ISSN:1984-2295

Revista Brasileira de Geografia Física

Homepage: https://periodicos.ufpe.br/revistas/rbgfe

Variability and trend of air temperature and rainfall at Ribeirão do Lobo Hydrographic Basin, Brazil [1]

Gabriela Leite Neves[1*], Gustavo Castilho Beruski[2], Jorim Sousa das Virgens Filho[3], Frederico Fabio Mauad[4]

[1*] Ph.D. Candidate, Graduate Program in Environmental Engineering Sciences, Center for Water Resources and Environmental Studies-CRHEA, São Carlos Engineering School (EESC), University of São Paulo (USP), CEP 13566-590, São Carlos, SP, Brazil. (16) 3373-8253. gabriela.leiteneves@usp.br (corresponding author). [2] Professor, Department of Agronomy, Santa Bárbara College of Higher Education - FAESB, CEP 18277-000, Tatuí, SP, Brazil. (15) 3259-3838. beruskigc@usp.br. [3] Associate Professor, Department of Mathematics and Statistics, State University of Ponta Grossa - UEPG, CEP 84030-900, Ponta Grossa, PR, Brazil. (42) 3220-3000. jvirgens@gmail.com. [4] Associate Professor, Graduate Program in Environmental Engineering Sciences, Center for Water Resources and Environmental Studies-CRHEA, São Carlos Engineering School (EESC), University of São Paulo (USP), CEP 13566-590, São Carlos, SP, Brazil. (16) 3373-8253. mauadffm@sc.usp.br.

Artigo recebido em 30/07/2019 e aceito em 16/12/2019

A B S T R A C T

Climate changes have been observed all over the world and are pointed out as responsible to impact the natural resources, especially the amount and the quality of the water in a hydrographic basin. Thus, the present research aimed to analyze the variability and trends of air temperature and rainfall data in the Hydrographic Basin of the Ribeirão do Lobo, São Paulo state, Brazil. The weather data from 1988 to 2017 were collected in the Center of Water Resources and Environment Studies of the University of São Paulo (CRHEA), and in five rainfall stations of the National Water Agency of Brazil (ANA) spread all over the basin. To identify climate changes were applied the simple regression, the run test, the Mann-Kendall and modified Mann-Kendall tests. The results showed significant positive trends in air temperature, especially in the annual period and during the third quarter with rising up to 0.068 °C $year^{-1}$. Significant increases were verified to minimum, maximum and mean air temperature, which suggests possible climate changes during the period in the analysis. To the rainfall data, periods with positive and negative trends were found, although, most of the time the trends were non-significant. However, a significant negative trend of the rainfall was observed in Ribeirão do Feijão station with a reduction of -10.03 mm $year^{-1}$.

Key words: climate changes, simple regression, Mann-Kendall, trend.

Variabilidade e tendência da temperatura do ar e precipitação na Bacia Hidrográfica do Ribeirão do Lobo, Brasil

R E S U M O

As mudanças climáticas têm sido observadas em todo o mundo e são apontadas como responsáveis por impactar os recursos naturais, especialmente a quantidade e a qualidade da água em uma bacia hidrográfica. Assim, o presente trabalho teve como objetivo analisar a variabilidade e as tendências da temperatura do ar e da chuva na Bacia Hidrográfica do Ribeirão do Lobo, Estado de São Paulo, Brasil. Os dados meteorológicos de 1988 a 2017 foram coletados no Centro de Recursos Hídricos e Estudos Ambientais da Universidade de São Paulo (CRHEA), e em cinco estações pluviométricas da Agência Nacional de Águas do Brasil (ANA) distribuídas por toda a bacia. Para identificar as mudanças climáticas, foram aplicados os testes de regressão simples, teste de run, Mann-Kendall e Mann-Kendall modificado. Os resultados mostraram tendências positivas significativas na temperatura do ar, especialmente no período anual e durante o terceiro trimestre, com aumento de até 0,068 °C por ano. Aumentos significativos foram verificados para temperatura mínima, máxima e média do ar, o que sugere possíveis mudanças climáticas no período analisado. Para os dados de chuva, foram encontrados períodos com tendências positivas e negativas, contudo, na maioria das vezes, as tendências não foram significativas. No entanto, uma tendência negativa significativa da precipitação foi observada na estação de Ribeirão do Feijão com redução de -10,03 mm ao ano.

Palavras-chave: mudanças climáticas, regressão simples, Mann-Kendall, tendência.

Introduction

Climate changes are defined as modification over the climate conditions through 30 years and, can be represented by air temperature rises, changes in rainfall patterns and by the increase of the frequency and intensity of extreme meteorological events. Due to the impact that climate change has on the environment, this theme has been the research focus worldwide. According to the International Panel of Climate Change (IPCC, 2013), these modifications are considered as non-natural, therefore are associated with the global warming, that can be the result of the human activities, which emit greenhouse gases, as carbon dioxide and methane into the atmosphere. However, climate changes also can be resulted by natural causes and, other human activities, for example, changes in land use.

The impact of the climate changes over natural resources are diverse and, promote drawbacks in the agriculture (Verhage et al., 2017) human health and food security (Myers et al., 2017) and, at the economic and social development of a region. Thus, the evaluation of these impacts must encompass different areas (agriculture, hydric resources, infrastructure and, industrial production) and spatial scale (local, regional and global) (Huber et al., 2014).

The local climate changes are distinct from the global scale, once human-specific activities are the main sources of regional climate modification (Wheeler and von Braun, 2013). Therefore, the regional analysis of climate change is crucial to understand their impacts over the environment, furthermore, this knowledge may be used in the development of climate models making their more reliable to predict a modification, since the local data have better quality for a region representation (Challinor et al., 2014; James et al., 2017).

Differences have been observed in climate changes comparing local and global scale, especially in Brazil, due to a large geographic dimension. Recent research showed raises in the month mean air temperature in the Southeast Brazilian region for a period between 1981 and 2010, wherein for the São Paulo State the mean air temperature was of 3.5 °C above the average for January (Marengo et al., 2016).

