Climatic trends of temperatures and precipitation in Brazilian localities

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Abstract:

In recent decades, scientific and academic researchers around the world have been concerned with the assessment of regional and global climate trends. Under the hypothesis of the presence of climate change in Brazil, the aim of this work was to verify annual climate trends of maximum and minimum air temperatures and precipitation in 243 localities over all the Brazilian political regions. The data were obtained from National Institute of Meteorology. In this work there were identified and analysed trends in annual time series distributed between in 1961 and 2017. The detections and analyses were performed by the application of the statistical tests of Mann-Kendall and the Pettitt to evaluate the presence of statistical trends. The statistical results and the trend distributions maps show that, from all the studied localities, for maximum temperature indicate increasing trends in 35% of the series, decreasing trends in 1 and no trends in 64%. The minimum temperature showed increasing trends in 30% of the analysed series, decreasing in 8% and no trends in 63%. The precipitation, showed increasing trends in 6% of the studied series, decreasing in 4 and no trends in 91%. The observed climate trends can be related to anthropological activities like urban spraw, industrial development and increasing population density.

KEYWORDS: trends detection, time series, statistical analysis, environmental changes.

Introduction

In recent decades, scientific and academic researchers around the world have been concerned with the assessment of regional and global climate trends. The assessment of climate trends is a planning tool for society because it enables the consideration of possible consequences of increasing air temperature and changes in precipitation that have been observed around the globe (Intergovernmental Panel on Climate Change [IPCC], 2013). Such studies also subsidize elements for better investigation of future climate behaviour.

According to the Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC), the increasing trend in atmospheric temperature is unequivocal and since the 70's variations are observed in global weather patterns (IPCC, 2013). The average atmospheric temperature has increased almost all over the globe, with increments of up to 2.5°C in the period 1901-2012 in southern South America, North Africa, central Asia and northern North America. Increases in annual rainfall of 50 mm year-1 decade-1 were observed in South America, northern Australia and Europe. Negative trends in this variable were observed in Africa, southern Asia and southern Europe, with a decrease of 5-50 mm year-1 decade-1 (IPCC, 2013).

Alexander et al. (2006) analysed data from 2000 temperature stations and 2200 rainfall stations around the globe and identified, in annual series, significant increasing trend in temperature in South America, especially in the second half of the twentieth century. For the parameters related to minimum temperature,

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analysed more than 1400 weather stations and observed increasing trend in 70.0% of the continental regions, including South America (Alexander et al., 2006).

According to Marengo and Camargo (2008), extreme temperature events in Brazil, especially in the South region, can be influenced by the increasing frequency of occurrence of El Niño event. However, Marengo and Camargo (2008) also observed increasing trend in the rates of extreme maximum temperature and decreasing trend in the rates of extreme minimum temperatures in the period of 1960 to 1980.

Sansigolo and Kayano (2010), observed an increase of 0.5°C per decade in the minimum temperature in southern Brazil in the period from 1913 to 2006. Positive trends for the minimum temperature in the state of São Paulo were also observed by Blain (2011) and Blain and Lulu (2011), respectively in the period of 1951 to 2010 and 1890 to 2010.

In order to verify the presence of possible changes in local weather patterns, many authors have used the statistical nonparametric test of Mann-Kendall (Back, 2001; Yue, Pilon, Phinney, & Cavadias, 2002; Blain, 2011). According to Yue et al. (2002), this test has been widely used in many parts of the world for the detection of meteorological and hydrological trends. Khaliq, Ouarda, Gachon, Sushama, and ST-Hilaire (2009) stated that nonparametric methods are used in most statistical detection studies of climate change and accordingly, Chandler and Scott (2011) point out that this test has been widely used in environmental studies.

Considering the above, the aim of this study was to evaluate the presence of trends in annual time series of precipitation and minimum and maximum temperatures, observed in all the Brazilian political regions by means of nonparametric statistical tests.

