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EARTH SCIENCES

Climatological aspects and changes in temperature and precipitation extremes in Viçosa-Minas Gerais

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Abstract: Extreme climatic events and their hazards have strong impact on society. Urban areas in Brazil are especially vulnerable to the impact of such events due to their rapid growth and inappropriate infrastructure. Viçosa is a mid-sized city in Southeastern Brazil that has been experiencing issues associated with urban expansion and population growth since the 1960s. Thus, this study aims to identify patterns of extreme climate events in Viçosa based on daily temperature and precipitation time series (1968-2017). Homogeneity tests were carried out in order to identify breaking points in these climate variables. Climate trends were analyzed through Mann-Kendall test and their magnitude was checked based on Sen's slope. Results have evidenced statistically significant and increasing trends in annual minimum temperature since the 1990s. Moreover, statistically significant breaking points in extreme temperature indices have shown increasing number of warm days, and decreasing number of cold nights, in both annual and seasonal analyses. Extreme climatic events have been observed more often in recent years, mainly in the number of consecutive dry days and maximum and heavy precipitation days. Based on results, Viçosa experiences warmer conditions throughout the year, whereas more (less) torrential rainfall events have been occurring during Summer (Winter).

Key words: Homogeneity, climate change, extreme climate indices, trend analysis.

INTRODUCTION

Extreme climatic events – heat or cold waves, intense rainfall and droughts – have been assumed to be natural phenomena (Rosso et al. 2015, Marengo et al. 2017, Soares et al. 2017). The analysis of temperature and precipitation extremes observed throughout the last century has shown that most areas worldwide have become warmer, whereas precipitation rates have been constantly increasing since the 1950's (Frich et al. 2002, Alexander et al. 2006, Donat et al. 2013a, b, Mudelsee 2019). Nevertheless, natural hazards triggers (e.g., floods, landslides, and droughts) associated with extreme climatic events are not easy to be detected due to the combination of natural and anthropogenic factors (IPCC 2013, 2018).

Undesired negative impacts caused by extreme climatic events, manly in agricultural and water management activities, may be more often observed in the future due to the global warming projected for the 21st century. For instance, shifts in precipitation distribution over tropical regions may impact human welfare, agricultural production, fresh water availability and ecosystem balance (Ray et al. 2015, Chadwick et al. 2016). Thus, it is essential understanding climate variability and its associated extreme events.

There has been an increasing number of studies carried out worldwide focused on identifying climate change through homogeneity and trend tests based on hydroclimatological time series (Wijngaard et al. 2003, Serinaldi & Kilsby 2015, Avila et al. 2016, Zilli et al. 2017, Murara et al. 2018). In South America, for example, Haylock et al. (2006) have analyzed over 40-year precipitation data from 54 stations and observed regional trend toward wetter conditions in Southern Brazil, Northwestern Peru and Ecuador, whereas drier conditions were noticed in Southern Chile, Southwestern Argentina and Southern Peru. The aforementioned authors also noticed general trend toward wetter conditions in Eastern and Southeastern Brazil, whereas the Northeastern region in the country showed the opposite trend, i.e., drier conditions. Skansi et al. (2013) performed a similar analysis in South America and recorded similar regional patterns for all annual temperature indices (e.g., cold/warm nights or days, coldest/tropical/summer nights or days), which clearly indicated temperature increase. Moreover, they found increased precipitation indices (total annual precipitation, annual wettest consecutive 5-day precipitation, very wet days and extremely wet days) from 1950 to 2010, which indicated wetter conditions.

Southern and Southeastern Brazil are featured by strong seasonal precipitation (wet Summer, dry Winter) due to the South Atlantic Convergence Zone (SACZ, Kodoma 1992), as well as frequent cold fronts. In many cases, these systems are linked to extreme climatic events, which can cause either floods, landslides or droughts (Teixeira & Satyamurty 2011, Brasiliense et al. 2018).

Temperature and precipitation extremes observed in the Southeastern and Southern regions have shown trend to increase the frequency of days presenting extreme climate events in recent decades (Vincent et al. 2005, Marengo et al. 2013, Carvalho et al. 2014, Silva et al. 2014, 2015, Avila et al. 2016, Zilli et al. 2017, Lima & Magaña 2018, Regoto et al. 2018). Silva et al. (2014) have found positive trend toward maximum and minimum temperatures in most weather stations in Rio de Janeiro State. Furthermore, they found statistically significant positive trend toward higher precipitation rates over the Southern costal lowland. Ávila et al. (2016) has also found that the frequency and intensity of extreme daily precipitation have increased over two mountainous regions in south southeastern Brazil, namely Serra do Mar which extends from Rio de Janeiro State to Santa Catarina state. The aforementioned authors have noticed that impact of changes in precipitation events is also associated with urban occupation in vulnerable regions.

Thus, urbanization and climate change may lead to changes in the incidence of extreme precipitation events (Tian et al. 2013, Zhou et al. 2017). According to the Instituto Brasileiro de Geografia e Estatística (IBGE), the population living in Viçosa city, Brazilian Southeastern region, increased from approximately 25 thousand inhabitants to more than 72 thousand between 1970 and 2010. Population density within this period has increased by factor of three, from 86 to 241 individuals per km^2. Thus, many studies have been analyzing the climate/urban interactions in Viçosa based on climatological averages (e.g., Rodrigues et al. 2010, Ferreira & Fialho 2016, Fernandes et al. 2017, Sanches et al. 2017). However, the literature still lacks studies focused on investigating extreme climate conditions. Therefore, the aim of the current study was to identify changes in extreme temperature (maximum and minimum values) and precipitation events over the last 50 years (1968-2017) based on daily observations in Viçosa – MG. Associations between hydrological hazard events, such as floods and landslides, and extreme climate indices were also investigated.

MATERIALS AND METHODS

Study area and data source

Daily and monthly precipitation and temperature datasets (maximum, minimum and mean values recorded from 1968 to 2017) were collected in the database of the Instituto Nacional de Meteorologia (INMET) and used in the current study. The weather station (WMO code: 83642) where data were collected is based in Viçosa, Minas Gerais State, at geographical coordinates -20.75 °S (latitude), -42.85 °W (longitude) and altitude 689.7 meters above sea level (Figure 1).