In spite of the consensus that climate change promotes raises in air temperature, their effects over the rainfall regime still are variable (Knapp et al., 2015). According to Zilli et al. (2017), there is no clear trend of increase or reduction in rainfall for the Amazonia, Southeast and Central-East regions. Rao et al. (2016) analyzing the rainfall trends and their variability for different Brazilian regions between 1979 and 2011, verified a rainfall reduction in the southeast region and, this negative trend caused detriment over the water availability, which impacted in the energy hydroelectric production and the agricultural production. Reduction in the rainfall trends for the Southeast region also was observed by Marengo et al. (2016), where were observed values of 10 to 20 mm per year lowest than the average for 1981 to 2010 period.

To confirm the presence of significant trends of the climate characteristics through a period in a specific site it is necessary to adopt statistical analysis. For this purpose, the use of linear regression, Mann-Kendall (Mann, 1945; Kendall, 1975) or both tests simultaneous has been used to identify a significant trend in climate data. In Brazil, these tests have been applied to identify significant changes in temperature (Ávila et al., 2014; Ferreira et al., 2015; Neves et al., 2016) and in rainfall (Ely and Dubreuil, 2017; Zilli et al., 2017). In the same way, worldwide studies were conducted to confirm changes in the weather variables mentioned previously (Chen and Zhai, 2017; Shi et al., 2018; Qian et al., 2019).

Although the Mann-Kendall test is an important statistical tool to identify trends in the climate data series, its use is possible when the data are random and the series must be independent. Therefore, previously to the Mann-Kendall test, it is mandatory to evaluate the serial correlation, whereas the serial correlation may alter the probability of rejecting the null hypothesis of non-tendency in the Mann-Kendall test, leading to the incorrect conclusions. Thus, to evaluate the presence of the serial correlation the run test has been used. In the case of a significant correlation, the modified Mann-Kendall test can be applied (Sridhar and Raviraj, 2017; Sa'adi et al., 2019).

The Ribeirão do Lobo Hydrographic Basin is located at the Central-East of the São Paulo state and it's important due to being the main component of the Lobo dam, which is used to generate electric energy, moreover, it's used to recreation tourism and fishing of the population around. Based on that, the research aimed to analyze the variability and trends of the air temperature and rainfall in this Hydrographic Basin, to identify regional climate changes in the historic period and to promote the environmental management of the region.

Material and Methods

Study area

The Hydrographic Basin of the Ribeirão do Lobo is distributed among the localities of Brotas, Itirapina and São Carlos, all in the São Paulo State, Brazil. This hydrological network is constituted by a damming of the Ribeirão do Lobo and the Itaqueri River (Água Branca and Limoeiro tributaries) and by the Geraldo and Perdizes Streams (Figure 1). The climate of the area, based on Köppen classification, is Cwa which is characterized by a humid subtropical, with dry winter and hot summer. The mean annual cumulative rainfall values range from 1300 to 1500 mm, with higher frequency and volume occurring during the summer season (Alvares et al., 2013).

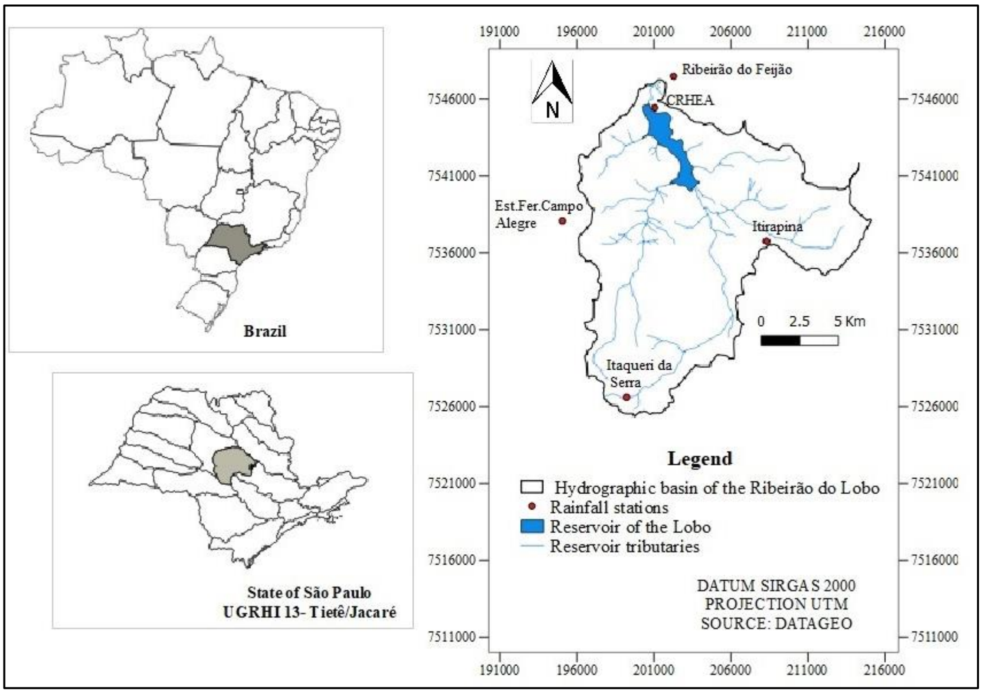

Figure 1. Hydrographic Basin of the Ribeirão do Lobo in the São Paulo State, Brazil. And the location of the climatological and rainfall stations used to obtain the meteorological data.

Temporal series analysis

The weather daily data was collected between 1988 and 2017 by climatological and rainfall stations spread of the Hydrographic Basin of the Ribeirão do Lobo (Figure 1). The daily air temperature data were obtained from a climatological station of the Center of Water Resources and Environment Studies of the University of São Paulo (CRHEA). The minimum (Tmin) and maximum (Tmax) air temperature were measured by a thermometer installed in standard conditions (1.5 m height and over a grass surface as the reference culture). The mean air temperature (Tmean) data was calculated following the extreme values method, considering the Tmin and Tmax data.