Material and methods

Study area and data

Brazil has an area of approximately 8,515,767.0 km2 and is located between longitudes -75° and -35° and + latitudes 5° and -30°. It has 5,569 municipalities besides the Federal District, in which are spread in five political regions: North, Northeast, Midwest, Southeast and South (Instituto Brasileiro de Geografia e Estatística [IBGE], 2010). The largest region in extension is the North, with 3,869,637.9 km2, which is equivalent to 45.2% of the Brazilian territory, and the lowest is the South Region, with 575,316.0 km2, corresponding to 6.8% of the national territory.

The present study used annual data of minimum air temperature ('T-Min'), maximum air temperature ('T-Max') and precipitation ('Perc') to the weather stations of National Institute of Meteorology (In met). The period of study of each series depended on the availability of the data in each weather station.

Maps were developed for the spatial visualization of the observed trends.

Gaps and errors were observed in some series. In some cases, months and even years did not have measurements, which resulted in a cut in the period of the series. Thus, the analysed period is variable according to weather station, but all of them had the end established to the year of 2017.

It is noteworthy that other problems were detected in measurements, such as the spatial discontinuity with difficulties in maintaining equipment in dangerous or inhospitable areas, changes of equipment location and the lack of funds for installation or maintenance. These factors explain the presence of large regions with lack of measuring stations.

Until the present date, at the electronic address of Instituto Nacional de Meteorologia (INMET, 2018), data are available from 266 conventional weather stations distributed across the country between 1961 and 2017 (Instituto Nacional de Meteorologia [Inmet], 2018). We studied the total of 243 localities (25 are state capitals), representing 91.35% of the total Inmet weather stations: 40 (15.04%) are located in the North

region, 90 (33.83%) in the Northeast, 23 (8.85%) in the Midwest, 60 (22.55%) in the Southeast and 30 (11.28%) in the South. These differences are justified due to the size, the quantity of urban occupations and the inherent geographical features of each political region (Inmet, 2018). It is noteworthy that the capital Campo Grande, in the state of Mato Grosso do Sul, and Porto Velho, in the state of Rondônia, do not have Inmet weather stations.

The assessment of changes in the climate system is a planning tool for society as it enables the consideration of possible consequences from the increasing air temperature and changes in precipitation that have been observed around the world.

The five Brazilian political regions and the positions of all-weather stations of INMET are shown in Figure 1. The circles indicate the state capitals and the diamonds represent the interior and coastal localities. The locations that we studied are indicated on the map in blue, while the weather stations that we did not study are shown in red.

The observed data was organized and processed in Microsoft Office Excel software. The climate trends were evaluated by means of non-parametric statistical Mann-Kendall (M-K) and Pettitt (PETT) tests.
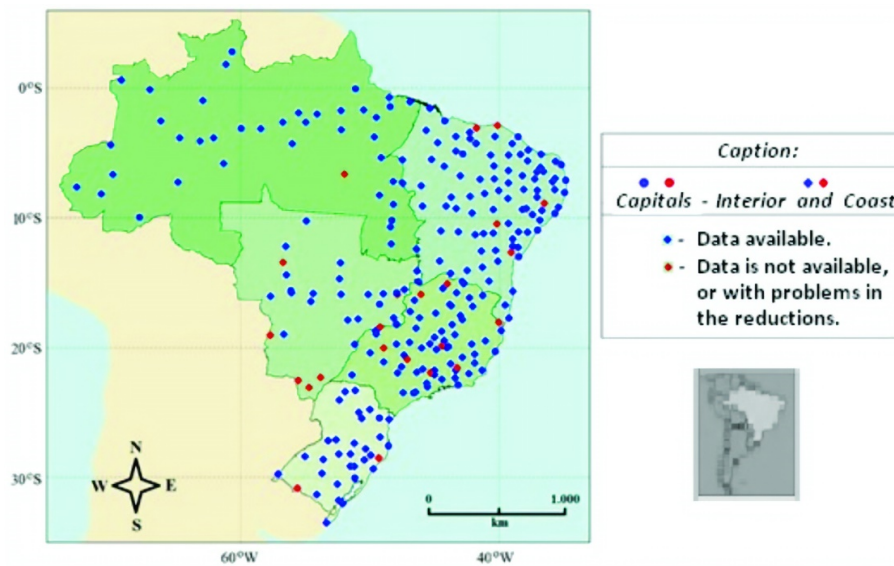

FIGURE 1.
Instituto Nacional de Meteorologia (Inmet) weather stations in Brazil.

