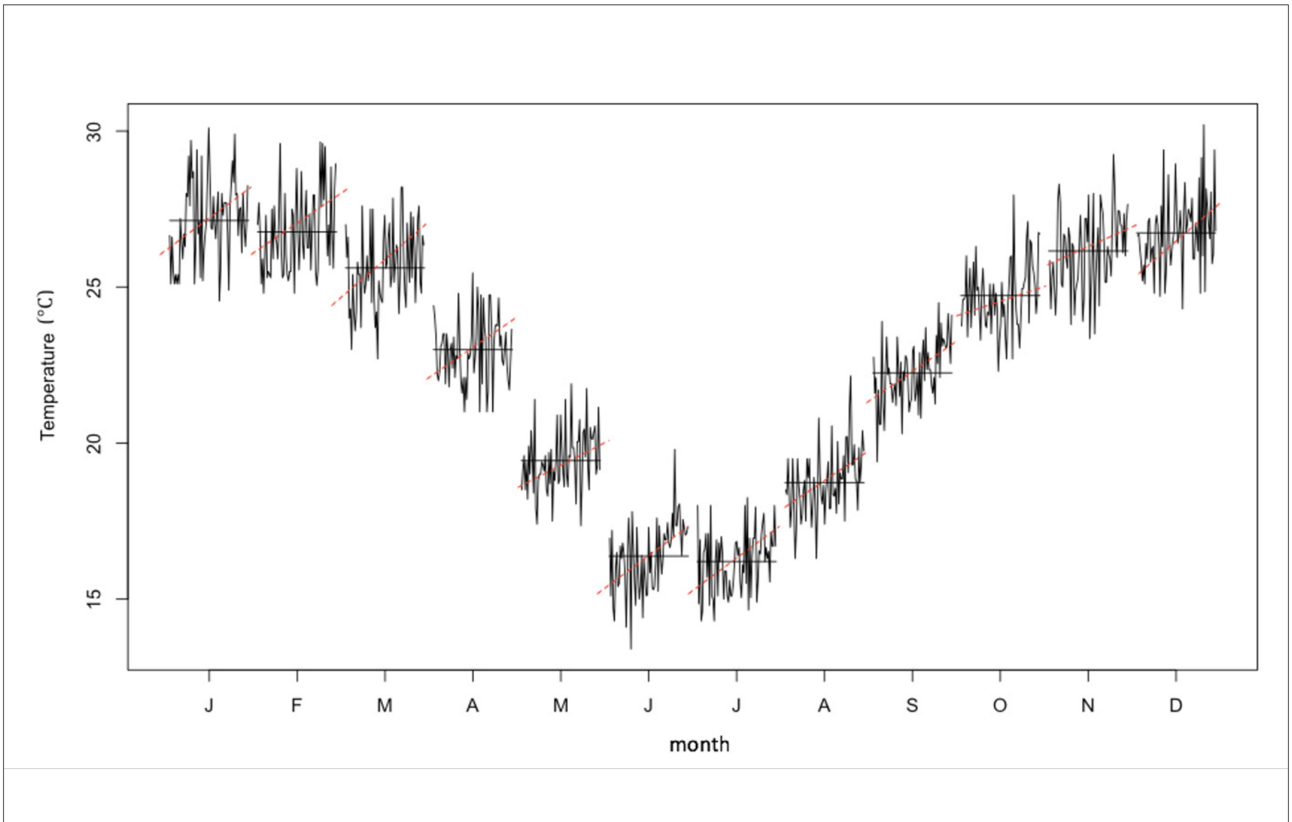


**Figure 3:** Mean monthly temperatures for northernmost Limpopo Province, 1950–2016. Horizontal lines represent monthly mean values and red dotted lines represent trend lines.

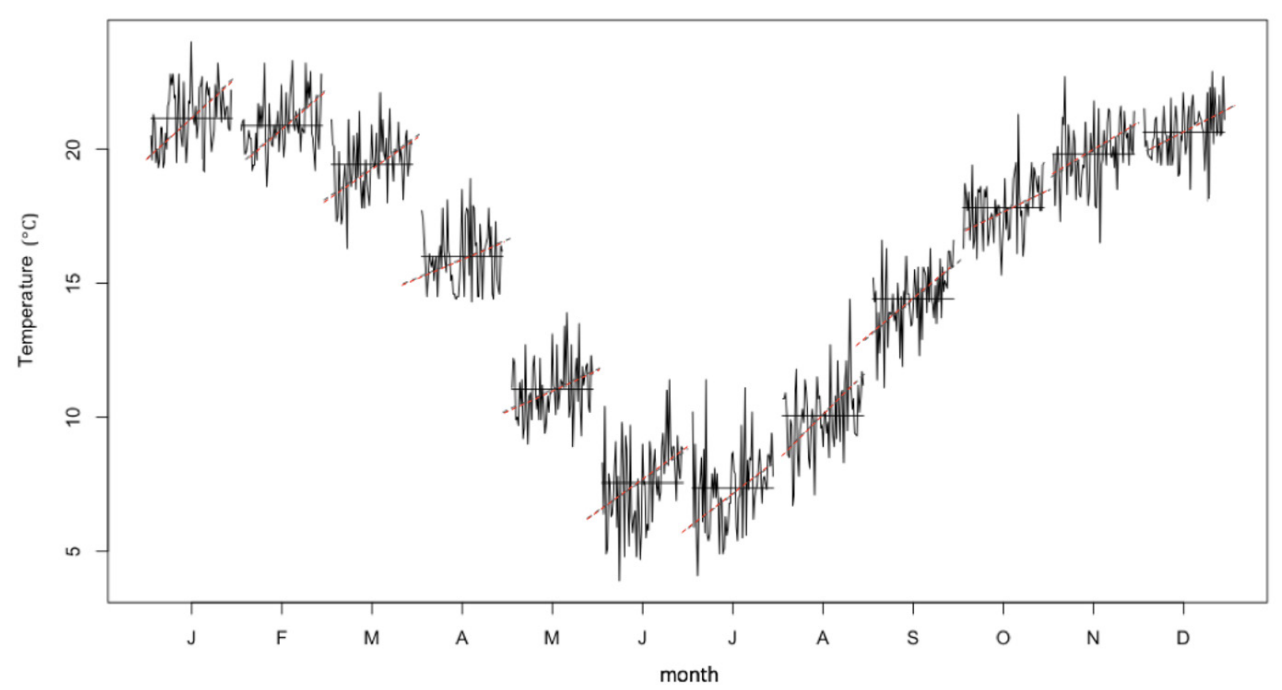


**Figure 4:** Mean monthly minimum temperatures for northernmost Limpopo Province, 1950–2016. Horizontal lines represent monthly mean values and red dotted lines represent trend lines.

**Table 1:** Monthly temperatures for northernmost Limpopo Province, 1950-2016

| | Trends in temperature | Mean temperature range | Maximum | Minimum |
|---|---|---|---|---|
| Maximum temperature | +0.02 °C/year | 28–33 °C | +45.2 °C<br>Summer (1992) | +15.5 °C<br>Winter (2010) |
| Mean temperature | +0.02 °C/year | 21–25 °C | | |
| Maximum temperature | +0.02 °C/year | 14–18 °C | +29.7 °C<br>Summer (2007) | -3.8 °C<br>Winter (1972) |

### *Relative humidity trends*

Results show a positive relative humidity trend (+0.06%/year), albeit not statistically significant ($p$=0.3) for the period 1980–2016, with mean seasonal relative humidity ranging between 10% during winter (July) of 1980, and 83.2% during autumn (April) of 2012. Generally, summers had the highest relative humidity (mean = 46.8%) and winters the lowest (mean = 36.3%) (Table 3). Seasonal relative humidity increased during summer (+0.12%/year) and autumn (+0.10%/year), and decreased during winter (-0.17%/year) and autumn (-0.15%/year) (Figure 8).

### *Variability in temperature and relative humidity*

Weather parameters across all seasons had low probability densities (below 50%), implying high variability (Figure 9). Highest probability densities of maximum temperature were observed for summer over the periods 1980–1989 and 1990–1999, and in autumn over the periods 2000-2009 and 2010-2016. Winter probability densities were lowest over the entire study period, except for the period 2000–2010, when spring recorded the lowest (~12%). The highest (~37%) summer probability densities were recorded for the period 1990–1999, and lowest (15%) over the period 2000–2009. For winter, however, maximum temperature probability densities were consistently at ~15% throughout the study period, indicating high variability.

For average temperatures, the highest and lowest probability densities were recorded for summer and winter respectively, throughout the study period. Highest summer (~52%) probability densities were recorded during the period 1990–1999 and lowest (~30%) during 2000–2009. As with maximum temperatures, winter probability densities were consistently at ~10% for the period 1980–2016. Consistent with probability densities for average temperatures, minimum temperatures were always highest for summer and lowest for winter. Summer probability densities were highest (~41%) over the period 2010-2016, and lowest (~30%) during the period 2000–2019. Again, winter probability densities were consistently lowest at ~15% for the entire study period.