DATA TREATMENT AND ANALYSIS

Extreme climate indices evaluation

In total, 13 indices were computed based on temperature and precipitation time series (Table I), as recommended by the Expert Team on Climate Change Detection Monitoring and Indices (ETCCDI). These indices portray details of extreme climatic events such as precipitation intensity, frequency, duration and increase/decrease in the number of either warm or cold nights (Frich et al. 2002, Zhang et al. 2011). They were selected based on a literature review about natural disasters (drought, flood and temperature extremes) (Sillmann et al. 2013, Skansi et al. 2013, Valverde & Marengo 2014, Ávila et al. 2016, 2019, Loaiza et al. 2020). The aforementioned indices were calculated at annual and seasonal scales (I- Summer: December, January and February

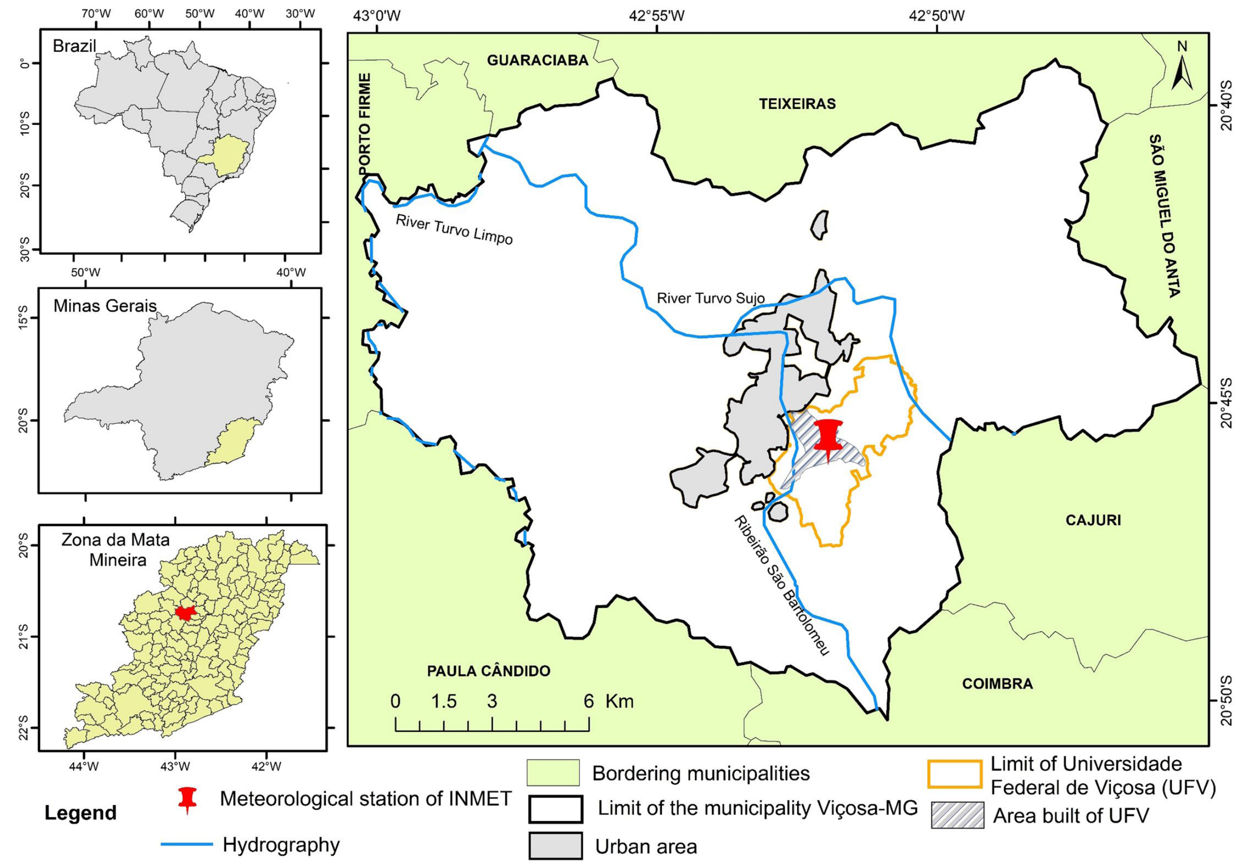

Figure 1. Study area and weather station location.

Table I. List of extreme indices recommended by ETCCDI (see http://etccdi.pacificclimate.org/list_27_indices.shtml). (a) Extreme temperature and (b) precipitation indices and their respective definition.

Indices	Descriptive name	Definition	Units
Extreme indices deriving from daily maximum and minimum temperature series			
TXx	Hottest day	Maximum value of daily max temperature	°C
TNn	Coldest night	Minimum value of daily min temperature	°C
TN10p	Cold nights	Percentage of time when daily min temperature < 10th percentile	% of days
TN90p	Warm nights	Percentage of time when daily min temperature > 90th percentile	% of days
TX10p	Cold days	Percentage of time when daily max temperature < 10th percentile	% of days
TX90p	Warm day	Percentage of time when daily max temperature > 90th percentile	% of days
Extreme indices deriving from daily precipitation series			
PRCPTOT	Annual total wet-day precipitation	Total precipitation from days ≥ 1mm	mm
RX1day	Max 1-day precipitation amount	Maximum 1-day precipitation	mm
RX5day	Max 5-day precipitation amount	Maximum consecutive 5-day precipitation	mm
R95p	Very wet days	Total PRCPTOT when RR > 95th percentile	mm
R50mm	Number of very heavy precipitation days	Annual/seasonal count when precipitation RR ≥ 50 mm	Days
CDD	Consecutive dry days	Maximum length of dry spell, maximum number of consecutive days with RR < 1mm	Days
CDW	Consecutive wet days	Maximum length of wet spell, maximum number of consecutive days with RR ≥ 1mm	Days

*** RR is the daily precipitation amount on a wet day.**

(DJF); II- Autumn: March, April and May (MAM); III- Winter: June, July and August (JJA); IV- Spring: September, October and November (SON)) in the R package "climind", which was developed and is maintained by the European Climate Assessment & Dataset team (ECA&D). The software is freely accessible online at https://rdrr.io/github/ECA-D/climind/; it runs on R platform.

Detection and evaluation of breaking points

Breaking point detection techniques were used to evaluate the temporal evolution of temperature and precipitation rates, as well as to investigate the incidence of discontinuity in the time series. They were based on three different tests: 1) Pettit test (Pettitt 1979), 2) Buishand test (Buishand 1982) and 3) Standard Normal Homogeneity test (SNHT), as suggested by Alexandersson & Moberg (1997). These tests are widely used to identify homogeneity in historical time series based on hydrometeorological variables (Wijngaard et al. 2003, Costa & Amílcar 2009, Martinez et al. 2010, Santos et al. 2012, Boccolari & Malmusi 2013).

All three homogeneity tests are capable of detecting the shift in the average associated with the moment when a rupture in the climate series takes place (e.g., precipitation and temperature data). The herein used testing variables were data about annual and seasonal extreme climate indices (Table I). Based on the test results, it was possible assuming that the null hypothesis (H_0) was independent and normally distributed, whereas the alternative hypothesis (H_1) referred to deviations from the mean. According to Wijngaard et al. (2003), time series can be divided into two categories: 1) if no test neglects the null hypothesis, the time series is classified as homogeneous (HM), 2) if all tests neglect null hypothesis or if 2 out of 3 tests detect the breaking point in the same year, that year is assumed to be a breaking year and the time series is classified as doubtful or non-homogeneous (NH). Homogeneity tests were conducted at significance level (p-value) of 0.01 (Wijngaard et al. 2003).