The Mann-Kendall test (M-K)

The M-K was performed, to evaluate the significance of a trend (Mann, 1945; Kendall & Stuart, 1967; Sneyers, 1975). The test, considers that, in the presence of stability of the series, the sequence of values occurs independently, and the probability of distribution must remain the same (single random series). As described by considering a time series Y_i, with N terms, being $1 \leq i \leq N$, the test starts by making the sum t_n of the number of terms m_i of the series, relative to Y_i value, whose the above terms ($j < i$) are lower than the same ($Y_j < Y_i$), as indicates the Equation 1:

$$t_n = \sum_{i=1}^{N} m_i$$

(1)

For series with a large number of terms (N > 8), under the null hypothesis (H0) of absence of trend, tn will present a normal distribution with average and variance given, respectively, by Equation 2 and 3 (Back, 2001):

$$E(t_n) = \frac{N(N-1)}{4}$$

(2)

$$\text{Var}(t_n) = \frac{N(N-1)(2N+5)}{72}$$

(3)

Testing the statistical significance of tn for the null hypothesis, using a two-tailed test, it can be rejected for large values of statistics U(tn) provided by Equation 4 (Back, 2001):

$$U(t_n) = \frac{(t_n - E(t_n))}{\sqrt{\text{Var}(t_n)}}$$

(4)

The probability value a1 is calculated by a standardized normal distribution Table, so that a1 = prob(|U| > |U(tn)|). As a0 the level significance test, the null hypothesis is accepted it. If the null hypothesis is rejected, it implies the existence of a significant trend, with the statistical signal U(tn) indicating w||hether the trend is downward (U(tn) < 0) or growing (U(tn) > 0).

The starting point of a change in series can be estimated by applying the same principle in reverse series. In that way, in the reverse sense of the original time series, the starting value i = N to i = 1 the inverse statistic is generated. The intersection of the two curves and statistics U(tn) and U(tn) correspond to the approximate point of change in trend. However, according to Back (2001), it is only meaningful if this point occurs within the bilateral significance range, between −1,65 and +1,96, corresponding to (10%) and (5%), respectively.

The Pettitt test (PETT)

The PETT checks if two samples Y1, Y2, ..., Yt and Yt+1, Y t+2, ..., YT come from identical populations (Pettitt, 1979). The statistic ut,T makes a count of the number of times a member of the first sample is greater than a member of the second sample, which, according to can be written by the Equation 5:

$$u_{t,T} = u_{t-1,T} + \sum_{j=1}^{T} \text{sgn}(Y_i - Y_j) \; t = 2,...., T$$

(5)

where:
sgn(x) = 1 for x > 0; sgn(x) = 0 to x = 0 and sgn(x) = -1 for x < 0.

From this prerogative, the statistic ut,T is calculated for values of $1 \le t \le T$. As a result, it was obtained the statistic K(t) calculating the absolute maximum value of ut,T It is the statistic K(t) that allows to locate the point when a sudden change in the average time series happened. For that, according to Back (2001), the level of significance is estimated by means of Equation 6:

$$p \simeq 2 \cdot e^{\left(\frac{-6 \cdot K(t)^2}{(T^3 - T^2)}\right)}$$

(6)

The abrupt change point is that in which the t value occurs for the maximum (or minimum) value of K(t), obtained by inverting the above equation, resulting in Equation 7:

$$K_{crit.} = \pm \sqrt{\frac{-\ln(p2) \cdot (T^3 + T^2)}{6}}$$

(7)

In this test, the change of significance levels was calculated to 5 and 10% of the value of Kcrit (Back, 2001).

Results and discussion

Due to the large amount of numerical information obtained, we decided to present some of the results in graphs, in order to present different characteristics and peculiarities, in addition to perform statistical interpretation.