Probability densities of relative humidity across all seasons were always very low (i.e. less than 10%), with considerable inter-annual and decadal variability. The period 2010–2016 presented the highest variations, with probability densities of <0.5% for relative humidity. The highest probability densities (from highest to lowest) were recorded for the period 1980–1989 (autumn), 2000–2009 (spring), 1990–1999 (autumn) and 2010–2016 (spring). Conversely, the lowest probability densities (from lowest to highest) were recorded in winter (2010–2016), summer (2000–2009), summer (1980–1989) and spring (1990–1999), respectively.

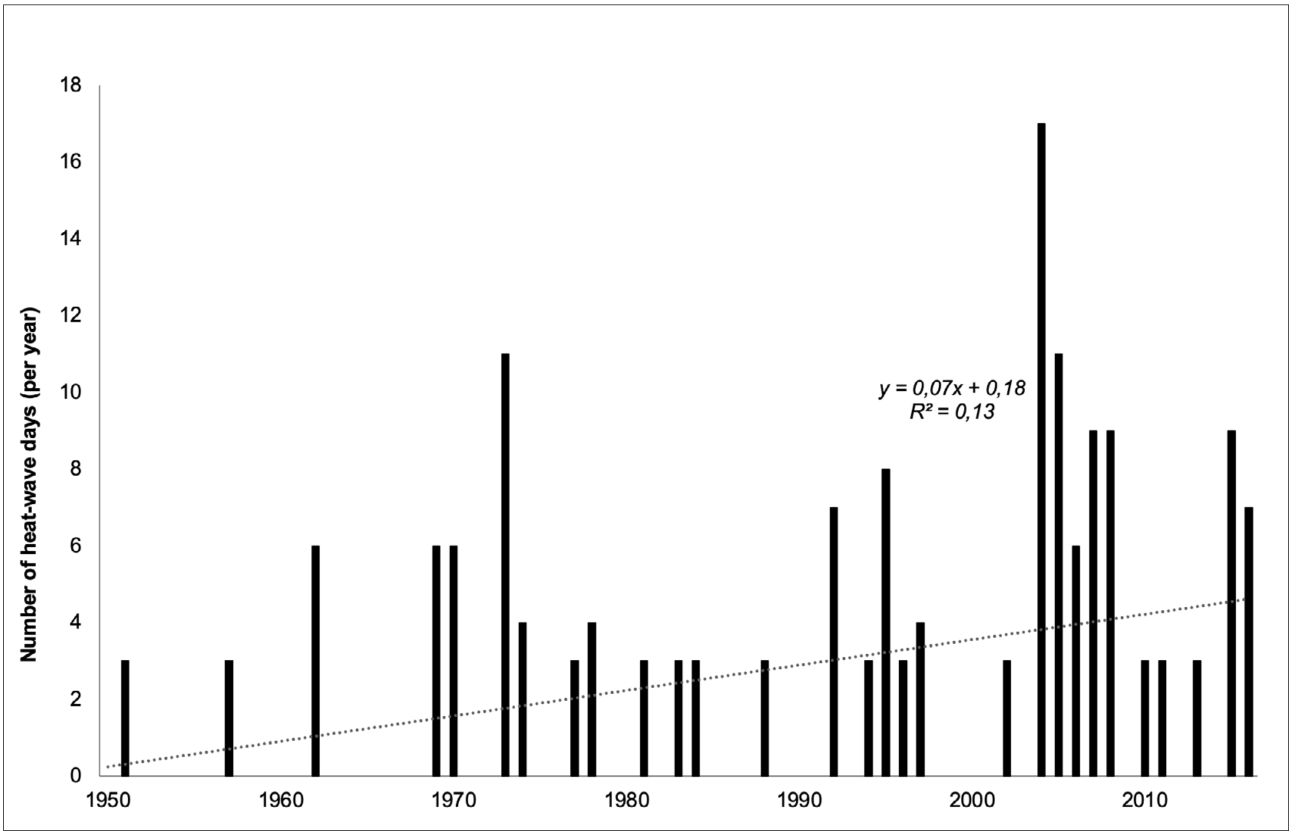


**Figure 5:** Number of heatwave days per annum for northernmost Limpopo Province, based on mean maximum temperature for the hottest month (January). The value for determining the threshold for a heatwave in northernmost Limpopo Province is 38.9 °C (i.e. 33.9 °C + 5 °C).

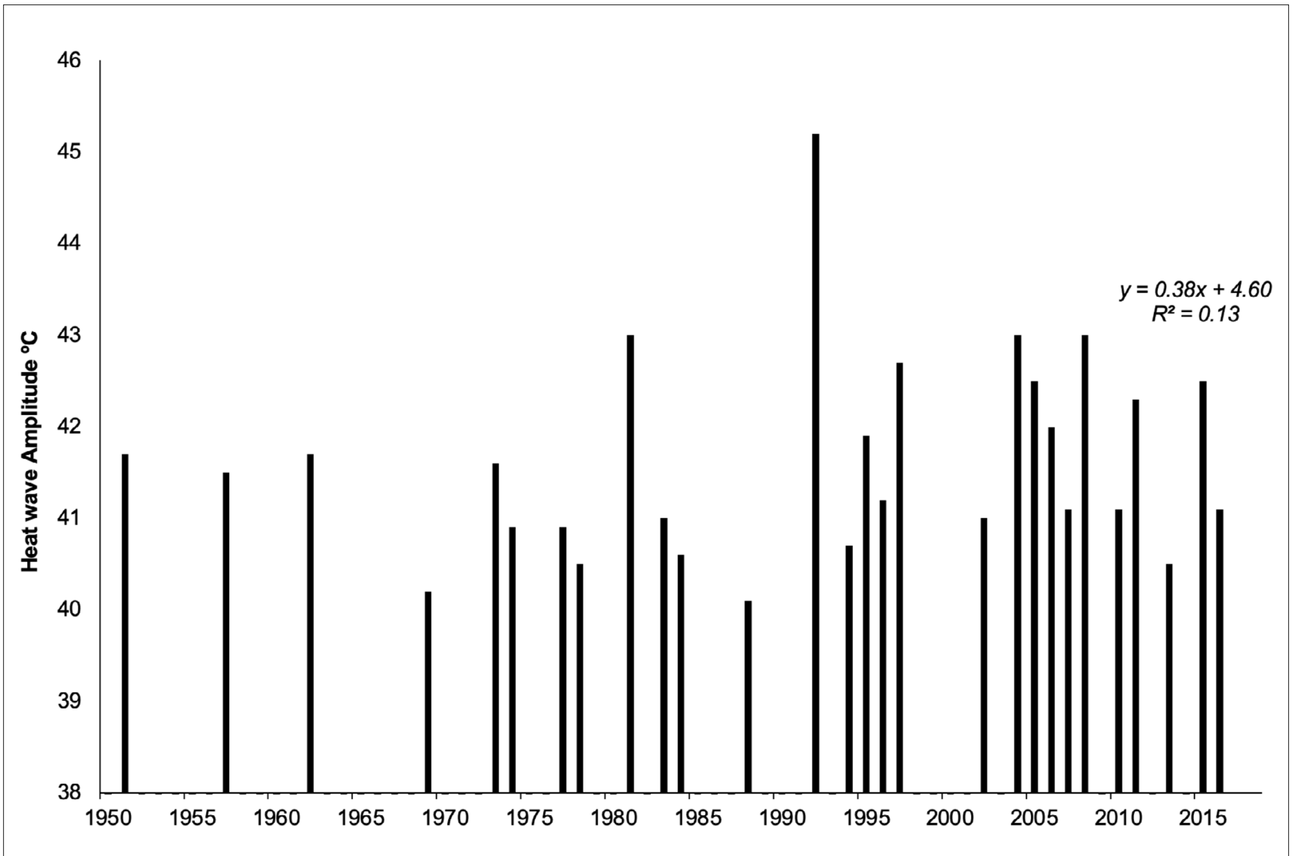


**Figure 6:** Annual heatwave amplitudes (i.e. highest temperature per year during periods associated with a heatwave) for northernmost Limpopo Province (1950–2016).