The daily rainfall data were collected in five rainfall stations (Est. Ferrov. Campo Alegre, Itaqueri da Serra, Itirapina and Ribeirão do Feijão). The data series were obtained HidroWeb Information System, which belongs to the National Water Agency of Brazil (the Portuguese acronym is ANA) and from a climatological station of the CRHEA (Figure 1). For both data sources, the rainfall was measured by conventional rain gauges, which were tested and calibrated based on specifications of the World Meteorological Organization (WMO).

The daily data of the corresponded period was organized monthly. The consistency of the data was verified and, when periods of missing data were found the filling was made using the PGECLIMA_R software (Virgens Filho et al., 2013). After that, the analyses were realized for each quarter of the year starting in January.

The data trend was determined following a simple regression approach, which can be represented by an equation:

$$y = a + bx \quad (1)$$

Where:

x = independent variable (time)

y = dependent variable, which was represented by an air temperature or the rainfall data

a = intercept standard for the period $t = 0$

b = coefficient that indicates the direction of the relationship between a predictor variable and the response variable.

Thus, the trend magnitude was obtained using the standard coefficient fitted to the data, which represent the changes in the climate variable per year.

To confirm the significance of the trend, the Student's t-test was applied (p-value ≤ 0.05) and the hypothesis tested was:

H_0 = there is no trend;

H_1 = there is trend considering the significance threshold (p-value ≤ 0.05).

The run test (p-value ≤ 0.05) was used to test the hypothesis that the elements of the sequence are mutually independent. The method is based on rejecting or not the null hypothesis (H_0), which considered that a data set is from a random process.

In the random data series, the Mann-Kendall test was used aiming to identify trends in climate data. The Mann-Kendall is a non-parametric test considered more robust than the simple regression to detect trends in series rainfall (Ely and Dubreuil, 2017).   .

Considering the sequence of values observed both for maximum and minimum temperature along the time (1980-2009), the hypotheses testes were:

H_0 = data comprise a random variable sample of *n* independent and identically distributed items", that is, there is no trend in this data set.

H_1: There is an increasing trend (positive) or decreasing (negative). For the data with no randomness, the modified Mann-Kendall was applied (Hamed and Rao, 1998).

The hypotheses tested were:

H_0 = there is no trend

H_1 = there is a positive or negative trend (p-value ≤ 0.05).

To indicate the trend direction Kendall's tau statistics was applied (Neves et al., 2016). A positive tau value means an increasing trend while a negative value represents a decreasing trend.

All tests were applied to annual and quarter data series using the R software (v.3.5.3). To the Mann-Kendall and modified Mann-Kendall test, the package "Kendall" (Hipel and McLeod, 1994) and "modifiedmk" (Hamed and Rao, 1998) were used.

Results and Discussion

Annual data variability

Analyzing the air temperature data from the CRHEA climatological station for the whole period, it was verified that the average minimum air temperature (Tmin) was of 14.0 °C, which presented a minimum value of 12.0 °C and maximum of 16.5 °C observed in 1999 and 2015, respectively. Concerning the maximum air temperature (Tmax), the values ranged from 26.6 °C to 29.3 °C resulting in an annual average of 26.6 °C. The values of mean air temperature (Tmean) varied between 19.7 ºC and 22.6 ºC at 1999 and 2015, respectively, resulting in an annual Tmean of 21.0 °C (Figure 2).

In the last 10 years was possible to identify an increase in Tmin, Tmean and Tmax, where the average increased by 0.7, 0.4 and 0.6 °C, respectively, compared to the historical air temperature average. During the year of 2011 was measured an average temperature of 15.5 ºC to Tmin, 28.5 ºC to Tmax and 22.0 ºC to Tmean. Among the variables in the analysis, the highest rise was observed in the Tmin, with values of 1.5 °C above the historical average (Figure 2b). Fante and Sant'Anna Neto (2017) analyzing changes in the air temperature patterns into the São Paulo state, found that raises in the minimum air temperature was more prominent compared with maximum air temperature.

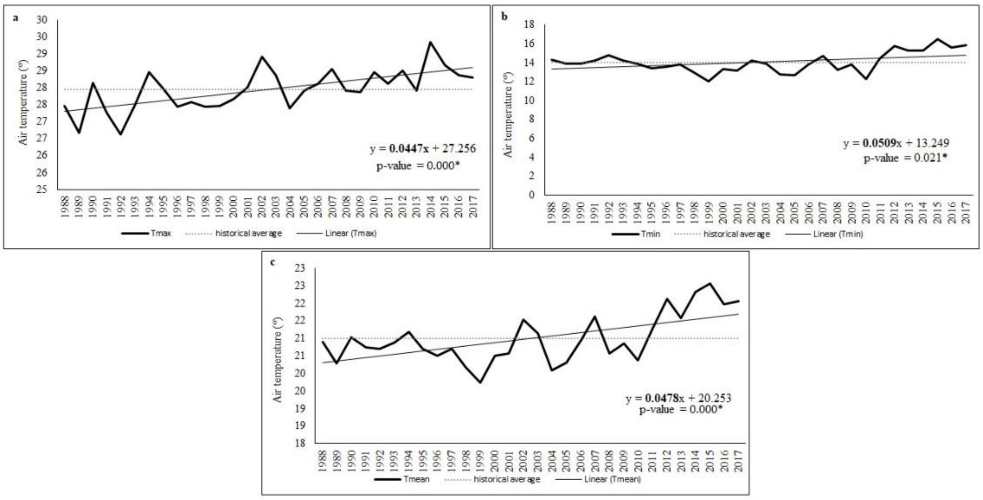

Figure 2. Variability, historical air temperature average, trend and their respective p-values (Student's t-test) of the maximum (Tmax) (a), minimum (Tmin) (b), and mean (Tmean) (c) air temperature collected in the CRHEA climatological station, between 1988 and 2017. São Paulo State, Brazil.
*significant – (p-value ≤ 0.05).