The graphics of M-K test were represented by black lines and the PETT test, in red (Figure 2). The dashed and dotted horizontal lines refer to confidence interval ± 5 to ± 10%, and statistical curve U(tn) shown in solid line and U(tn) in dashed line. Similarly, in the PETT test, the confidence levels of ± 5 to ± 10% are highlighted in dashed and dotted horizontal lines, respectively, the statistical curve K(t) is shown in solid line.

Figure 2 shows the graphics of the nonparametric analysis for 'T-Max' of Curitiba (state of Paraná, 1961 to 2017; Figure 2a), 'T-Min' for São Gabriel da Cachoeira (state of Amazonas, 1961 to 2017; Figure 2b) and 'Perk' for Recife (state of Pernambuco, 1961 to 2017; Figure 2c).

For the analysis of 'T-Max' in Curitiba (Figure 2a), due to the intersection of M-K curves U(tn) and U(tn) with the confidence intervals lines (Sneyers, 1975; Back, 2001), we observed an increasing trend for 'T-Max' starting in 1999. Additionally, the abrupt change point of PETT curve K(t) crossed the critical limits of 5 and 10% in the same year of 1999, confirming the positive trend (Back, 2001).

In the Figure 2b, for 'T-Min' for São Gabriel da Cachoeira, both M-K and PETT tests confirmed negative trend in 'T-Min' starting in 1995. The intersection of M-K curves U(tn) and U(tn) with the confidence intervals happened in 1997, while PETT curve K(t), shown in the top graphic of the same figure, crossed the two confidence levels with the maximum inferred in 1995. However, according to Penereiro, Martins, and Beretta (2016), the PETT test is a statistical method focused on detecting abrupt changes in historical series. Thus, even though these observed years are delayed in two years of each other, we decided to confirm that there is a negative trend in this series starting in 1995, considering the date inferred by PETT test.

The statistical graphic for 'Perk' in the locality of Recife is showed in the Figure 2c. No trend was identified. This is because when applying statistical tests, multiple crossings of the M-K curves U(tn) and U(tn) occurred with the confidence intervals of ± 5 and ± 10%. In addition, the curve from the PETT test shown on top did not intersect the levels of confidence of 5 and 10%. As result, there is no trend in 'Prec' in Recife during the analysed period.