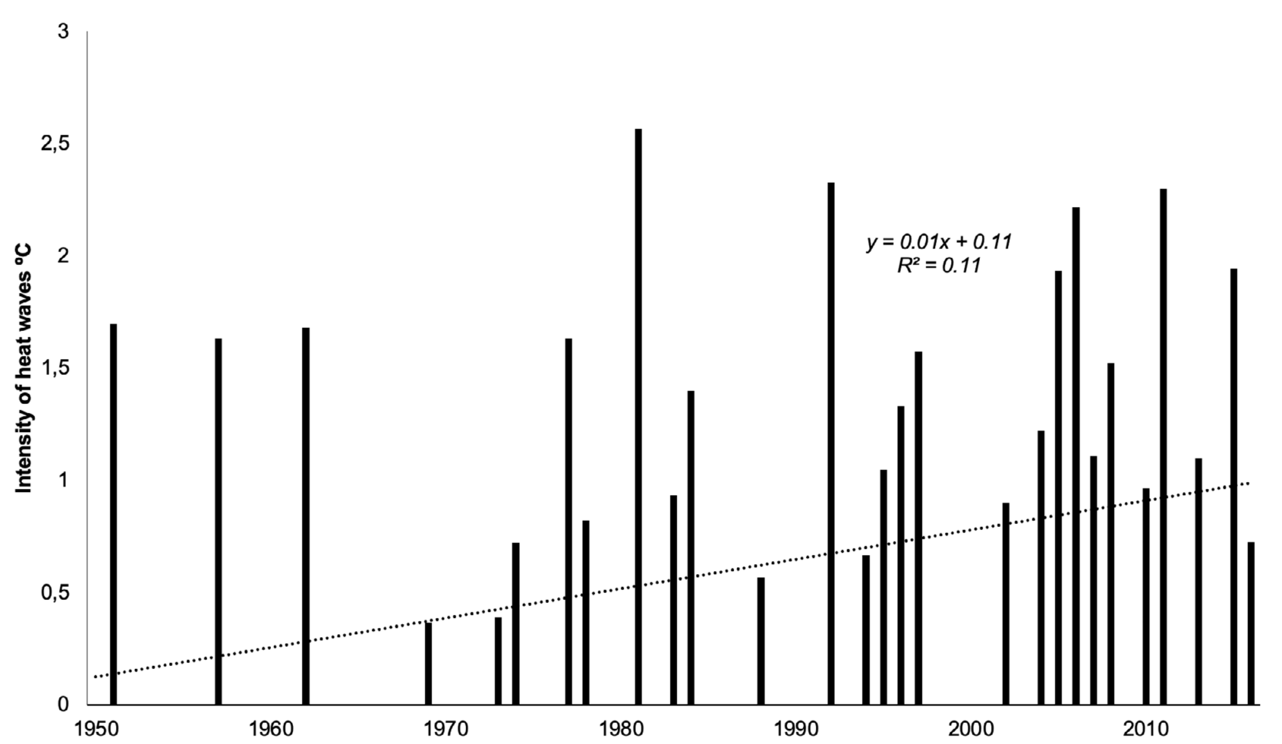


**Figure 7:** Intensity of heatwaves (i.e. average yearly exceedance temperature of heatwave threshold during heatwave days) for northernmost Limpopo Province, plotted against time for the period 1950–2016.

**Table 2:** Heatwave trends for the period 1950–2016 in northernmost Limpopo Province

| | Trend | *p*-value |
|---|---|---|
| Heatwave amplitude | +0.38 °C/year | 0.04 |
| Intensity of heatwaves | +0.01 °C/year | 0.04 |

**Table 3:** Relative humidity seasonal means for northernmost Limpopo Province, 1950–2016

| | Trends | Range | Average | | | |
|---|---|---|---|---|---|---|
| | | | Summer | Autumn | Winter | Spring |
| Relative humidity | +0.06%/ year | 10–83.2% | 46.8% | 42.5% | 36.3% | 38.1% |

Of the two variables (temperature and relative humidity), relative humidity was the least predictable weather variable across seasons for the study period. Mean summer temperatures across all decades were significantly ($p=0.03$) more predictable (~50%) than other temperature parameters during summer and other seasons. The only exceptions were predictions for autumn maximum temperatures over the years 2000–2009 and 2010–2016, both having probability densities of ~25%, a value which exceeded the summer percentages.

### *Heat index*

Heat index values (using R Package weathermetrics) were calculated for the period 1980–2016, based on available relative humidity and maximum temperature data. According to seasonal and trend decomposition time series (see Figure 10), the heat index ranged between 24 °C and 35 °C. Highest heat index measurements were observed during the summer of 2007, and the lowest (+24 °C) during the winter of 1996.

Over the study period, positive trends were observed for all seasons (Figure 11) i.e. summer (+0.05 °C/year), autumn (+0.05 °C/year), winter (+0.04 °C/year) and spring (+0.05 °C/year). Overall, there has been a positive heat index trend (+0.05 °C/year). RClimdex calculations validating these results are provided in Supplementary figures 4 (TX90p) and 5 (WSDI).

## Discussion

Our analysis shows that there has been a positive mean annual warming trend (+0.02 °C/year) for northernmost Limpopo Province over the period 1950–2016, which is in line with what other recent studies in the southern African region have reported.[12,14,33,34] Temperature increases have also resulted in increased frequency, amplitude and intensity of heatwaves and a positive heat index trend (+0.03 °C/year). Climate studies from other southern African regions[1,4,28,35-37] have also reported increased frequency of heatwaves and hot days, associated with accelerated global warming. The primary concern with such climatic changes is that they significantly impact sectors such as agriculture and water resources, directly and/or indirectly, reducing productivity.[37,38] Thus, the rapid increase in heatwave frequency and intensity over northernmost South Africa poses major concerns to agriculture in an already water-scarce environment, and even more so, given that evaporation rates and water consumption demands have increased.[8,28] High temperatures, especially when combined with high humidity and low air movement, can exceed species-specific threshold levels (or thermal comfort zones), thereby causing heat stress.[39] It is likely that farming systems in the northern border region of Limpopo Province are already adversely impacted by climate change, particularly so in small-scale subsistence settings where farmers have limited capacity to adapt. This is in line with findings from an earlier study in Limpopo Province, which established that, although farmers were able to recognise climate change, only a few employed some form of adaptation strategy.[15]