Identifying trends, floods and landslides records

Temperatures and precipitation trends were analyzed by Mann Kendall (M-K) test (Mann 1945, Kendall 1975) and their magnitude was assessed through Sen's slope estimator (Sen 1968). The M-K test allows assuming that the null hypothesis (H_0) lies on lack of no trend in climate extremes over time and that the alternative hypothesis (H_1) lies on the evidence of monotonic trend in them (increasing or decreasing). Trends in the current study were statistically significant based on the M-K test, at 95% significance level. Both the M-K test and Sen's slope estimator method were calculated in the R package "trend" (version 1.1.1) developed and maintained by Thorsten Pohlert.

The M-K test and Sen's slope method are nonparametric methods applied to identify trends and magnitudes of deviations in temporal series of climate data (Skansi et al. 2013, Zilli et al. 2017, Ongoma et al. 2018, Serrano-Notivoli et al. 2018). Further details on the equations and procedures adopted in these methods can be found in studies by Yue et al. (2002) and Ahmad et al. (2015).

Floods and landslides recorded in Viçosa city– MG - as reported in Atlas Brasileiro de Desastres Naturais - from 1991 to 2012 were evaluated in order to check whether they were associated with climate extremes, as well as to feature the current results in a more useful manner (Batista & Rodrigues 2010, CEPED-UFSC 2013 or https://s2id.mi.gov.br/paginas/atlas/). Moreover, local journalistic sources were analyzed and compared to anomalies in extreme climate indices.

RESULTS AND DISCUSSION

Climatological aspects of climate extreme indices

Viçosa city is located in Minas Gerais State, which is part of the Brazilian Southeastern region. The mean annual temperature in the region is approximately 21 °C (Figure 2a). According to Nunes et al. (2009), the region is influenced by its topography, which induces decrease in air temperature in comparison to nearby areas.

However, in the near future, variations in near surface air temperature are quite different among seasons (Figure 2b). Mean air temperature during austral Summer (DJF) is close to 24 °C -the lowest temperature values (from 18 °C to 19 °C) are often recorded in Winter (JJA). Larger amplitude of the mean temperature is observed in transitional seasons: it is during the austral Autumn (MAM) decreases to 23 °C in March until it reaches 19 °C in May. On the other hand, temperature in Spring (SON) ranges from 20 °C in September to 23 °C in November.

Extreme air temperature values indicate high temperature variability in Viçosa city during Winter and Summer. Based on Figure 2, the interquartile range (i.e., the range between the 25th and 75th quantiles) of minimum temperature (TNn) is overall greater from April to June, or between the transition from Autumn to austral

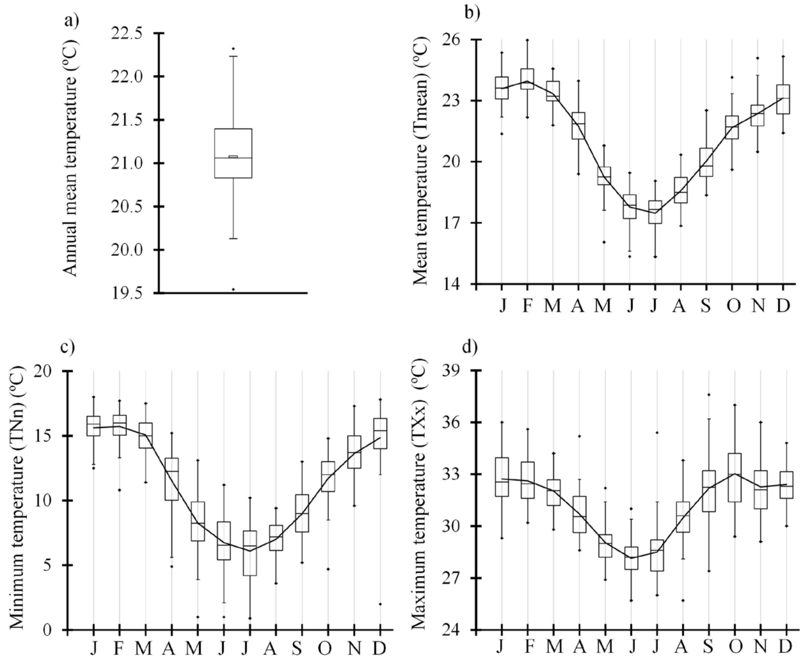

Figure 2. **Annual cycle of the air temperature: (a) Annual mean temperature, (b) monthly mean temperature, (c) monthly minimum temperature and (d) monthly maximum temperature. Boxes represents the interquartile spread (25th and 75th quantiles) with the horizontal line indicating the median and the whiskers showing the extreme range of the variables; solid line indicates mean from 1968-2017.**

Winter. On the other hand, the period between late Winter and early Spring (from August to October) is featured by higher variability in maximum temperature (TXx). The interquartile range of mean temperature (Tmean) does not strongly vary throughout the year.

The TNn index in Viçosa has large amplitude (Figure 2c), which ranges from 0 °C in July and to over 18 °C in January. TNn during JJA is approximately 7 °C, whereas DJF presents temperature of approximately 16 °C. The TXx index shows values higher than 28 °C (Figure 2d). However, it can reach values higher than 36 °C in September and October. Mean TXx during DJF reaches values up to 33 °C, whereas JJA presents TXx ranging from 28 °C to 30 °C.

It is important emphasizing that the highest TXx values are more often recorded during austral Spring (SON), which is associated with low incidence of clouds and, consequently, with higher solar radiation incidence. On the other hand, the presence of SACZ and frontal systems in DJF actively contributes to precipitation accumulation and increased cloudiness (Natividade et al. 2017), which enables maintaining mild temperatures.

Viçosa is featured by significant precipitation in DJF. This season encompasses 47.8% of total annual precipitation - mean precipitation is approximately 254.8 mm, 223.9 mm and 123.9 mm in December, January and February, respectively (Figure 3a). Precipitation concentrated during DJF is mainly caused by the presence of SACZ and recurrent frontal systems (Carvalho et al. 2004).

The South Atlantic Dipole (SAD) is another component influencing the climate regime in Southeastern Brazil. Variations in SAD phases affect SACZ position and performance and, consequently, they affect the precipitation regime in the Southeastern region. SAD plays a major role in modulating cyclogenesis and SACZ features during neutral El Niño–Southern Oscillation (ENSO) phases. On the other hand, SACZ and frontal system are absent or rare during JJA, a fact that leads to low precipitation amount in Viçosa (Bombardi & Carvalho 2011, Bombardi et al. 2014).