Table 1 summarizes the results of M-K and PETT tests for the studied locations in each political region of Brazil. To establish a criterion to express the results of the M-K and PETT tests, the following convention were used: signs (+) and (-) to positive and negative trends, respectively, when it is equal to or above 10% of range bilateral trust. A sign (?) was adopted if it was not possible to confirm trend in the evaluated grade.
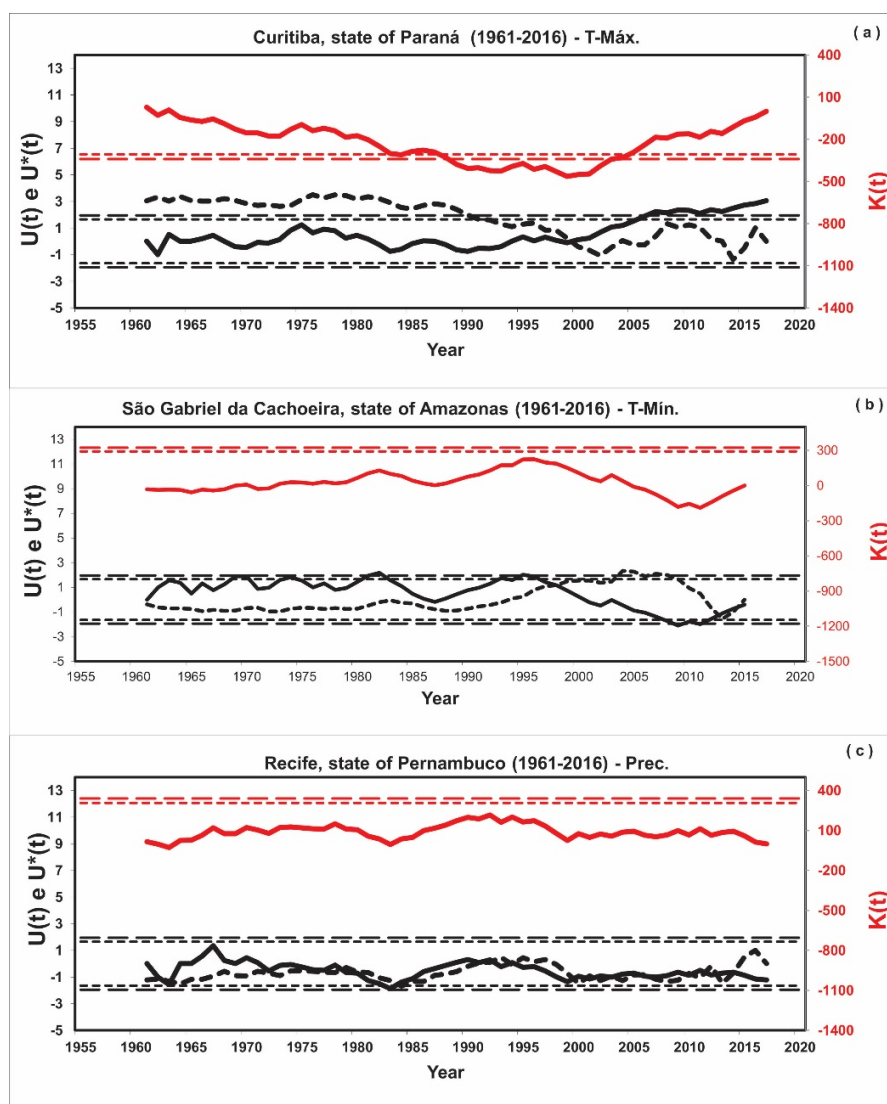
FIGURE 2.
Statistics of PETT (top, red) and M-K tests (bottom, black) for (a) 'T-Max' of Curitiba, state of Paraná, (b) 'T-Min' of São Gabriel da Cachoeira, state of Amazonas and (c) 'Perk' of Recife, state of Pernambuco.

Política Region	'T-Min'			'T-Max'			'Perk'		
	(–)	(+)	(?)	(–)	(+)	(?)	(–)	(+)	(?)
North	1	20	19	0	20	20	6	4	30
Norteaste	12	20	58	1	20	69	1	0	89
Midwest	2	6	15	0	7	16	1	3	19
Southeast	2	20	38	1	24	35	1	1	58
South	2	5	23	0	14	16	0	6	24
Total	19	71	153	2	85	156	9	14	220

TABLE 1.
Number of studied localities, in each political region of Brazil, classified by climate trend identified by statistical tests of M-K and PETT.

It is important to emphasize the number of localities in which positive trend in 'T-Min' and 'T-Max' were observed, with exception of the Central West Region. Nevertheless, there is a large number of series that did not accuse trend, especially in the 'Perk'.

The results of the analysis of 'T-Min', 'T-Max' and 'Perk' from all 243 weather stations are presented in maps of spatial distribution of trends for each variable. In each map it is possible to identify locations where there were observed positive and negative trends in the significance level of 10%.

Trend maps

Figure 3 shows the map of the spatial distribution of the observed trends for 'T-Min': 71 localities have positive trends detected by M-K and PETT tests, corresponding to 29.22% of all the analysed locations. The North, Northeast and Southeast were the ones that showed the highest number of observed trends (20 each), followed by the Midwest (6) and South (5). Negative trends were detected in 19 localities, corresponding to 7.82%. The Northeast was the one with the highest number of cases (12), followed by the Midwest, Southeast and South (2 each), and the Northern Region which recorded only one location. Non-significative trends in 'T-Min' have been observed in 153 localities, equivalent to 62.96%.

Most of the significative trends, whether positive or negative, are located within the country, except for some localities located near or by the coast of the Northeast and South regions. Non-significative of trends in 'T-Min' have been identified in a spread-out way in Brazil, particularly in coastal regions (Figure 3).