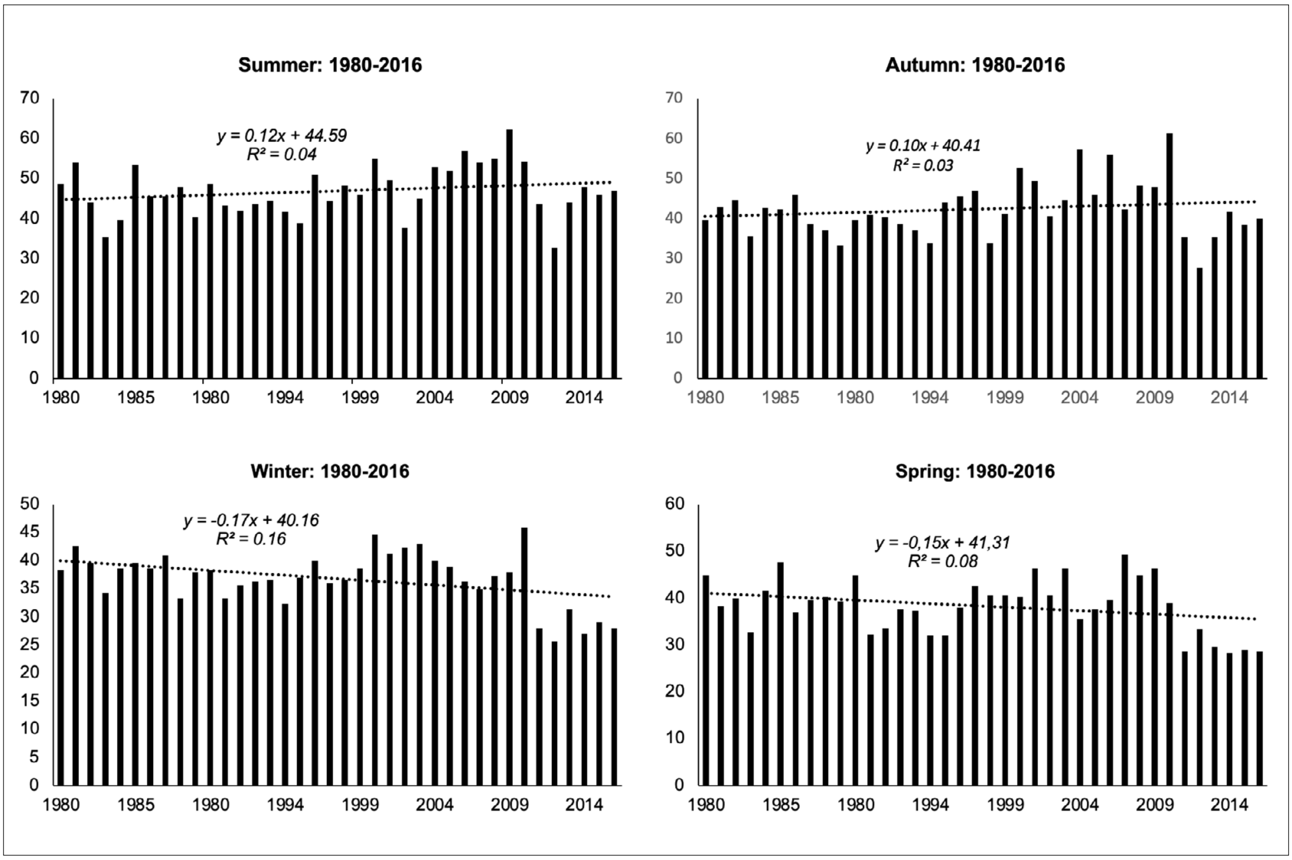


**Figure 8:** Mean seasonal relative humidity trends for northernmost Limpopo Province, 1980–2016.

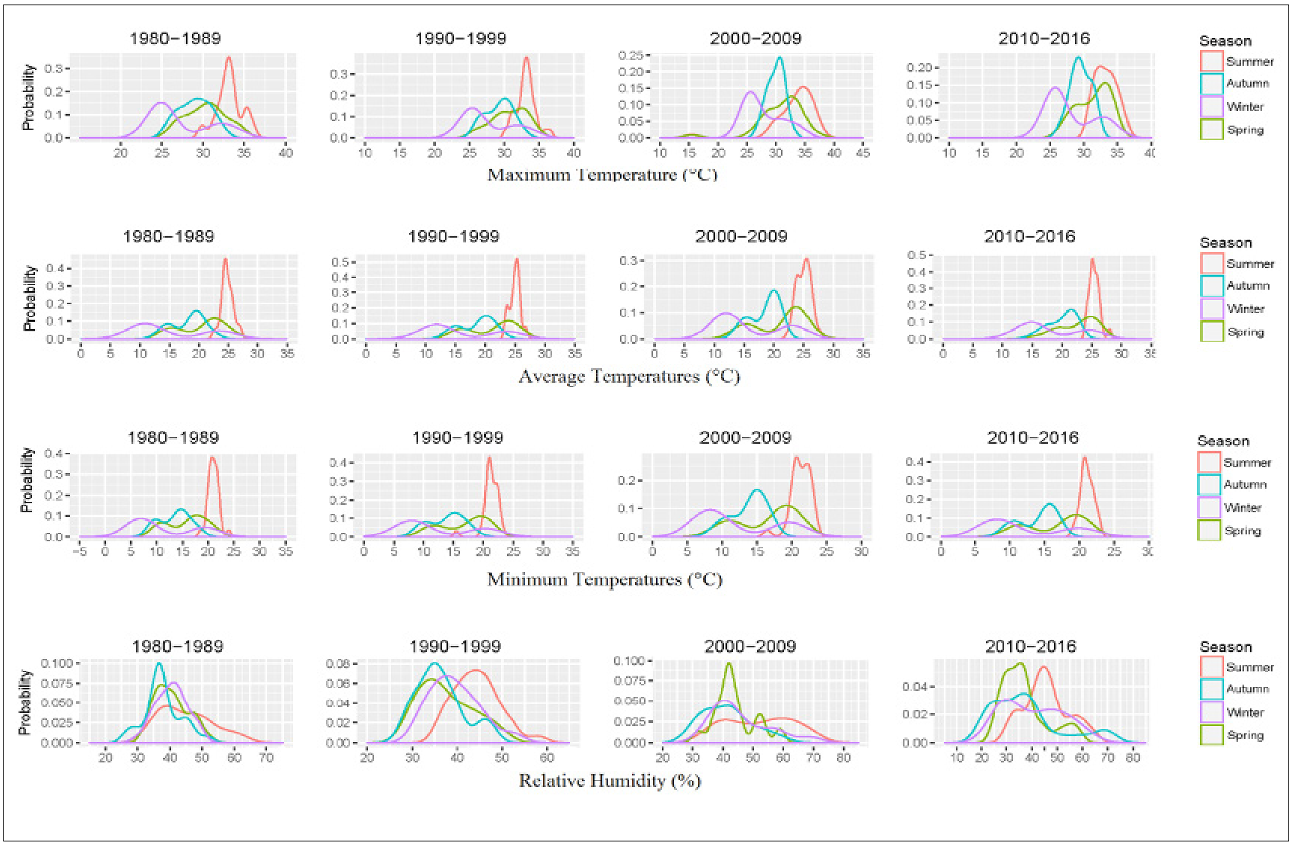


**Figure 9:** Decadal probability densities of seasonal relative humidity and air temperature (maximum, average and minimum) trends for northernmost Limpopo Province, 1980–2016. Probability density plots, which establish variability of relative humidity and air temperature, were calculated using R software package ggplot2.

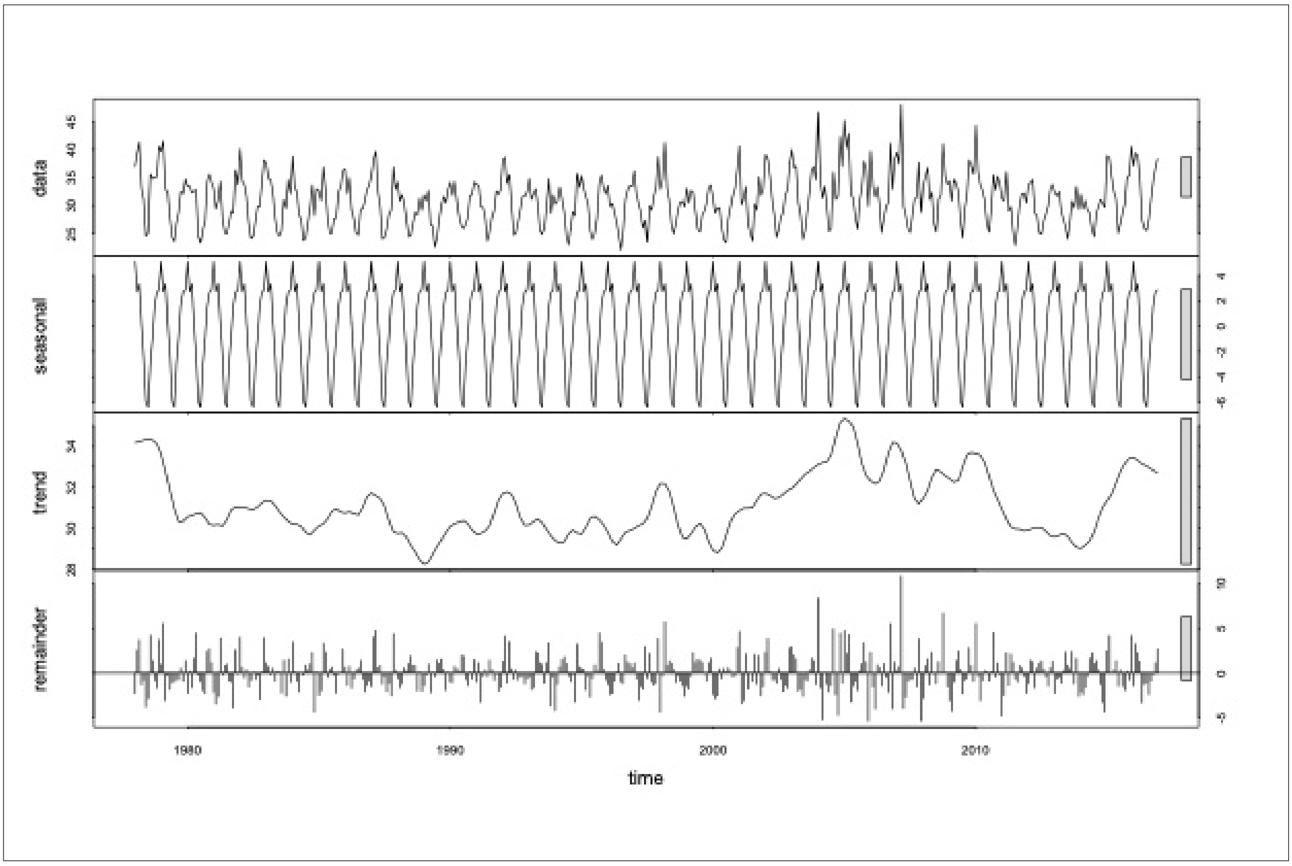


**Figure 10:** Seasonal and trend decomposition of the heat index (°C) for northernmost Limpopo Province, 1980–2016. 'Data' = set of actual values; 'seasonal' component = period; 'trend' = increasing or decreasing direction in the data; and 'remainder' = residual. The grey bar at the right-hand side of each graph allows for a relative comparison of the magnitudes of each component.