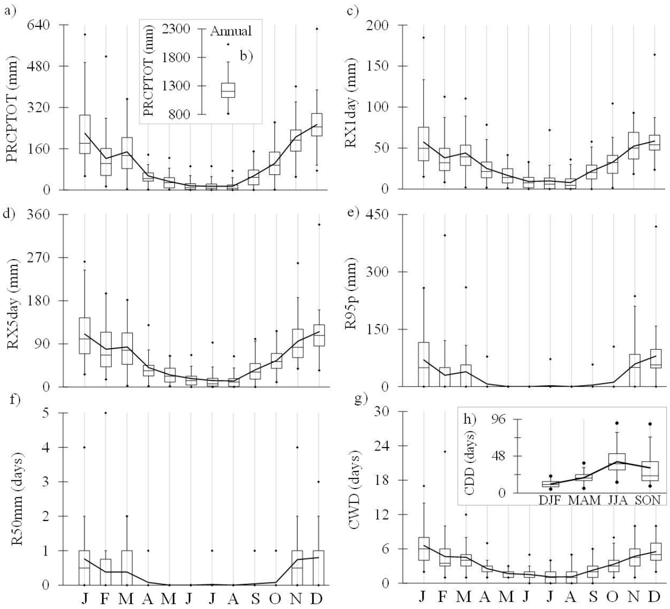

Figure 3. Annual cycle of precipitation indices (Table II) from 1968 to 2017; (a) PRCPTOT, (c) RX1day, (d) RX5day, (e) R95p, (f) R50mm and (g) CWD. (b) Variability of annual precipitation. (h) Variability of seasonal of consecutive dry days. Boxes represents the interquartile spread (25th and 75th quantiles) with the horizontal line indicating the median and the whiskers showing the extreme range of the indices; solid line indicates mean from historical record.

Annual precipitation in Viçosa from 1968 to 2017 was highly varying; it ranged from less than 813 mm to 2,030 mm (Figure 3a, b). Accumulated precipitation values are often low from April to August, since they do not reach 50 mm a month. On the other hand, mean monthly precipitation values recorded from October to March range from 140 mm to 200 mm. Based on the interquartile range of precipitation indices (Figure 3), the highest precipitation variability (except for consecutive dry days-CDD) happens from October to March; this finding is in line with the South American Monsoon activity (Grimm & Silva 2011).

The maximum precipitation amount in one day (RX1day), and the maximum precipitation accumulated in five consecutive days (RX5day), present their highest values between October and March (Figures 3c, d). Based on Figures 3e and 3f, the total precipitation at very wet days (R95p) and the number of cases presenting precipitation higher than 50 mm a day, are more often recorded between November and March.

The maximum number of consecutive dry days (CDD) is observed in JJA - 40 days (Figure 3h). It is important emphasizing that CDD index climatology is analyzed at seasonal scale because the longest period of consecutive dry days is observed in Winter (JJA). On the other hand, the maximum CDD duration throughout DJF does not reach 20 days. Given the higher precipitation accumulation from October to March, the maximum duration of consecutive wet days (CWD) is observed in these months (Figure 3g).

Breaking points in temperature and precipitation indices

Statistical trend estimation methods are well developed and comprise linear curves, change-points, accelerated increases, as well as other nonlinear behaviors and nonparametric descriptions (Mudelsee 2019). Data analysis in the present study has shown statistically significant breaking points in both seasonal and annual temperature patterns from 1968 to 2017 (Figures 4 and 5, respectively).

Based on the seasonal scale, TXx index (maximum value of daily maximum temperature; Figures 4a, b, c) has increased after the 1990s. The mean TXx index rose by 0.9 °C in 1993 (DJF);

by 1.0 °C in 1990 (JJA); and by 1.6 °C in 1992 (SON), respectively.

Seasonal analyses have also shown breaking points in the TNn index (minimum value of daily minimum temperature), which increased by 1.4 °C in DJF and by 1.7 °C in JJA, after 1980 and 2000, respectively (Figures 4d, e). Similarly, cold night index rates (TN10p) in MAM (Figure 4f) and JJA (Figure 4g) have decreased by 10% and 12%, after 1980 and 2000, respectively.

Based on the seasonal scale, the TN90p index (warm nights) presented increase by 12%, 8%, 6%, and 9% in the number of warm nights after 1997 (DJF; Figures 4h), 1982 (MAM; Figures 4i), 1997 (JJA; Figure 4j) and 2000 (SON; Figure 4k), respectively. It is important emphasizing that Minuzzi et al. (2010) have found increased (from 0.86°C to 3.4°C) minimum temperature in Viçosa between 1961 and 2004, mainly in January and September.

Based on the annual scale, the TXx index has indicated temperature 1.5 °C higher after 1992 (Figure 5a), which was followed by TX10p index decrease (cold days; Figure 5b) by 3% and TX90p (warm days; Figure 5c) increase by 6%. In addition, breaking points were identified after 1997 and highlighted decrease by 7% in the number of cold nights and increase by up to 8% in the number of warm nights in comparison to the mean in 1968-1996 period (Figures 5d, e).