A considerable increase in the air temperature also was observed during 2014 and 2015. In this period, the values of Tmin, Tmean, and Tmax were of 2.4, 1.6 and 1.4 °C, respectively, above the historical air temperature average. According to Marengo et al. (2015), the high temperature observed into the referee period can be related to a rise in evaporative demand generating a severe drought in this region. Furthermore, a source of heat located in the north and northeast of Australia caused a displacement of the South Atlantic Subtropical Anticyclone (SASA) that implies in positives anomalies in the atmospheric pressure in southeast Brazilian region promoting an increase in the sea surface temperature which causes a reduction in the rainfall frequency and volume (Reboita et al., 2015; Coelho et al., 2016).

The rainfall occurrence showed a similar pattern throughout the years and among the sites, which represent a spatial homogeneity of this variable into the Hydrographic Basin of the Ribeirão do Lobo (Figure 3). Considering the 30 years, the average annual rainfall values ranged from 1473.9 mm year^{-1} to 1611.6 mm year^{-1} for CRHEA (Figure 3-1) and Itaqueri (Figure 3-3), respectively. Spite of the homogeneity in the average rainfall values, periods of variability in the rainfall of each year can be observed.

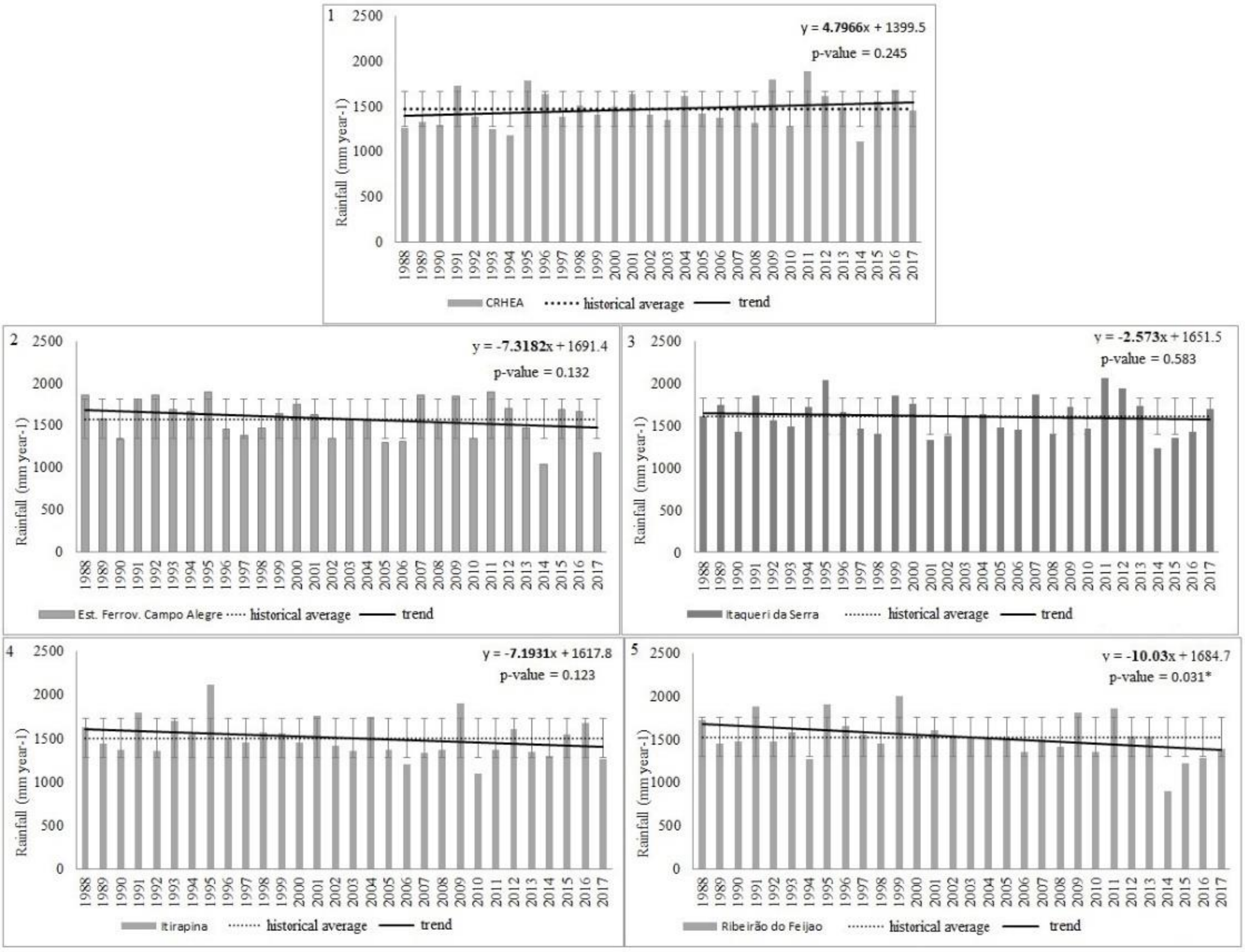

Figure 3. Cumulative rainfall values (bars), historical rainfall average, standard deviation (bar error), trend and their respective p-values (Student's t-test) observed in the CRHEA climatological station (1) and in five rainfall stations: Est. Ferrov. Campo Alegre (2), Itaqueri da Serra (3), Itirapina (4) and Ribeirão do Feijão (5), from 1988 to 2017. São Paulo State, Brazil.
*significant – (p-value ≤ 0.05).

The higher annual rainfall values were recorded in Itirapina (Figure 3-4) and Est. Ferrov. Campo Alegre (Figure 3-2) stations in 1995. The maximum rainfall values were measured in Itirapina with a cumulative value of 2122.6 mm year^{-1}, 616 mm above the historical average, and in Est. Ferrov. Campo Alegre which presented a value of 2042.5 mm year^{-1}, 316 mm above the historical average. Considering the CRHEA and Itaqueri stations a high annual rainfall volume was identified during 2011, which showed raises of 418 mm year^{-1} and 450mm year^{-1}, respectively, compared to the historical average value (Figure 3).