The spatial distribution of climate trends in 'T-Max' is shown in Figure 4. In 85 localities (34.98%) we observed positive trend. The South region was the one with the highest number of observed trends (24), followed by North and Northeast (20 cases each), then the Southeast (14) and the Midwest (7). Negative trend was observed in 'T-Max' in 0.82% of all the studied localities. They are in located the Northeast region, in the south of the state of Bahia, and Southeast region, in the state of Minas Gerais.

In the same figure, we observed that 156 localities (64.20%) did not show evidence of trends for 'T-Max', in which 69 are located in the Northeast region, in the northern portion of the Southeast region (35) and in the Southern region (16) of the country. The positive trends were observed in the Southeast and North Brazil, as well as in the western Northeast.

The 'Perk', showed in Figure 5, was the climate variable that we most observed no trend: 220 localities, representing 90.53% of all the localities we studied (Figure 5). In the Northeast region we observed 89 localities with no significative trends, Southeast, 58, North, 30, South, 24 and Midwest, 19 localities.

Positive trend for 'Perk' were observed in 14 localities (5.76%), with the largest number of records in the South region (6), followed by the North (4), Midwest (3) and Southeast (1) (Figure 5). In the Northeast Region we did not observe increasing trend for Prec. However, negative trends were observed in 9 localities (3.70%), in which 6 are in located the North, 1 in the Northeast, 1 in the Midwest and 1 in the Southeast. The map also shows that no locality in the Southern region presented decreasing trend in 'Perk' (Figure 5).

The results in 'Perk' trends discussed here do not agree with those found by Alexander et al. (2006). As can be seen in Figure 5, there were few localities with trends (18), whether positive or negative, and they are spread across of all political regions of Brazil.
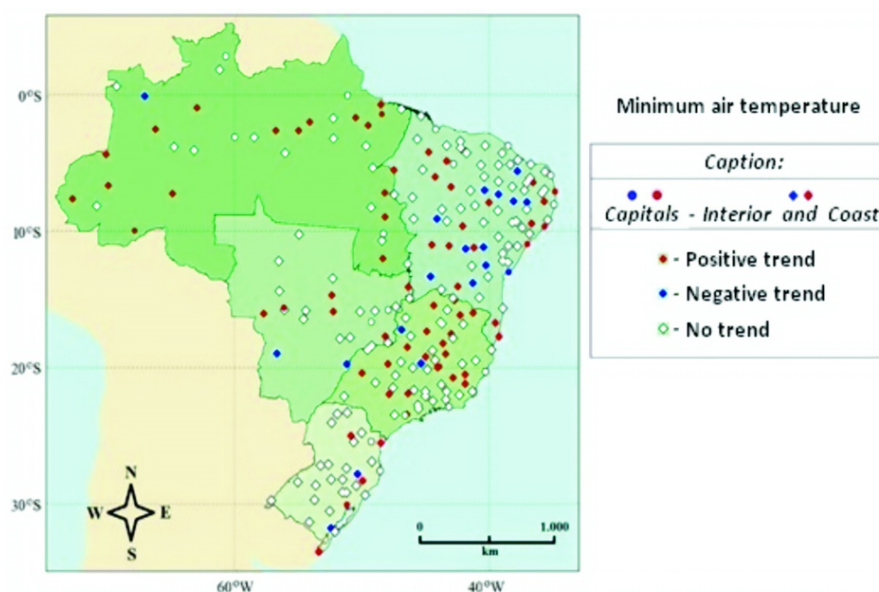
FIGURE 3.
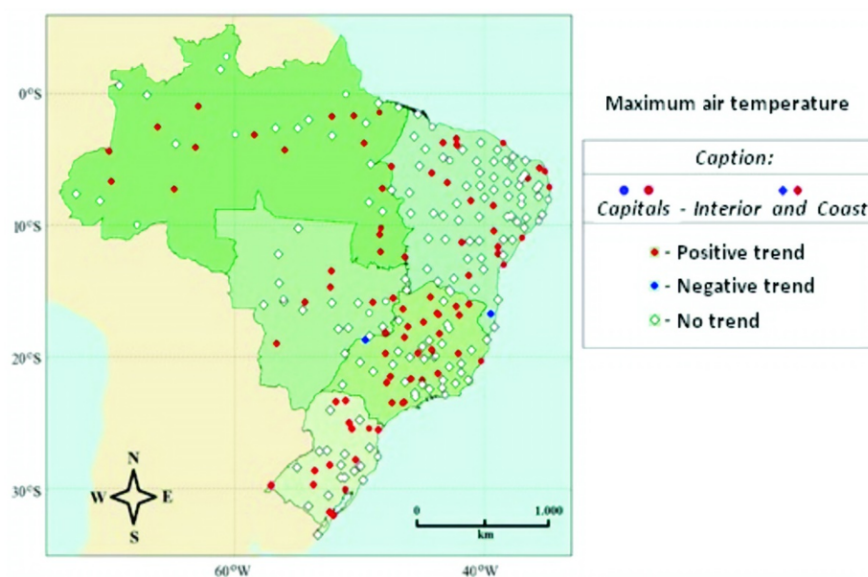Map of climate trends for 'T-Min' detected in Brazilian cities.