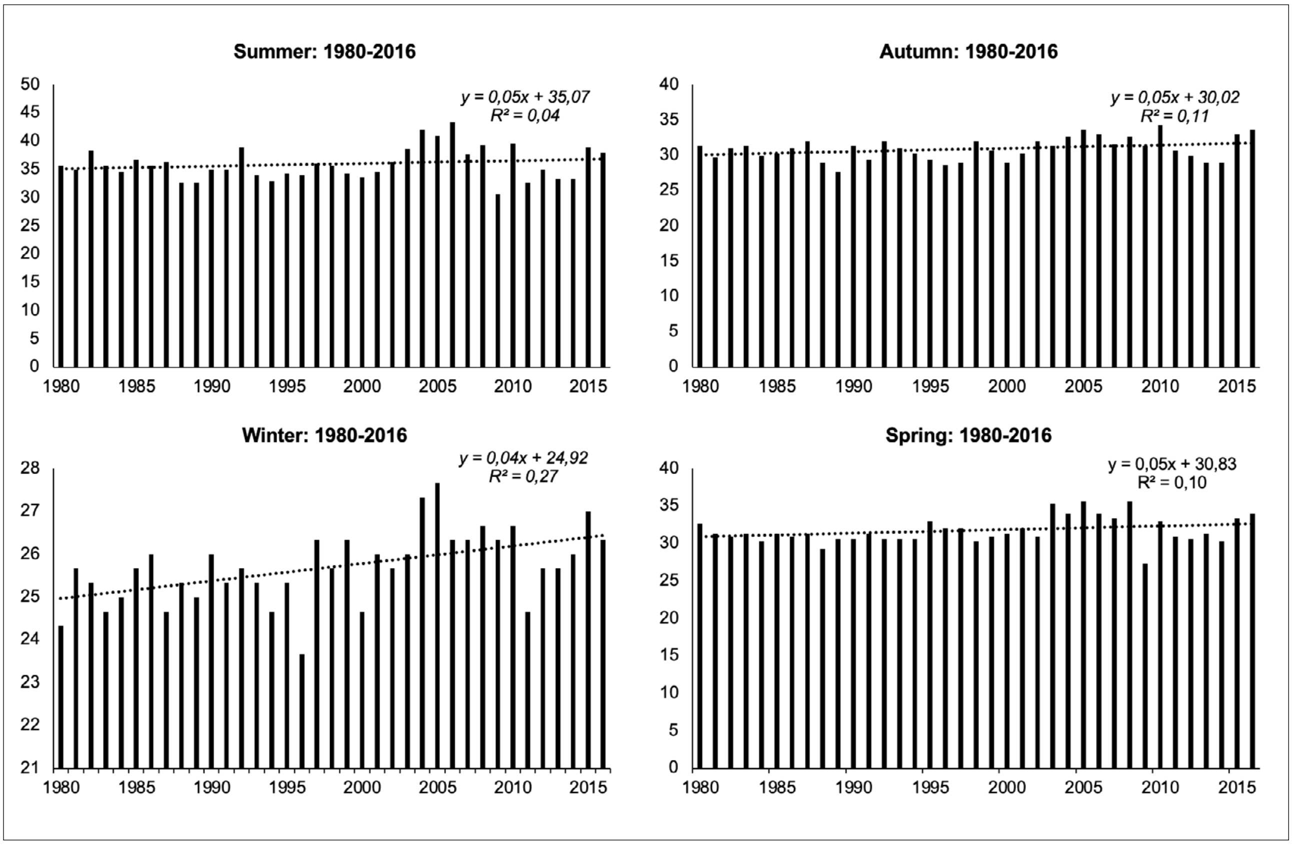


**Figure 11:** Seasonal heat index values based on maximum temperatures and relative humidity for the period 1980–2016 in northernmost Limpopo Province.

Increases in the frequency, occurrence, intensity and amplitude of heatwaves, as well as positive trends in the heat index (i.e. how hot it feels) have direct adverse effects on agriculture, especially livestock production. High temperatures cause heat stress in livestock.[40] For instance, in poultry production, ambient temperatures above 30 °C are known to cause heat stress in chickens, resulting in reduced feed intake and body weight, and, in some cases, high mortality.[4,41] This is a cause for concern in rural communities of northernmost Limpopo Province, which are resource limited, with low adaptive capacities. A recent study by Mbokodo et al.[28] focusing on expected heatwaves in a future warmer South Africa, projects an increased frequency and duration of heatwaves. Such a scenario carries the likely consequence of significant adverse impacts on human health, economic activities (especially climate-sensitive farming) and livelihoods in vulnerable communities such as the northern border region of Limpopo Province.

Both minimum and maximum temperatures increased at a similar rate (+0.02 °C/year) over the study period – a finding inconsistent with previous studies in the region and elsewhere, which reported more rapid increases in maximum temperature compared to minimum temperatures.[14,33,42,43] The observed rates of increase in minimum and maximum temperatures in northernmost Limpopo Province are inconsistent with several global warming reports, which have shown a decreasing diurnal temperature range due to minimum temperatures increasing at a faster rate than maximum temperatures.[42-46] Diurnal temperature range is an important indicator of climate change, and is influenced by various spatial and temporal factors, including land-use / land-cover changes, irrigation, station moves, desertification, and a host of other indirect climatic effects.[47] Thus, although global and regional perspectives on changes in the climate system are important, there are complex spatial variations, which necessitate local analysis of trends.

Simulated climate models (e.g. regional climate models and general circulation models) are often used for climate change projections. However, models may have limitations in determining local weather conditions.[13,33] It is thus important to test and refine model reports using observed variations to ensure the accuracy of climate change projections. For instance, Jury[13] analysed spatial and temporal historical climate observations in southern Africa to validate simulation models for projecting climate trends. Kruger et al.[48] investigated historical trends in near-surface minimum and maximum temperatures, as well as extreme temperature indices in South Africa. This was achieved through critically comparing quality-controlled station observations with downscaled model projections, so as to provide valuable information concerning the interpretation of model-generated projections. Kruger et al.'s[48] results demonstrate that model outputs tend to simulate the historical trends accurately for annual means of daily maximum and minimum temperatures, but have limitations when assessing temperature extremes. For correctly estimating the potential impact of climate change in a given region, particularly for sectors such as agriculture, it is necessary to reconcile climate observations and model projections.

Climate change research in remote rural areas such as the northern region of Limpopo Province should be ongoing, especially given that trends of concern seem to be increasing. Thus, climate change has an ever-changing impact on farming, especially on small-scale farming systems and enterprises in the region. Information on climatic trends, especially at local level, is important to help understand the likely impacts on farming productivity, and to inform appropriate strategic interventions to improve adaptation mechanisms.[47] It is likely that temperatures in northernmost Limpopo Province are frequently surpassing livestock heat stress thresholds each year, ultimately compromising productivity, yet farmers continue with agricultural production without such insights. It is possible that the reported low productivity of rural poultry in the northern region of Limpopo Province may, in part, be a function of heat stress.[41] Thus, access to climate information is essential to provide understanding of likely implications of climate change on agricultural production – something that needs to be effectively communicated to small-scale subsistence farmers for appropriate adaption.

## Conclusion

Temperatures in northernmost Limpopo Province have steadily increased over the period 1950–2016. Consequently, heatwave frequency, intensity and amplitude have also increased. Further, temperatures and relative humidity have become more variable in recent decades. Of particular concern is the fact that, according to heat index trends, heat indices have increased. Such increases are likely to have adverse effects on sectors such as agriculture, especially in small-scale farming systems where farmers have limited adaptive capacities. To establish appropriate preparedness, an important starting point would be for future research to focus on establishing heat-stress tolerance thresholds for specific agricultural sectors in the northern border region of Limpopo Province.

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## Competing interests

We have no competing interests to declare.

## Authors' contributions

N.M.B.N. was the principal researcher and main author of the manuscript. S.G. was the main supervisor of the research work and reviewed the manuscript. J.M. and E.A. co-supervised the research, analysed the data and reviewed the manuscript.

## References

1. Stocker TF, Qin D, Plattner GK, Tignor M, Allen SK, Boschung J, et al. Summary for policymakers. In: Climate change 2013: The physical science basis: Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge: Cambridge University Press; 2014. https://doi.org/10.1017/cbo9781107415324.004
2. Ziervogel G, New M, Archer van Garderen E, Midgley G, Taylor A, Hamann R, et al. Climate change impacts and adaptation in South Africa. WIREs Clim Change. 2014;5(5):605–620. https://doi.org/10.1002/wcc.295
3. Van Wilgen NJ, Goodall V, Holness S, Chown SL, McGeoch MA. Rising temperatures and changing rainfall patterns in South Africa's national parks. Int J Climatol. 2016;36(2):706–721. https://doi.org/10.1002/joc.4377
4. South African Department of Environmental Affairs. Long-Term Adaptation Scenarios Flagship Research Programme (LTAS) for South Africa. Climate trends and scenarios for South Africa [document on the Internet]. c2013 [cited 2017 Mar 04]. Available from: https://www.sanbi.org/sites/default/files/documents/documents/ltasclimate-trends-and-scenarios-tech-report2013low-res.pdf
5. Thornton PK, Ericksen PJ, Herrero M, Challinor AJ. Climate variability and vulnerability to climate change: A review. Glob Change Biol. 2014;20(11):3313–3328. https://doi.org/10.1111/gcb.12581
6. Diallo I, Giorgi F, Sukumaran S, Stordal F, Giuliani G. Evaluation of RegCM4 driven by CAM4 over Southern Africa: Mean climatology, interannual variability and daily extremes of wet season temperature and precipitation. Theor Appl Climatol. 2015;121(3–4):749–766. https://doi.org/10.1007/s00704-014-1260-6
7. Engelbrecht F, Adegoke J, Bopape MJ, Naidoo M, Garland R, Thatcher M, et al. Projections of rapidly rising surface temperatures over Africa under low mitigation. Environ Res Lett. 2015;10(8):1–16. https://doi.org/10.1088/1748-9326/10/8/085004
8. Kusangaya S, Warburton ML, Archer van Garderen ERM, Jewitt GP. Impacts of climate change on water resources in southern Africa: A review. Phys Chem Earth. 2014;67–69:47–54. http://dx.doi.org/10.1016/j.pce.2013.09.014
9. Keggenhoff I, Elizbarashvili M, King L. Recent changes in Georgia's temperature means and extremes: Annual and seasonal trends between 1961 and 2010. Weather Clim Extrem. 2015;8:34–45. https://doi.org/10.1016/j.wace.2014.11.002