In contrast, the lowest annual rainfall values were observed during 2014 among the stations, except to Itirapina. The minimum annual value was of 906.1 mm year^{-1} measured in Ribeirão do Feijão (Figure 3-5) station, this value was 623 mm year^{-1} below the average. For the remained stations the reductions in the rainfall annual values were of 362, 375, and 540 mm to CRHEA, Itaqueri, and Est. Ferrov. Campo Alegre, respectively. Considering the Itirapina station, the lowest value of annual cumulative rainfall was observed during 2010 with the total amount of 1096 mm year^{-1}, 409 mm below the historical average.

The low rainfall values during 2014 can be related to a long drought period that affected the southeast Brazilian region, especially the São Paulo state throughout the rainy season (December to February). In general, the rainfall regime in the São Paulo state is characterized by high volume during the summer season and lower values in the wintertime. All over the summer, rainfall in this location is caused by the South Atlantic convergence zone (SACZ), by the movement of the cold air mass, and by the strong condition of the thermodynamic atmospheric instability (Marengo et al., 2015). However, during the summer of 2014, a high-pressure (anticyclone) persisted during 45 days upon the southeast Brazilian region, this system create a blocked and did not permit the arrival of humidity flow from the Amazonia region, as a consequence reducing the volume and frequency of rainfall in this region (Marengo et al., 2015).

The figures 4, 5 and 6 show the linear regression analyzes applied to Tmin, Tmax and Tmean data for the CRHEA station for each quarter.

Trend analysis

Air temperature

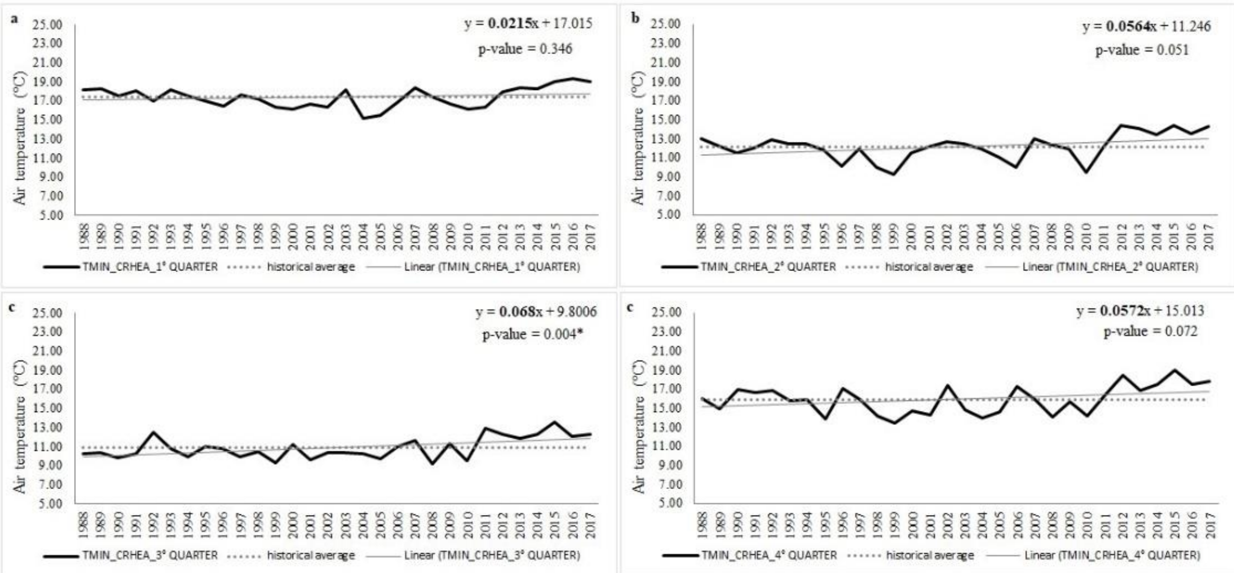

Figure 4. Simple regression approach, values of b coefficient and their respective p-values (Student's t-test) obtained confronting the Tmin data, calculated in CRHEA climatological in different periods: 1° Quarter (a), 2° Quarter (b), 3° Quarter (c) and 4° Quarter (d).
*significant – (p-value ≤ 0.05).

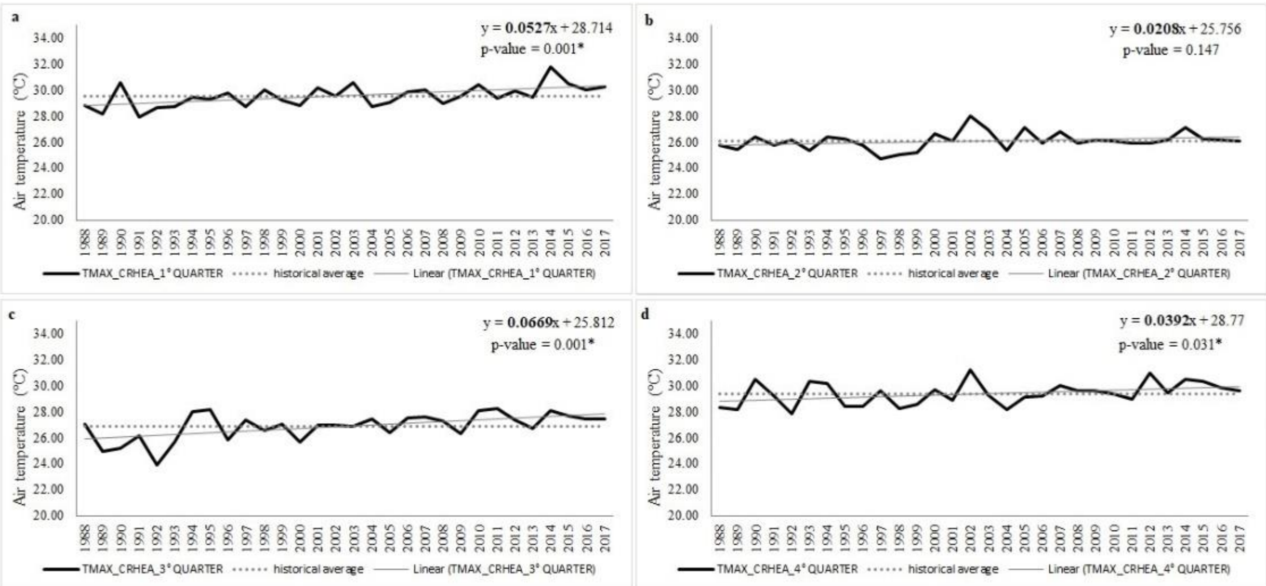

Figure 5. Simple regression approach, values of b coefficient and their respective p-values (Student's t-test) obtained confronting the Tmax data, calculated in CRHEA climatological in different periods: 1° Quarter (a), 2° Quarter (b), 3° Quarter (c) and 4° Quarter (d).
*significant – (p-value ≤ 0.05).