FIGURE 4.
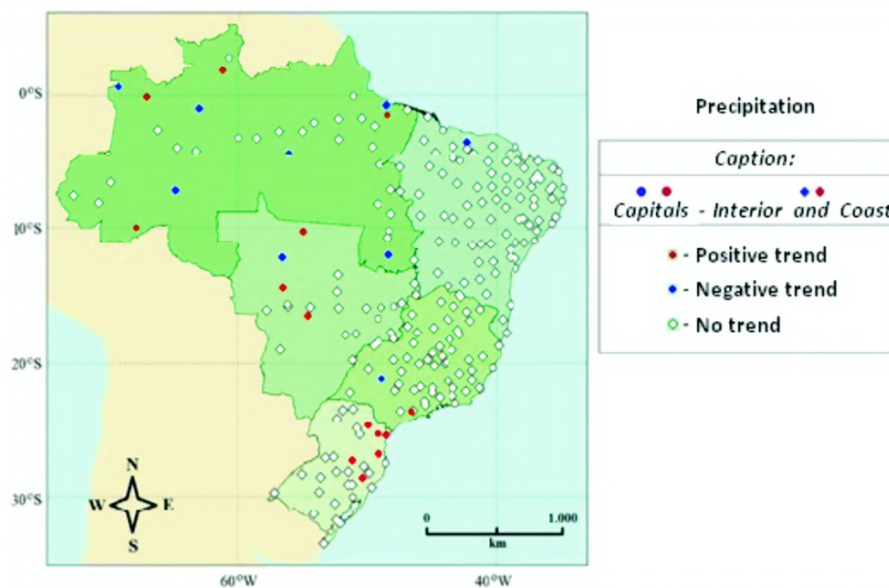Map of climate trends for 'T-Max' detected in Brazilian localities.

FIGURE 5.
Map of climate trends for 'Perk' detected in Brazilian localities.

The histogram presented in Figure 6 has the purpose to show the temporary frequency trends in annual series inferred for the three climate variables studied here.