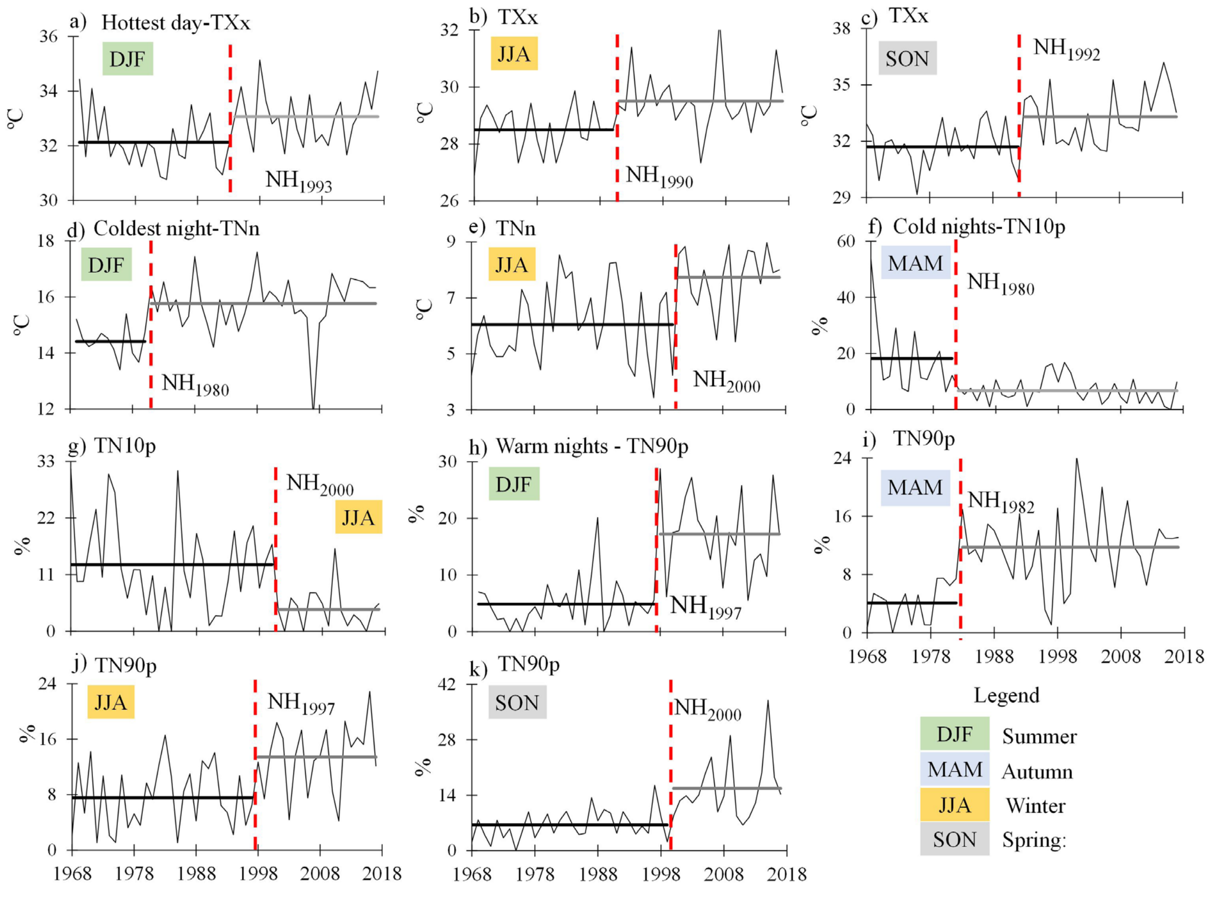

Figure 4. Temporal distribution of the extreme temperatures indices that presented abrupt changes points during 1968–2017 for the seasonal scale. Dashed red line indicates a nonhomogeneous series and the respective year of rupture (NHx).

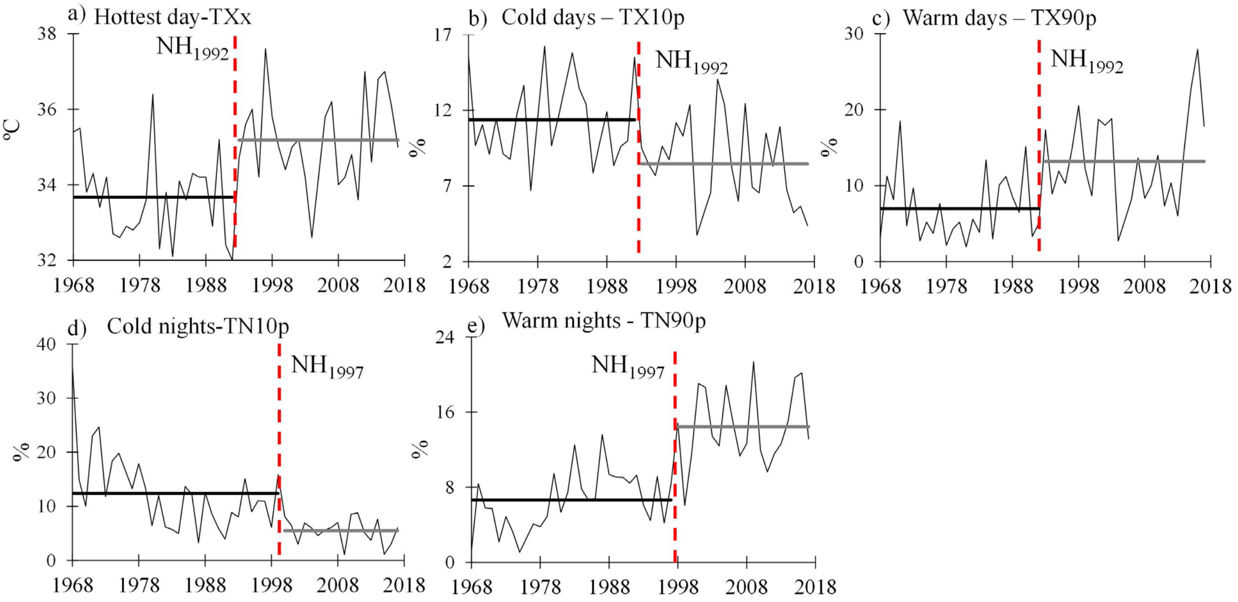

Figure 5. Temporal distribution of the extreme temperatures indices that presented abrupt changes points during 1968–2017 for the annual scale. Dashed red line indicates a nonhomogeneous series and the respective year of rupture (NHx).

Most statistically significant changes were observed in the 1990s. The larger number of breaking points recorded for both maximum and minimum temperature series was observed in 1992 and 1997 (Figures 4 and 5). Similar temperature results were reported by Minuzzi et al. (2010) and Santos et al. (2012) in a much broader area in Minas Gerais State. Seasonal and annual analyses applied to extreme precipitation data series have shown homogeneous data (no breaking points were identified).

It is necessary emphasizing that the heterogeneity observed in the analyzed time series was not associated with equipment changes, since sensors were not replaced and the station remained where it was. The current study advocates that these temperature changes were associated with environmental changes such as urbanization. According to Fernandes et al. (2017) Viçosa has experienced intense urbanization in recent decades, which might have caused local impacts; however, these impacts were not clearly identified in the analyzed climatological time series. All trends on meteorological variables were coherent with broader scale changes in Minas Gerais State (Rodrigues et al. 2010). Thus, it is necessary being cautious at the time to point out urban influences as the primary cause of such changes. Certainly, urban area growth in Viçosa has played an important role in these trends and breaking points, but it is quite interesting to mention that these conditions were also observed in its rural zone (Fialho et al. 2011).

Trend analysis of extreme temperature indices

Table II presents the trends of seasonal and annual temperature indices from 1968 to 2017. The Mann-Kendall and Sen Slope estimator methods have shown statistically significant trend toward warmer conditions. For instance, based on the annual scale, the minimum temperature (TNn) and mean minimum temperature (TNmean) indices revealed significant positive trend of 0.47 °C and 0.29 °C per decade, respectively. In addition, mean minimum temperature in

Summer and Spring has been increasing at the rate of 0.2 °C and 0.18 °C per decade (both trends were statistically significant at $p<0.05$).

The number of cold nights (TN10p) is decreasing, whereas the frequency of warm nights (positive TN90p values) is increasing. This pattern can be seen in the TX10p (negative values) and TX90p (positive values) indices, which presented reduced total number of cold days and, consequently, increased frequency of warm days. Previous studies conducted in Southern and Southeastern Brazil have also found increased number of warm nights and minimum temperature in the Brazilian Southeastern region in the last decades (Vincent et al. 2005, Alexander et al. 2006, Skansi et al. 2013, Rosso et al. 2015).

Sanches et al. (2017) have identified increased monthly maximum (except for May) and minimum temperatures, which is in compliance with the current results. The aforementioned authors have emphasized that minimum temperature trends were statistically significant in most months, mainly in Winter; this finding has indicated that Viçosa is getting warmer. Rodrigues et al. (2010) have also observed these patterns in daily series of maximum and minimum temperatures recorded for Viçosa . However, based on large scale data, they reported that such temperature increase is also corroborated by the regional pattern. Natividade et al. (2017) performed a clustered evaluation of reanalysis, as well as observed and simulated data about Northern and Southern Minas Gerais State. They also noticed increased temperatures based on indices such as decreased number of cold nights (TN10p) and days (TX10p), and increased number of warm nights (TN90P) and days (TX90p).