10. Hachigonta S, Nelson GC, Thomas TS, Sibanda LM, editors. Southern African agriculture and climate change: A comprehensive analysis. Washington DC: International Food Policy Research Institute; 2013. http://dx.doi.org/10.2499/9780896292086

11. Tadross M, Jack C, Hewitson B. On RCM-based projections of change in southern African summer climate. Geophys Res Lett. 2005;32(23):1–4. https://doi.org/10.1029/2005gl024460

12. MacKellar N, New M, Jack C. Observed and modelled trends in rainfall and temperature for South Africa: 1960–2010. S Afr J Sci. 2014;110(7–8), Art. #2013-0353. https://doi.org/10.1590/sajs.2014/20130353

13. Jury MR. Climate trends in southern Africa. S Afr J Sci. 2013;109(1–2), Art. #980. http://dx.doi.org/10.1590/sajs.2013/980

14. Kruger AC, Sekele SS. Trends in extreme temperature indices in South Africa: 1962–2009. Int J Climatol. 2013;33(3):661–676. https://doi.org/10.1002/joc.3455

15. Gbetibouo GA. Understanding farmers' perceptions and adaptations to climate change and variability: The case of the Limpopo Basin, South Africa. Washington DC: International Food Policy Research Institute; 2009. https://www.ifpri.org/publication/understanding-farmers-perceptions-and-adaptations-climate-change-and-variability

16. Tshiala MF, Olwoch JM, Engelbrecht FA. Analysis of temperature trends over Limpopo province, South Africa. J Geog Geol. 2011;3(1):13. https://doi.org/10.5539/jgg.v3n1p13

17. Kalumba AM, Olwoch JM, Van Aardt I, Botai OJ, Tsela P, Nsubuga FW, et al. Trend analysis of climate variability over the West Bank-East London Area, South Africa (1975-2011). J Geog Geol. 2013;5(4):131. https://doi.org/10.5539/jgg.v5n4p131

18. Lakhraj-Govender R, Grab S, Ndebele NE. A homogenized long-term temperature record for the Western Cape Province in South Africa: 1916-2013. Int J Climatol. 2017;37(5):2337–2353. https://doi.org/10.1002/joc.4849

19. Archer van Garderen ER. (Re) considering cattle farming in southern Africa under a changing climate. Weather Clim Soc. 2011;3(4):249–253. https://doi.org/10.1175/wcas-d-11-00026.1

20. Shisanya S, Mafongoya P. Adaptation to climate change and the impacts on household food security among rural farmers in uMzinyathi District of Kwazulu-Natal, South Africa. Food Secur. 2016;8(3):597–608. https://doi.org/10.1007/s12571-016-0569-7

21. Makhado R, Potgieter M, Luus-Powell W, Cooper S, Oppong C, Kopij G, et al. *Tragelaphus strepsiceros* browse during the dry season in the mopani veld of Limpopo Province, South Africa. Trans R Soc S Afr. 2016;71(1):17–21. https://doi.org/10.1080/0035919x.2015.1102174

22. Tankson JD, Vizzier-Thaxton Y, Thaxton JP, May JD, Cameron JA. Stress and nutritional quality of broilers. Poult Sci J. 2001;80:1384–1389. https://doi.org/10.1093/ps/80.9.1384

23. Boissonnade AC, Heitkemper LJ, Whitehead D. Weather data: Cleaning and enhancement. In: Dischel RS. Climate risk and the weather market: Financial risk management with weather hedges. London: Risk Books; 2002. p. 73–93. Available from: http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.527.2282&rep=rep1&type=pdf

24. Vincent LA, Wang XL, Milewska EJ, Wan H, Yang F, Swail V. A second generation of homogenized Canadian monthly surface air temperature for climate trend analysis. J Geophys Res Atmos. 2012;117(D18):1–13. https://doi.org/10.1029/2012jd017859

25. Wang XL, Feng Y, Vincent LA. Observed changes in one-in-20-year extremes of Canadian surface air temperatures. Atmos Ocean. 2014;52(3):222–231. https://doi.org/10.1080/07055900.2013.818526

26. Spinu V, Grolemund G, Wickham H. lubridate: Make dealing with dates a little easier. R package version 1.7.4; 2018.

27. Hyndman RJ, Athanasopoulos G, Bergmeir C, Caceres G, Chhay L, O'Hara-Wild M, et al. Package 'forecast'; 2020. Available from: https://cran.r-project.org/web/packages/forecast/forecast.pdf

28. Mbokodo I, Bopape MJ, Chikoore H, Engelbrecht F, Nethengwe N. Heatwaves in the future warmer climate of South Africa. Atmosphere. 2020;11(7):712. https://doi.org/10.3390/atmos11070712

29. Wickham H. ggplot2. WIREs Comp Stat. 2011;3(2):180–185. https://doi.org/10.1002/wics.147

30. Anderson GB, Peng RD. weathermetrics: Functions to convert between weather metrics (R package). Version 1.2.2. 2016.

31. National Weather Service Hydrometeorological Prediction Center Web Team. Heat Index Calculator; 2015. Available from: https://www.wpc.ncep.noaa.gov/html/heatindex.shtml

32. Zhang X, Feng Y, Chan R. Introduction to RClimDex v1.9. Environment Canada; 2018. Available from: https://usermanual.wiki/Document/manual.2056401896/view

33. Davis CL, Hoffman MT, Roberts W. Recent trends in the climate of Namaqualand, a megadiverse arid region of South Africa. S Afr J Sci. 2016;112(3–4), Art. #2015-0217. https://doi.org/10.17159/sajs.2016/20150217

34. Kruger AC, Nxumalo M. Surface temperature trends from homogenized time series in South Africa: 1931-2015. Int J Climatol. 2017;37(5):2364–2377. https://doi.org/10.1002/joc.4851

35. Huth R, Kyselý J, Pokorná L. A GCM simulation of heat waves, dry spells, and their relationships to circulation. Clim Change. 2000;46(1–2):29–60. https://doi.org/10.1023/a:1005633925903

36. Meehl GA, Tebaldi C. More intense, more frequent, and longer lasting heat waves in the 21st century. Science. 2004;305(5686):994–997. https://doi.org/10.1126/science.1098704

37. Schlenker W, Roberts MJ. Nonlinear temperature effects indicate severe damages to US crop yields under climate change. Proc Natl Acad Sci USA. 2009;106(37):1594–1598. https://doi.org/10.1073/pnas.0906865106

38. Van der Velde M, Tubiello FN, Vrieling A, Bouraoui F. Impacts of extreme weather on wheat and maize in France: Evaluating regional crop simulations against observed data. Clim Change. 2012;113(3–4):751–765. https://doi.org/10.1007/s10584-011-0368-2

39. Lefcourt AM, Adams WR. Radiotelemetry measurement of body temperatures of feedlot steers during summer. J Anim Sci. 1996;74(11):2633–2640. https://doi.org/10.2527/1996.74112633x

40. Thornton PK, Van de Steeg J, Notenbaert A, Herrero M. The impacts of climate change on livestock and livestock systems in developing countries: A review of what we know and what we need to know. Agric Syst. 2009;101(3):113–127. https://doi.org/10.1016/j.agsy.2009.05.002

41. Nyoni NMB, Grab S, Archer ER. Heat stress and chickens: climate risk effects on rural poultry farming in low-income countries. Clim Dev. 2019;11(1):83–90. https://doi.org/10.1080/17565529.2018.1442792

42. Easterling DR, Horton B, Jones PD, Peterson TC, Karl TR, Parker DE, et al. Maximum and minimum temperature trends for the globe. Science. 1997;277(5324):364–367. https://doi.org/10.1126/science.277.5324.364

43. New M, Hewitson B, Stephenson DB, Tsiga A, Kruger A, Manhique A, et al. Evidence of trends in daily climate extremes over southern and west Africa. J Geophys Res Atmos. 2006;111(D14):1–11. https://doi.org/10.1029/2005jd006289

44. Karl TR, Jones PD, Knight RW, Kukla G, Plummer N, Razuvayev V, et al. A new perspective on recent global warming: Asymmetric trends of daily maximum and minimum temperature. Bull Am Meteor Soc. 1993;74(6):1007–1024. https://doi.org/10.1175/1520-0477(1993)074<1007:anporg>2.0.co;2

45. Liu B, Xu M, Henderson M, Qi Y, Li Y. Taking China's temperature: Daily range, warming trends, and regional variations, 1955-2000. J Clim. 2004;17(22):4453–4462. https://doi.org/10.1175/3230.1