By looking at the Figure 6, we observed that the largest quantities of trends were observed in air temperatures at the end of the last century, especially temperature increases. For 'T-Min' were observed 39 positive trends (+), in which 8 cases occurred in 1997, and 6 negative trends (-) between the years 1991 and 2000. We observed 23 positive trends (+) and 13 negative trends (-) between the years 2001 and 2010. For 'T-Max' we observed 46 positive trends (+), especially for the year 2000 with 11 records, and 2 negative trends (-) between the years 1991 and 2000. We also observed 33 positive trends (+) between 2001 and 2010, with no cases of negative trends in this period.
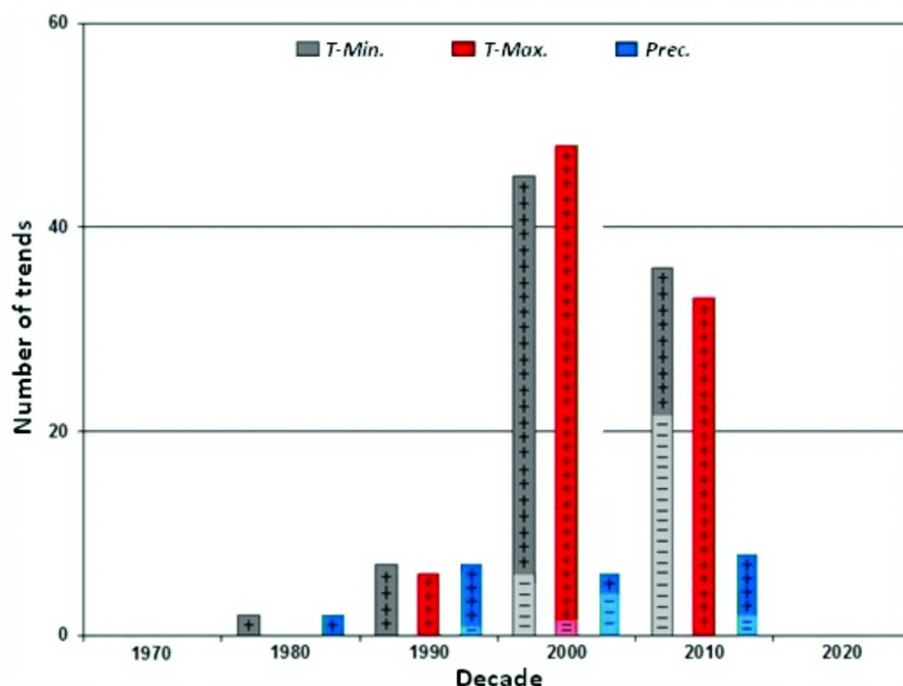
FIGURE 6.
Histogram with trends counts related to the occurrence
decades in the three climatic quantities covered by the survey.

Finally, for 'Perk', the greatest evidence of trends was observed between 2001 and 2010, with 6 positive trends (+) and 2 negative trends (-). Between 1991 and 2000, there were observed 2 positive trends (+) and 4 negative trends (-), and between 1981 and 1990, 6 positive trends (+) and 1 negative trend (-).

Our analysis shows that the climate of Brazil is very complex, as in other parts of the world. One possible explanation for the trends we observed here appear to be related to the geographical characteristics of each region. In addition, we remark that the change in the lifestyle, from rural to urban area, provided an economic and social development and allowed the technological advances experienced. However, this range of elements boosted environmental crises, especially in the nearby urban centre's regions (Fialho & Souza, 2007).

CONCLUSION

It is worth remembering that in this type of scientific work a relevant challenge, when working with long-term climate series in Brazil, is even greater when the scientist needs to describe how spatial variability occurred during a certain time. This is mainly due to the lack of reliable weather data.

It is possible to conclude, in general terms, that no trend of rainfall was recorded. In contrast, there were identified increasing trends in minimum and maximum temperature mainly in the North, East and South regions, especially in localities that had an increase, in the last two decades, of urban area, deforestation and agricultural and industrial development.

Considering the limits imposed by the de lack of available data to study, the occurrence of increase is the most significant and within temperature trends.

The explanations whether the observed climate trends in Brazilian localities are related to anthropological changes or caused by natural climate variability is still a challenge for science.

Therefore, according to the results presented here, the anthropological changes also appear to have influenced the climate of the five political regions of Brazil, as may be constituted in the most populous localities frequently reported by the general media.

Finally, according to the results presented in this paper draw attention to the care that must be taken, once it points out that the causes of natural disasters that are currently occurring in several Brazilian localities are due to climate change. In this context, it is noticeable the increase in storms and floods, prolonged droughts, increased magnitude and frequency occurrence of extreme events, among others. Therefore, these events can bring not only damage to the environment where it is located (a specific city) but can also bring damage to economies and people's health. This may occur due to the complexity to dissociate these changes from simply natural climate variations. However, despite the uncertainties associated to climate changes and, consequently, the impact of these possible changes in time series as shown and discussed above, such studies are relevant and necessary to assist municipal managers in the current environment scenario of intense questioning and discussion of environmental issues.

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