Trend analysis of extreme precipitation indices

Table III presents results of the analyses applied to extreme precipitation indices. Statistically significant positive trends - at 95% significance level ($p<0.05$) – were recorded for maximum consecutive 5-day precipitation (RX5day; Figure 6a) and very heavy days (R50mm; Figure 6b) in DJF. However, maximum 1-day precipitation

Table II. Seasonal and annual trends of temperature indices from 1968 to 2017. Trends highlighted in bold are statistically significant at 95% significance level. Negative values indicate decreased trends, whereas positive values indicate increased trends. NT: No trend or values equal to zero. ┘ : Trends recorded for data series after discontinuity points were identified in Figure 2.

Indices (units/decade)	Summer (DJF)	Autumn (MAM)	Winter (JJA)	Spring (SON)	Annual
TXx (°C/decade)	+0.14┘	**+0.25**	NT┘	+0.65┘	+0.05┘
TXmean (°C/decade)	+0.36┘	+0.13	+0.31┘	+0.75┘	+0.37
TNn (°C/decade)	+0.17┘	**+0.37**	+0.26┘	+0.11	+**0.47**
TNmean (°C/decade)	**+0.20**┘	**+0.08**	**+0.03**┘	**+0.18**	**+0.29**
TN10p (% of days/decade)	**−3.45**	−0.95┘	−0.16┘	−0.87	**−1.35**┘
TN90p (% of days/decade)	−3.12┘	**+0.36**┘	+1.84┘	+1.31┘	+0.75┘
TX10p (% of days/decade)	−0.57	**−0.64**	**−1.04**	**−1.50**	−1.37┘
TX90p (% of days/decade)	+1.95	+1.47	**+1.55**	**+2.49**	+0.78┘

amount (RX1day; Figure 6c), very wet days (R95p; Figure 6d) and consecutive wet days (CWD) have shown statistically significant and increasing trend at 90% significance level ($p<0.10$). These indices are linked to torrential precipitation events associated with extreme wet events during the rainy season in Southeastern Brazil (Muza et al. 2009, Bombardi & Carvalho 2011, Marengo et al. 2020).

Based on the seasonal scale, Autumn (MAM) has shown positive PRCPTOT (total precipitation with days ≥ 1mm), RX1day, RX5day and CDD trends (Table III). However, these results were not statistically significant. Extreme events related to R95p and R50mm have presented even distribution in the entire time series. The CWD index (consecutive wet days) recorded significant decrease in Autumn (MAM), which indicated shorter consecutive precipitation intervals.

PRCPTOT (Figure 7a), RX5day (Figure 7b) and CWD (Figure 7d) presented statistically significant negative trends in Winter (JJA). Seasonal RX5day results were similar to the ones reported by Alexander et al. (2006) from 1951 to 2003. The indication of drier winter was reinforced by statistically significant CDD index (consecutive dry days; Figure 7c). Sanches et al. (2017) reported similar reduction in total winter precipitation rates from 1968 to 2015.

PRCPTOT, RX1day, RX5day and R95p indices have shown decreased precipitation rates and increased sequence of dry days (CDD) during Spring (SON). Based on the Mann Kendall test, PRCPTOT, RX1day, and R95p were statistically significant at 90% significance level.

Based on the annual scale (Table III and Figure 8), all extreme precipitation indices presented positive trends - statistically significant results were recorded for indices such as RX1day, R50mm and CDD. Thus, statistically significant results have indicated longer duration of dry periods (Table III). However, there was increased frequency and intensity of extreme precipitation events: higher than 50 mm concentrated in 1-day periods. Actually, precipitation events in Viçosa became more intense and concentrated in a shorter interval. These findings corroborate the study by Zandonadi et al. (2015), who confirmed higher total precipitation rates in almost all analyzed stations in Paraná River Basin. According to such

Table III. Seasonal and annual trends of precipitation indices from 1968 to 2017. Trends highlighted in bold were statistically significant at 95% significance level. Negative values indicate decreased trends, whereas positive values indicate increased trends. NT: No trend or values equal to zero.

Indices (units/decade)	**Summer (DJF)**	**Autumn (MAM)**	**Winter (JJA)**	**Spring (SON)**	**Annual**
PRCPTOT (mm/decade)	+13.72	+14.35	**−6.81**	−22.12	+10.83
RX1day (mm/decade)	+4.07	+1.93	−1.60	−3.53	**+9.08**
RX5day (mm/decade)	**+8.80**	+1.09	**−3.05**	−2.45	+0.71
R95p (mm/decade)	+21.83	NT	NT	−9.00	+23.42
R50mm (days/decade)	**+0.27**	NT	NT	NT	**+0.23**
CDD (days/decade)	+0.40	+0.43	**+3.58**	+0.67	**+4.62**
CWD (days/decade)	+0.40	**−0.28**	**−0.26**	−0.26	NT

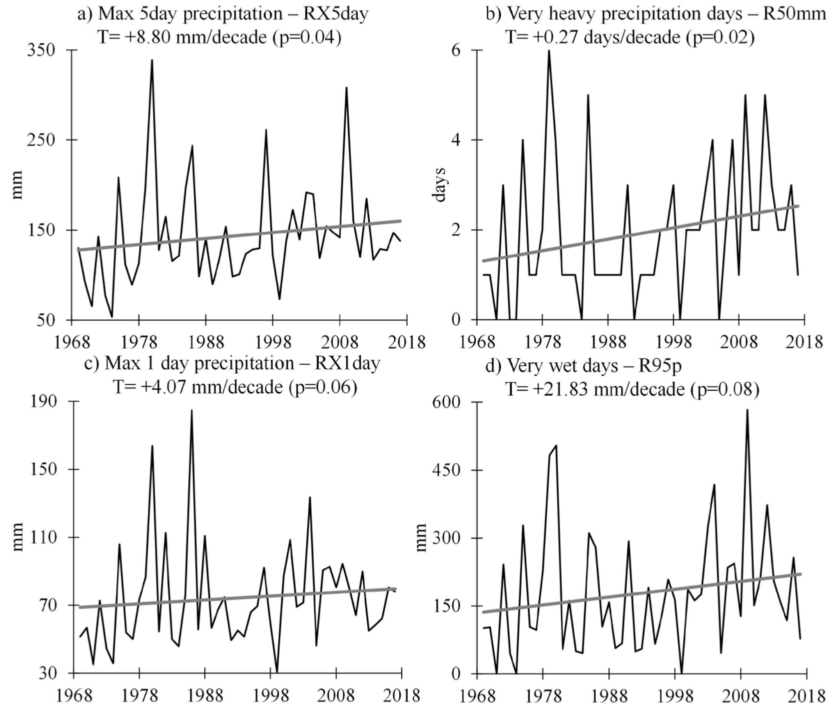

Figure 6. Temporal distribution of the extreme precipitation indices in the 1968–2017 period for summer (DJF = December, January and February). Index with gray line indicates significant linear trend (Table III), T indicates magnitude of trend, and p stands statistical significance.

authors, extreme precipitation events play an important role in positive trends. Skansi et al. (2013) have also observed that the precipitation indices clearly indicate increased wetter conditions and intensified heavy rain events in Eastern South America. Annual precipitation rates have been significantly rising in Southern South America. Very wet and extremely wet days, annual maximum 5-day and 1-day precipitation have shown the highest upward trends, which indicated intensified precipitation events in South America (Carvalho et al. 2014, Ávila et al. 2016, Zilli et al. 2017).