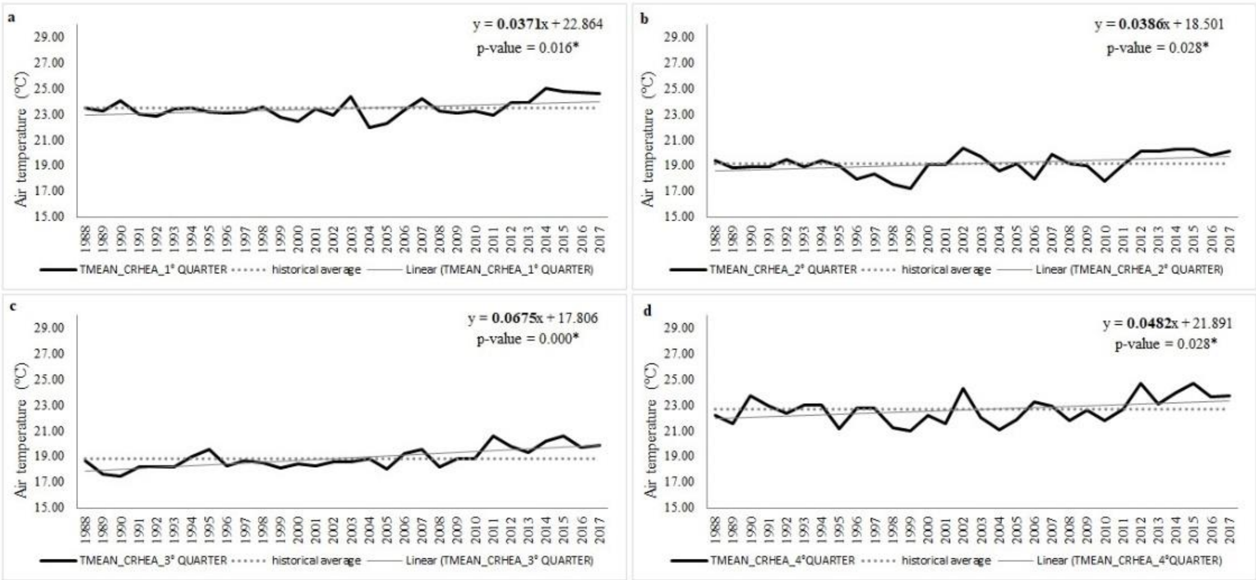

Figure 6: Simple regression approach, values of b coefficient and their respective p-values (Student's t-test) obtained confronting the Tmean data, calculated in CRHEA climatological in different periods: 1° Quarter (a), 2° Quarter (b), 3° Quarter (c) and 4° Quarter (d).
*significant – (p-value ≤ 0.05).

According to the *b* coefficient, it was verified an increase in air temperature in all stations and periods in analysis, which ranged from 0.02 ºC to 0.07 ºC year^{-1}. Through the quarter periods, the higher rise in Tmin, Tmax, and Tmean was observed in the third quarter (p-value ≤ 0.05), which pointed out that increase in air temperature was high during the winter season (Figures 4c, 5c and 6c). For the remained quarters positive changes in the air temperature were founded, however, no significant rise was observed during the second quarter for Tmax (Figure 5b) and all remained quarters for Tmin (Figures 4a, 4b and 4d). In the annual period significant changes were verified for Tmin (*b* = 0.051 °C year^{-1}) (Figure 2b), Tmax (*b* = 0.045 °C year^{-1}) (Figure 2a), and Tmean (*b* = 0.048 °C year^{-1}) (Figure 2c).

A positive change in air temperature represented by the *b* coefficient also was obtained by Penereiro and Ferreira (2017) for the most of the São Paulo state, including the municipally of São Carlos, the location where is located the Hydrographic Basin of the Ribeirão do Lobo. The authors previously mentioned verified a rise of 0.03 °C year^{-1} to Tmin, Tmax, and Tmean, being this modification statistically significant.

Previously to the Mann-Kendall test, the run test was applied to check the randomly of the data (Table 1).

Table 1. Values of p-values calculated by the use of the run test in different quarters for air temperature in CRHEA climatological station.

	Annual	**1st Quarter**	**2nd Quarter**	**3rd Quarter**	**4th Quarter**
	p-value	p-value	p-value	p-value	p-value
Tmin	0.009*	0.063	0.009*	0.137	0.063
Tmax	0.137	1.000	0.265	0.265	0.457
Tmean	0.063	0.710	0.265	0.026*	0.137

*significant – (p-value ≤ 0.05).

Based on the run test output, the randomness was not verified for Tmin in the annual period and second quarter and Tmean in the third quarter. Thus for these periods, the modified Mann-Kendall test was used.

With the trend tests analysis, the positive tau values pointed out a positive trend for Tmin, Tmax and Tmean, which confirm the results, obtained using the simple regression. However, with the use of the Mann-Kendall and the modified Mann-Kendall tests, non-significant trends were found differently of the results from the t-test of the simple regression analysis. In this case, the contrasting results were verified to Tmin during the annual period and to Tmean in the second and fourth quarter periods (Table 2).

Table 2. Values of tau and p-values calculated by the use of the Mann-Kendall and Mann-Kendall modified tests to the air temperature data in different quarters in CRHEA climatological station.