46. Blunden J, Arndt DS. State of the climate in 2011. Warming: Asymmetric trends of daily maximum and minimum temperature. Bull Am Meteor Soc. 2012;93(7):S1–282. https://doi.org/10.1175/3230.1

47. Qu M, Wan J, Hao X. Analysis of diurnal air temperature range change in the continental United States. Weather Clim Extrem. 2014;4:86–95. https://doi.org/10.1016/j.wace.2014.05.002

48. Kruger AC, Rautenbach H, Mbatha S, Ngwenya S, Makgoale TE. Historical and projected trends in near-surface temperature indices for 22 locations in South Africa. S Afr J Sci. 2019;115(5–6), Art. #4846. https://doi.org/10.17159/sajs.2019/4846

# Self-esteem and antiretroviral therapy adherence among young people living with HIV: An exploratory serial mediation analysis

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Capitalising further on the benefits of antiretroviral therapy (ART) for individual treatment requires an improved understanding of the psychological processes that may affect optimal ART adherence among people living with HIV. We examined internalised HIV/AIDS-related stigma and body appreciation as mediators of the association between self-esteem and ART adherence among young people living with HIV (YPLHIV). A sample of 76 YPLHIV ($M_{age}$ = 19.36, $s.d._{age}$ = 2.56; male 56.58%) residing in an HIV hyperendemic region of South Africa completed self-report measures of self-esteem, internalised HIV/AIDS-related stigma, body appreciation, and ART adherence. Path-analytic mediation modelling was performed to test for direct and indirect effects linking self-esteem with ART adherence. Results of serial mediation analyses indicated that self-esteem and ART adherence were indirectly associated through a two-step path of internalised HIV/AIDS-related stigma and then body appreciation, as well as a one-step path through internalised HIV/AIDS-related stigma. The results provide preliminary support for internalised HIV/AIDS-related stigma and body appreciation as mechanisms underlying the association between self-esteem and ART adherence. Implications of the findings for promoting ART adherence among YPLHIV are discussed.

**Significance:**

- Self-esteem and ART adherence were indirectly related through internalised HIV/AIDS-related stigma followed by body appreciation.
- Outcomes of intervention initiatives designed to promote ART adherence among young people living with HIV may be further improved by integrating components that target internalised HIV/AIDS-related stigma and body appreciation.

## Introduction

Increased availability and uptake of antiretroviral therapy (ART) among people living with HIV (PLHIV) have played an important role in the decline of new HIV infections.[1] ART promotes viral suppression, improves physical and emotional well-being, and reduces mortality.[2] In regions of HIV hyperendemicity where it has been particularly challenging to stay on track with global treatment and prevention targets, ART uptake represents a key avenue for reducing the burden of HIV. However, the benefits of ART for preventing and treating HIV may be undermined by treatment non-adherence, which can lead to impairments in psychosocial functioning (e.g. weakening of social relationships and loss of self-esteem resulting from periods of illness), increase risk of HIV transmission to non-infected sexual partners, and is a common cause of death among PLHIV.[3,4] To advance health promotion initiatives designed to improve ART adherence, further research is needed to identify and better understand salient mechanisms underlying ART non-adherence in populations residing in HIV hyperendemic contexts and for which unique social-structural vulnerabilities exist.

The burden of the global HIV epidemic is highest among young people living in the countries within eastern and southern Africa.[5] Alongside the social-structural issues (e.g. inadequate health infrastructure) that pose challenges to HIV testing and treatment-related behaviour of young people living in the eastern and southern African region[6], the effectiveness of HIV treatment in promoting the health and longevity of this population is highly contingent on the individual choices young people make about treatment-related behaviour. Wide-ranging reasons for non-adherence to ART have been reported among young people. The more frequently identified patient-related factors include perceived or internalised HIV/AIDS-related stigma[7], body image concerns[8], forgetfulness, alcohol use, and depression[9]. Patient-related factors are closest in proximity to the individual, many of which appear amenable to change through targeted efforts that are directed towards harnessing and developing personal resources of young people living with HIV (YPLHIV). Although various psychological resources (e.g. self-efficacy, resilience) have been linked to better ART adherence[10,11], one underexplored avenue that also has the potential to promote ART adherence among YPLHIV is self-esteem.

Self-esteem is an important inner resource encompassing an individual's overall positive evaluation of the self, including perceived competence and sense of worth.[12] Self-esteem has been conceptualised as a protective factor that contributes to better health and well-being by buffering the impact of negative and stressful life experiences.[13,14] Research involving young people has revealed that self-esteem is associated with lower health risk behaviour (e.g. fewer sexual partners[15], lower alcohol use[16]), which suggests that those with higher self-esteem might be more inclined to make choices that support rather than degrade health and well-being (e.g. adhere to medication regimens).

Few studies have investigated the association between self-esteem and ART adherence, which is important for several reasons. First, negative self-evaluation and a low sense of self-worth may affect concentration and memory, both of which are associated with ART non-adherence.[17] For example, impairment in prospective memory (i.e. remembering to perform a specific task in the future) has been associated with ART non-adherence.[18] Second, lower self-esteem is linked to increased alcohol misuse and recreational substance use, which can impair judgement and may interfere with a person's ability to adhere to treatment.[16] Third, high self-esteem can precipitate resilience-promoting psychological qualities (e.g. self-confidence) that may enhance medication adherence.[13] To further examine the association between self-esteem and ART adherence, in the present study we tested for evidence of internalised HIV/AIDS-related stigma and body appreciation as serial mechanisms linking self-esteem and ART adherence in a sample of South African YPLHIV.

### *Self-esteem and internalised HIV/AIDS-related stigma*

Internalised HIV/AIDS-related stigma refers to the negative perceptions and abasement of the self that may be endorsed by those diagnosed with HIV.[19] It is characterised by self-denigrating thoughts (e.g. self-blame) and feelings (e.g. shame, guilt), as well as concealment of HIV status.[20] Internalisation of stigma is not an inevitable response to possession of a stigmatised attribute[21], but the risk of such increases when existing beliefs about one's self-worth and self-regard are low. In particular, low self-esteem is associated with a higher likelihood of acquiring identity standards from society, appropriating perspectives about the self from others, and evaluating the self negatively.[22]

Although few studies have directly investigated the impact of self-esteem on internalised HIV/AIDS-related stigma, existing research indicates that self-esteem may protect against the negative effects that perceived or experienced stigma can have on internalisation of HIV/AIDS-related stigma.[23] Some findings suggest that positive changes in self-esteem (e.g. increased self-worth) can play a role in adaptive resistance to HIV/AIDS-related stigma (e.g. open disclosure of HIV seropositive status to confront negative labelling).[24] Other evidence points to the risk of internalising HIV/AIDS-related stigma when self-esteem is low, which could have negative downstream implications for health and well-being.[25,26]

### *Internalised HIV/AIDS-related stigma and body appreciation*

Internalised HIV/AIDS-related stigma may be pronounced when PLHIV have physical attributes that are common markers of the disease.[27] Previous studies have established a link between internalised HIV/AIDS-related stigma and body image[28], with one study reporting that high stigma significantly lowered the probability of having a positive body image[29]. Even in the absence of visible body changes, self-deprecating psychological processes that are attributable to internalised HIV/AIDS-related stigma (e.g. feelings of shame and worthlessness) can impact negatively on the body image perceptions of PLHIV.[30]

Internalised HIV/AIDS-related stigma may affect different dimensions of body image, including body appreciation. Body appreciation is a component of positive body image that is conceptualised as being respectful, approving, and appreciative of the characteristics and health of one's body, regardless of shape, weight, and imperfections.[31] Internalising social norms and discriminatory characterisations towards PLHIV may have a negative effect on how PLHIV view and appreciate their bodies.[27] The negative implications of internalised HIV/AIDS-related stigma may be especially pronounced among YPLHIV, given the complex interplay of biopsychosocial processes that occur during the developmental transition from childhood to adulthood.[6]

### *Body appreciation and antiretroviral therapy adherence*

A variety of physical and psychological complications commonly accompany HIV infection, including weight loss, skin lesions, depression, suicidal ideation, and body dissatisfaction.[32,33] Research suggests that fear of bodily changes (e.g. weight loss) resulting from HIV and ART may be implicated in medication non-adherence.[8] Although there are few direct links between body appreciation and adherence, there is some evidence that improving the perspectives of PLHIV about their body can lead to better health behaviour, including adherence to ART.[34] Extensive evidence indicates that body appreciation is associated with an appreciation of diverse appearances and shapes[31], better physical health, and higher levels of psychological well-being[35]. Efforts to promote body appreciation may have implications for ART adherence among PLHIV, especially among young people who tend to be particularly susceptible to the influence of bodily perceptions on positive health behaviour.[36]

## The present study

In this study, we examine associations between self-esteem, internalised HIV/AIDS-related stigma, body appreciation, and ART adherence in YPLHIV who reside in an HIV hyperendemic country within the eastern and southern African region. Exploring these interrelationships could offer an improved understanding of mechanisms that are implicated in ART adherence, particularly those that could be targeted to promote adherence in seropositive young people. Thus, we used an integrative modelling approach to explore internalised HIV/AIDS-related stigma and body appreciation as serial mechanisms linking self-esteem and ART adherence among YPLHIV in the Durban area of KwaZulu-Natal, South Africa. To our knowledge, this is the first study examining body appreciation as a mediator of this association, particularly as a precursor to ART adherence. We hypothesised that self-esteem and ART adherence would be linked indirectly via a sequential path of internalised HIV/AIDS-related stigma followed by body appreciation.