During the austral summer (DJF), the Viçosa region is often affected by the monsoon regime in austral Summer (DJF) (Zhou & Lau 1998). Monsoon-related rainfall in South America influences the SACZ, along with the transport of warm and humid air from the Amazon region which is transported by the low-level jet stream (LLJS, Mechoso et al. 2005). These events end up causing landslides and floods when they happen at great intensity (Ávila et al. 2016). Increased trends in RX1day, RX5day, R95p and R50mm during austral Summer can likely lead to larger number of natural disasters if no action is taken (Table III).

Five urban disasters were identified in Viçosa; among them one finds floods and landslides, which caused serious damages to the local population from 1968 to 2017. The first two years were identified by Batista & Rodrigues (2010), who reported disasters in January 1986, and in January and February 2004. The Atlas Brasileiro de Desastres Naturais (CEPED-UFSC 2013) reported flood-related events in December 2008 and January 2012. Zona da Mata newspaper reported flood and mudslide events after strong and intense precipitation in March 2015.

The herein recorded extreme events mainly happened in DJF (Figure 9), which is associated with higher precipitation rate anomalies recorded for RX5day, R50mm and R95mm. Natural disasters recorded in the region are correlated to precipitation indices presenting positive anomalies. For example,

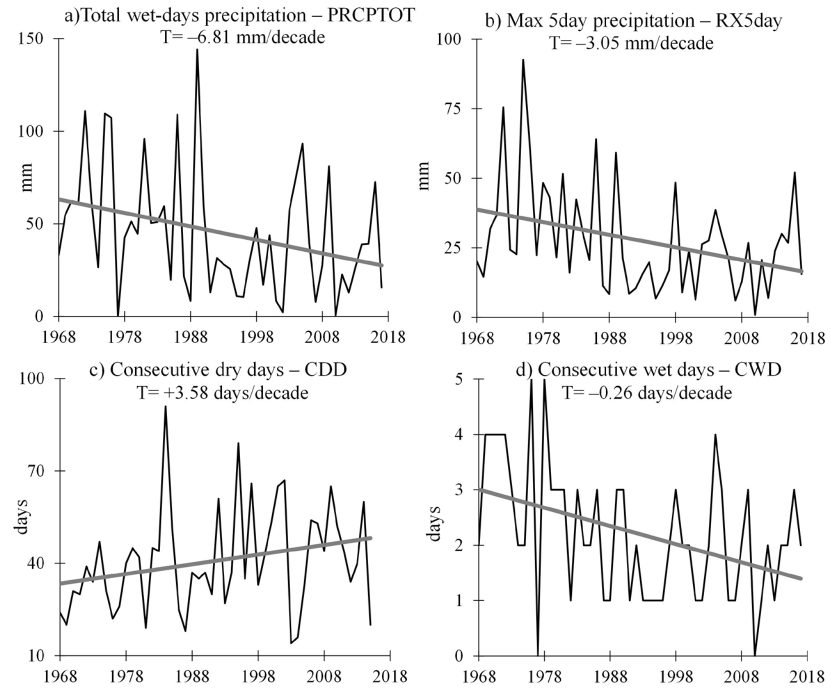

Figure 7. Temporal distribution of the extreme precipitation indices in the 1968–2017 period for winter (JJA= June, July and August). Index with gray line indicates significant linear trend (Table III), at least at the 95% confidence level. T indicates magnitude of trend.

the R95p index observed in January (1986 and 2012) and February (2004) recorded magnitude 1.7 times higher than the climatological mean (see Figures 3e and 9). December 2008 recorded 625 mm (PRCPTOT) of precipitation, which is 2.4 times higher than the historical mean (254 mm; see Figures 3a and 9). In addition, maximum precipitation in five consecutive days (RX5day) and very wet days (R95p) exceeded 180 mm and 339 mm, respectively. On the other hand, 2015 presented maximum precipitation anomalies in March, which was the month recording the flood event.

According to Ávila et al. (2016) and Zilli et al. (2017), the high population density in cities in Southeastern Brazil, in association with the inadequate occupation of risk areas and positive trends toward extreme precipitation events, suggest increasing risk of precipitation-related disasters in this region. However, Rodrigues et al. (2010), based on the historical series of the meteorological station of Viçosa from 1968 to 2008, have claimed that climatic patterns in the city are closely linked to the interaction of far-reaching atmospheric circulation systems and the physiography of the region. They emphasized that expansion and urbanization processes have little potential to change weather patterns, mainly precipitation. Although daily precipitation did not show trends, changes in monthly precipitation rates can influence minimum temperature trend due to changes in water vapor amount.

According to Sanches et al. (2017), Viçosa has experienced slightly positive precipitation trend in Summer and Spring, from 1968 to 2015, as well as significant precipitation decrease in Winter and almost no changes in Autumn. These observations corroborate the current results, according to which the dry season get longer (PRCPTOT and CDD) and precipitation gets concentrated in shorter periods during the wet season (RX1day, RX5day, R95p and R50mm) over time.

Results in the current study were in compliance with extreme precipitation trends

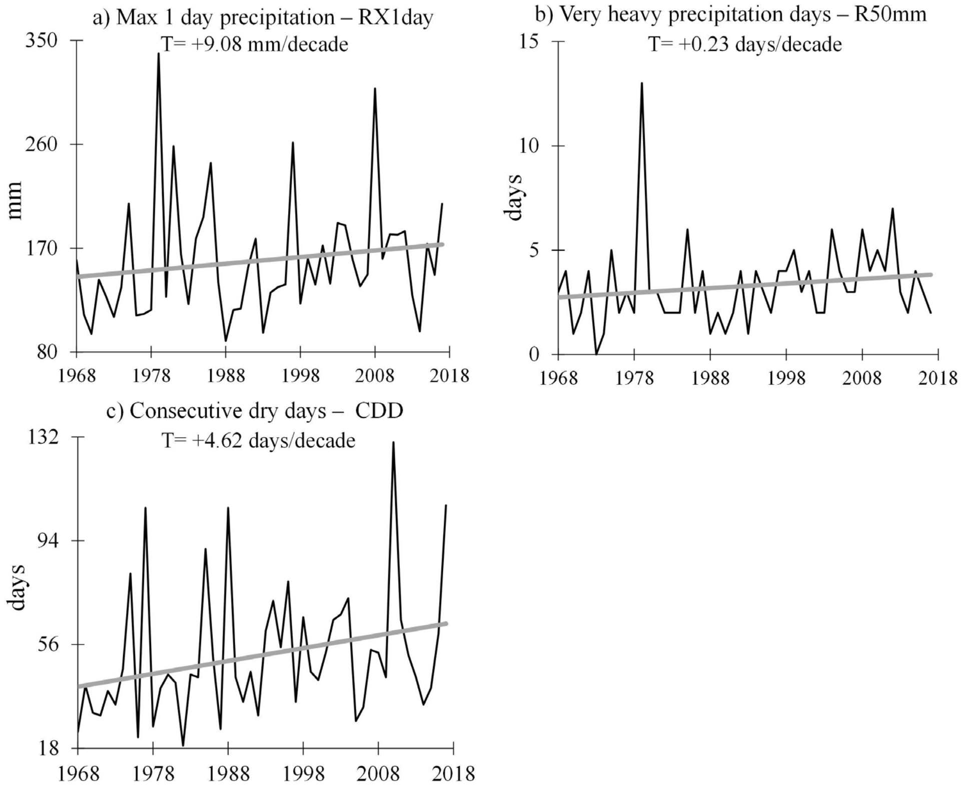

Figure 8. Temporal distribution of the extreme precipitation indices in the 1968–2017 period for the annual scale. Index with a gray line indicates significant linear trend (Table III), at least at the 95% confidence level.