	Annual		**1st Quarter**		**2nd Quarter**		**3rd Quarter**		**4th Quarter**	
	tau	p-value	tau	p-value	tau	p-value	tau	p-value	tau	p-value
Tmin	0.179^{m}	0.402^{m}	0.085	0.521	0.230^{m}	0.199^{m}	0.305	0.019*	0.228	0.080
Tmax	0.436	0.001*	0.414	0.001*	0.187	0.153	0.379	0.003*	0.295	0.023*
Tmean	0.329	0.011*	0.218	0.094	0.322	0.013*	0.524^{m}	0.000*^{m}	0.226	0.083

*significant – (p-value ≤ 0.05); ^{m} modified Mann-Kendall test.

The opposite results obtained by the application of the simple regression and the Mann-Kendall test suggest an upper estimation of the significant trend using the simple regression method, which may induce to an incorrect conclusion. This divergent result also was identified by Bombardi and Carvalho (2017) analyzing a rainfall series in the Brazilian central region, in this case, the authors verified a significant trend by the use of the simple regression and a non-significant using the Mann-Kendall test, which confirm the robustness of the test, being this trustworthy to identify trends in temporal series of weather data.

Blain et al. (2009) analyzing the minimum air temperature in Campinas, Piracicaba, Cordeirópolis/Limeira, Monte Alegre do Sul, Pindorama and Ribeirão Preto, all in São Paulo state, during 1917 until 2006 detected positive trend in all sites, however, significant raises were found just in Campinas, Cordeirópolis/Limeira and Ribeirão Preto. Related to the maximum annual air temperature, Blain (2010) also analyzing different locations in São Paulo state, verified significant positive trend in Piracicaba, Campinas, Pindorama and Ubatuba, contrarily to Cordeirópolis, Mococa, Monte Alegre do Sul and Ribeirão Preto was observed stability or even reduction trend was found. Opposite results to locations in São Paulo state were observed by Ferrari (2012), where significant reduction trend for the mean air temperature was identified to Pirassununga.

Divergent results in the air temperature trend into the São Paulo state can be related to the different periods in analysis, thus, it is important to mention that the present research used recent data period (1980 to 2017), compared to other studies previously described, showing a current trend for the air temperature data, which may indicate that the increase has occurred most clearly in the last 10 years over the Hydrographic Basin of the Ribeirão do Lobo. Therefore, the changes found must to be considered in practices that intend to manage the water in this region, due to increase in air temperature promote raise the evaporative atmospheric demand, as a consequence impact positively the evapotranspiration and results in changes in all hydrological cycle and at the hydric availability in the Hydrographic Basin of the Ribeirão do Lobo.

Rainfall

The figures 7 to 11 show the linear regression analyzes applied to rainfall data for stations for each quarter.

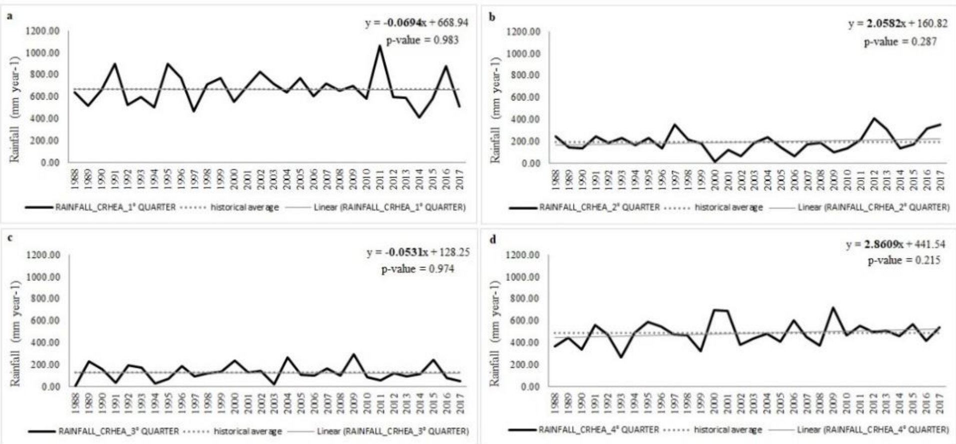

Figure 7. Simple regression approach, values of *b* coefficient and their respective p-values (Student's t-test) obtained confronting the rainfall data, calculated in CRHEA climatological station in different periods: 1° Quarter (a), 2° Quarter (b), 3° Quarter (c) and 4° Quarter (d).

*significant – (p-value ≤ 0.05).

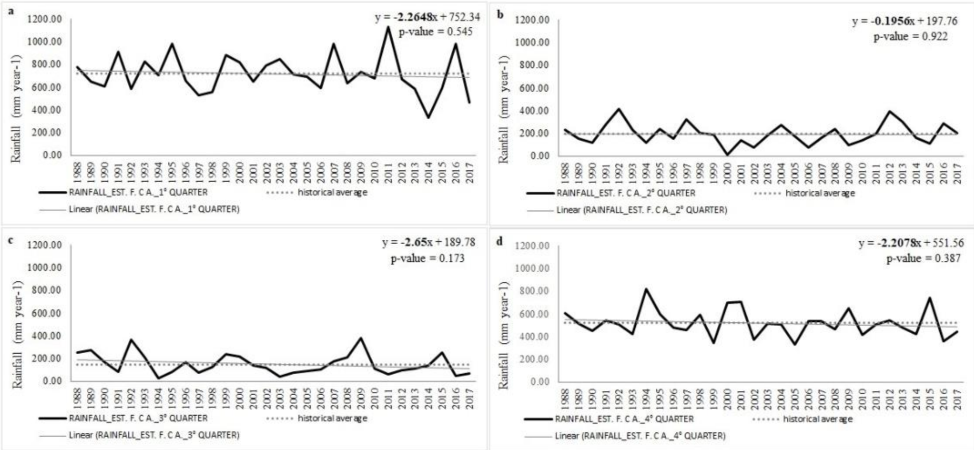

Figure 8. Simple regression approach, values of *b* coefficient and their respective p-values (Student's t-test) obtained confronting the rainfall data, calculated in Est. Ferrov. Campo Alegre rainfall station in different periods: 1° Quarter (a), 2° Quarter (b), 3° Quarter (c) and 4° Quarter (d).
*significant – (p-value ≤ 0.05).