## Method

### *Participants*

The sample comprised 76 (56.58% male) seropositive young people residing in the city of Durban, South Africa. Durban is located within the province of KwaZulu-Natal, which has the highest HIV prevalence rate in the country.[37] Participants ranged from 15 to 24 years of age ($M_{age}=19.36$, s.d.$=2.56$) and identified racially as African (82.89%) or coloured (17.11%). A majority of the sample had fulfilled high school equivalency requirements (67.11%) or completed post-secondary education (28.95%). A small proportion of the participants had not completed any formal education (3.95%). Almost half of the sample (52.63%) indicated that they had acquired HIV after birth from a source other than their mother (i.e. horizontal infection), and the remainder (47.37%) reported that they had been infected through mother-to-child transmission (i.e. vertical infection).

### *Measures*

#### Rosenberg Self-Esteem Scale

The Rosenberg Self-Esteem Scale (RSES)[12] is a 10-item measure of self-respect and self-acceptance. Items (e.g. 'I feel that I am a person of worth, at least on an equal plane with others') are rated using a four-point response scale (1 = Strongly disagree; 4 = Strongly agree), half of which are reverse scored. In this study, responses to all items were aggregated for a total raw score (range: 10 to 40). Findings of various studies support the construct validity of the RSES.[38,39] Estimated internal consistency reported for the RSES in prior research has been $\geq 0.80$.[40]

#### Internalised AIDS-Related Stigma Scale

The Internalised AIDS-Related Stigma Scale (IA-RSS)[41] consists of six items that were adapted from the AIDS-Related Stigma Scale[42] to measure negative self-perceptions and self-abasement about being a person living with HIV. Items (e.g. 'I hide my HIV status from others') are rated on a dichotomous response scale (0 = Disagree; 1 = Agree) and are summed for a total score ranging from 0 to 6. Higher scores indicate greater internalised HIV/AIDS-related stigma. Support for the construct validity of the IA-RSS has been evidenced through associations with indicators of mental health and well-being (e.g. depression, quality of life).[19] Prior research involving samples of South Africans have revealed internal consistency values of $\geq 0.73$ for the IA-RSS.[41]

**Body Appreciation Scale-2**

The Body Appreciation Scale-2 (BAS-2)[43] contains 10 items that measure a person's perceptions of their body (e.g. acceptance, appreciation, inner positivity) and attention towards their body's needs through the adoption of healthy behaviours.[43] Participants rate the items (e.g. 'I feel good about my body') using a five-point response scale (1 = Never; 5 = Always). Item responses are summed for a total score ranging from 10 to 50. Higher scores indicate greater levels of body appreciation. The BAS-2 has been cross-culturally validated in samples from diverse countries (e.g. China, England).[44,45] Previous studies have reported internal consistency values of ≥0.80 for women and men[44], and evidence supports the convergent, incremental, and discriminant validity of the BAS-2[43].

**Morisky Medication Adherence Questionnaire**

The Morisky Medication Adherence Questionnaire (MMAS-8)[46] comprises eight items that assess patient adherence to medication for chronic conditions. The first seven items (e.g. 'When you feel like your symptoms are under control, do you sometimes stop taking your medicine') are rated using a dichotomous response format (0 = Yes; 1 = No). A five-point response format is used to rate the final item (e.g. 'How often do you have difficulty remembering to take all your medicine'), which is transformed to a dichotomous score prior to aggregation of item responses (0 = A; 1 = B–E). In this study, participants completed the MMAS-8 by referencing their adherence to ART medication. We aggregated responses to each of the MMAS-8 items for a total score ranging from 0 to 8, with higher scores reflecting greater adherence to ART. Evidence supports the psychometric utility of the MMAS-8 as a valid and reliable measure of medication adherence[46], including ART adherence[47]. Previous research has reported internal consistency values of ≥0.75 for the MMAS-8, and the findings of several studies support the construct validity of the measure.[46,48]

### *Procedure*

Ethical approval for this study was granted by the Humanities and Social Sciences Research Ethics Committee of the University of KwaZulu-Natal (HSS/0522/018D). Written permission was acquired from a local HIV youth centre to access YPLHIV who received ART from the organisation. A purposive, convenience sampling approach was used to recruit participants. Specifically, YPLHIV who presented at the youth centre to collect their monthly medication were invited by a team of researchers to participate in this study. Interested individuals were directed to a private administrative office where they were initially given details about the study purpose, the participation procedures, and ethical considerations (e.g. anonymity, confidentiality). Those who agreed to participate were invited to provide their written informed consent. With the assistance of the nurses at the youth centre, parents and legal guardians of potential participants below 18 years were informed of the research. Written parental consent was obtained on behalf of all legal minors who indicated their interest in participating. Written assent was also obtained from legal minors. The measures were administered in English, which participants completed in an office provided by the youth centre. The research team was present and available to address any questions or issues that arose during the course of the subjects' participation.

## Results

Statistical processing was performed using R.[49] Study variables were initially screened for gross univariate and multivariate outliers. Standardised values for all variables were within acceptable limits (i.e. $z \leq |3.29|$)[50], indicating there were no univariate outlier concerns. Mahalanobis distance ($\chi^2$ (4) = 18.47, $p<0.001$) did not reveal any multivariate outliers (all $D^2$ values ≤11.92). Univariate skewness (max. = |0.86|) and kurtosis (max. = |0.76|) values indicated that all variables were approximately normal in distribution. Descriptive statistics, internal consistency estimates, and zero-order correlations among the study variables are reported in Table 1. Omega total ($\omega_t$) estimates of internal consistency for all measures were ≥0.74. Self-esteem evidenced a small negative association with internalised HIV/AIDS-related stigma and a small positive association with body appreciation, but its association with ART adherence was negligible. Moderate negative associations were found linking internalised HIV/AIDS-related stigma with both body appreciation and ART adherence. There was a moderate positive association between body appreciation and ART adherence.

Path modelling procedures were performed using maximum likelihood estimation with robust standard errors. Evidence of mediation was tested using a global approach, which involves determining mediation effects after first establishing adequacy of model fit. Following existing recommendations[51,52], model fit was evaluated using a combination of absolute, incremental, and residual-based fit indices. Specifically, we report the chi-square goodness-of-fit statistic (and its associated *p*-value), the comparative fit index, the Tucker Lewis index, the standardised root mean square residual, and the root mean square error of approximation. Along with the statistical significance of the chi-square test statistic ($p>0.05$), values of ≥0.90 for comparative fit index and Tucker Lewis index and values ≤0.10 for root mean square error of approximation and standardised root mean square residual were used as benchmarks to guide our evaluation of model fit.[53,54] We also report the Akaike information criterion to allow comparisons between estimated models, with lower Akaike information criterion values indicative of a more favourable level of fit.[55] Based on our theorising that internalised HIV/AIDS-related stigma and body appreciation would be serial mediators linking self-esteem with medication adherence, we began with the most parsimonious baseline full mediation model in which the association between self-esteem (X) and ART adherence (Y) was specified to occur via internalised HIV/AIDS-related stigma ($M_1$) and then body appreciation ($M_2$). Additional paths were sequentially integrated into subsequent models to determine whether less restrictive models were favoured over those that were more parsimonious. Because model estimation was based on cross-sectional data, a series of conceptually viable alternative models was also estimated.

**Table 1:** Descriptive statistics, internal consistency estimates, and zero-order correlations among study variables ($N$=76)

| Variable | Mean ± s.d. (observed range) | (1) | (2) | (3) | (4) |
|---|---|---|---|---|---|
| (1) Self-esteem | 15.61 ± 1.63 (11, 19) | (0.82) | | | |
| (2) Internalised HIV/AIDS-related stigma | 2.93 ± 1.37 (1, 6) | -0.23** [-0.43, -0.01] | (0.74) | | |
| (3) Body appreciation | 40.49 ± 5.20 (29, 50) | 0.20* [-0.02, 0.41] | -0.40*** [-0.57, -0.19] | (0.84) | |
| (4) Antiretroviral therapy adherence | 5.17 ± 1.59 (1, 8) | 0.06 [-0.17, 0.28] | -0.36** [-0.54, -0.15] | 0.44*** [0.24, 0.61] | (0.77) |

**p<0.10; **p<0.05; ***p<0.001.*

*95% confidence intervals presented in brackets.*

*Omega total ($\omega_t$) internal consistency estimates presented in parentheses along diagonal.*