observed in Southeastern and Southern Brazil by Teixeira & Satyamurty (2011) and Carvalho et al. (2014); these authors observed increasing trend toward extreme events in the Brazilian Southeastern region.

Natividade et al. (2017) have investigated extreme precipitation events in Minas Gerais State and only found weak trends - few of them were significant. They also observed positive trend for consecutive dry days (CDD) from 1970 to 2010 and maximum precipitation in 5 days (RX5day) from 1948 to 2005, in Southern Minas Gerais State; however, they did not find trends toward consecutive wet days (CWD) and very humid days (R95p).

Reboita et al. (2018) have analyzed the historical period corresponding to 1980-2005 and the future RCP 8.5 scenario (2070-2095) in Minas Gerais State and observed increased precipitation trend in Summer and reduced trend in Winter. Future climate projections indicate that the sequence of consecutive wet days tends to reduce, whereas the sequence of consecutive dry days tends to increase (Reboita et al. 2018). This pattern is similar to the ones found in the current study, a fact that reinforces the likely influence of large-scale factors in the incidence of extreme climate events in Viçosa -MG.

CONCLUSIONS

The present study has identified changes in the incidence of extreme climatic events, as well as trend toward these events in Viçosa City from 1968 to 2017. Variations in temperature (maximum and minimum) and precipitation rates were analyzed based on daily observations. Potential interactions between natural hazards, such as floods and landslides, and extreme indices

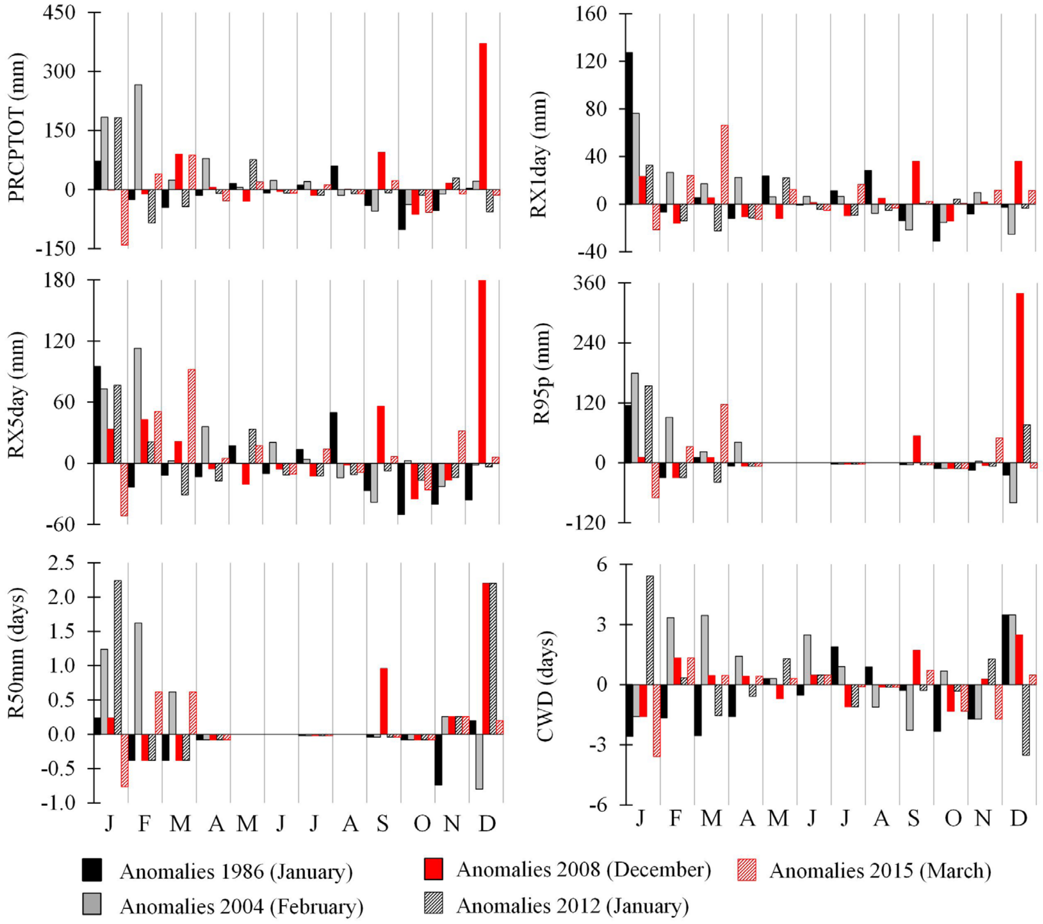

Figure 9. Monthly distribution of anomalies of extreme precipitation indices in years with natural disasters occurred: 1986 (January), 2004 (February), 2008 (December), 2012 (January) and 2015 (March); month between parentheses indicate the month floods or landslides happened. Anomalies are computed with respect to the 1968–2017 climatological mean for each index.

were also taken into consideration. This study is justified by the fact that Viçosa city is located in the Brazilian Southeastern region, which is under SACZ influence (between October and April) and has experienced substantial urban population increase in the last 3 decades.

Local changes in precipitation, as well as in maximum and minimum air temperature, were observed from 1968 to 2017. Although the total annual precipitation did not statistically change, the other indices showed significant trends, mainly toward longer dry periods and smaller number of annual wet days. Furthermore, the largest anomalies observed for precipitation indices took place in Summer, in compliance with most occurrences of natural disasters.

Thus, based on analyses conducted in the current study, it was possible concluding that:

I) The annual maximum temperature increased by more than 0.9°C, on average, after 1992, according to breaking point tests. II) The number of warm nights increased more than 6% from 1968 to 2017, mainly after 1997. III) There has been statistically significant positive trend toward minimum temperature (2.3 °C) over the past 50 years. And, IV) Viçosa has been experiencing warmer conditions throughout the year, whereas more torrential precipitation events have been happening in Summer, in opposition to drier Winter.

Despite the statistically significant results observed in the current study, is it necessary applying further analysis to the influence of dynamic atmosphere conditions on temperature extremes in Viçosa. A follow-up investigation is also necessary to help better understanding changes in temperature and precipitation extremes in Viçosa region.

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