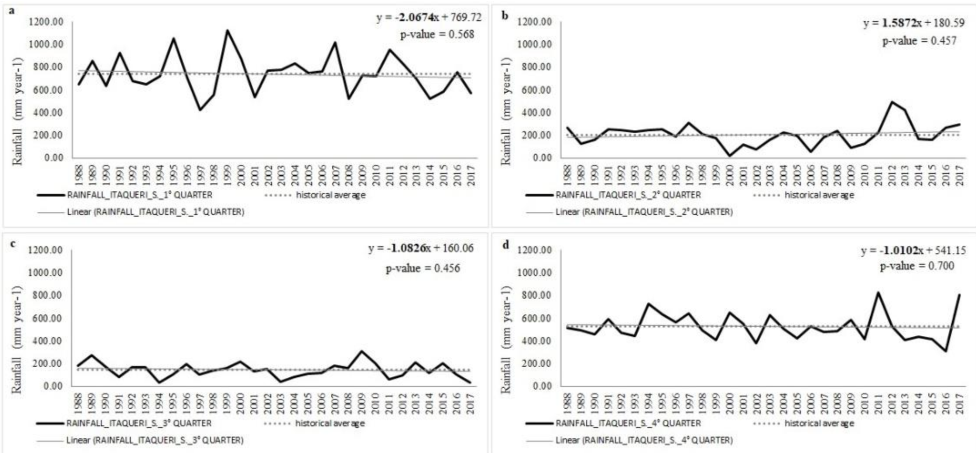

Figure 9. Simple regression approach, values of *b* coefficient and their respective p-values (Student's t-test) obtained confronting the rainfall data, calculated in Itaqueri da Serra rainfall station in different periods: 1° Quarter (a), 2° Quarter (b), 3° Quarter (c) and 4° Quarter (d).
*significant – (p-value ≤ 0.05).

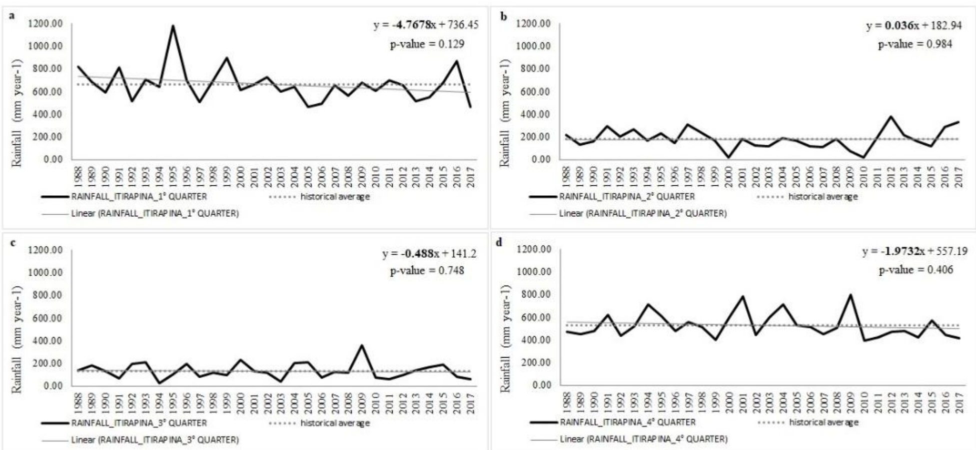

Figure 10. Simple regression approach, values of *b* coefficient and their respective p-values (Student's t-test) obtained confronting the rainfall data, calculated in Itirapina rainfall station in different periods: 1° Quarter (a), 2° Quarter (b), 3° Quarter (c) and 4° Quarter (d).
*significant – (p-value ≤ 0.05).

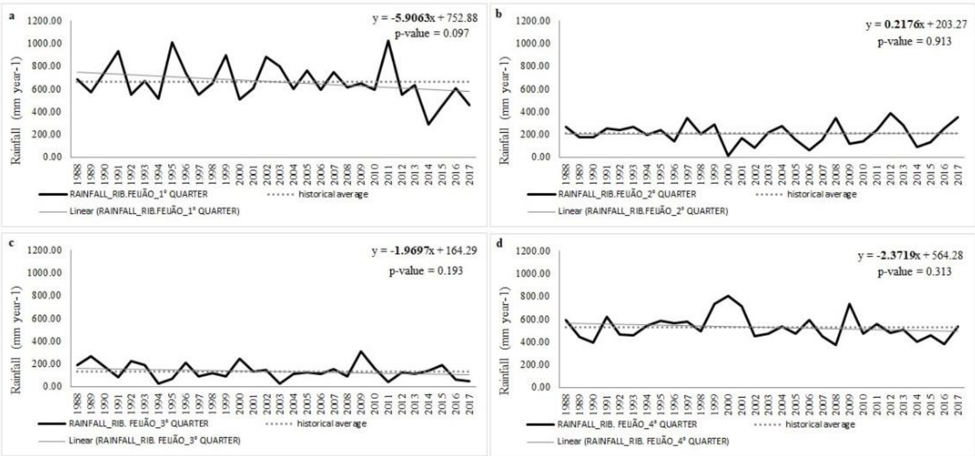

Figure 11. Simple regression approach, values of *b* coefficient and their respective p-values (Student's t-test) obtained confronting the rainfall data, calculated in Ribeirão do Feijão rainfall station in different periods: 1° Quarter (a), 2° Quarter (b), 3° Quarter (c) and 4° Quarter (d).
*significant – (p-value ≤ 0.05).

Based on the *b* coefficient obtained by the simple regression, it was verified increases and reductions in rainfall data throughout the analyzed period (Figures 7 to 11). In the annual scale rise in rainfall was observed only to CRHEA station (Figure 3-1), with an increase of 4.797 mm year^{-1}, however, this value was not significant by the Student's s t-test. In contrast, reductions in rainfall were verified in the remain stations with values until -10.030 mm year^{-1} to Ribeirão do Feijão station (p-value ≤ 0.05) (Figure 3-5).

A considerable variability on the rainfall data was verified all over the quarter periods (Figures 7 to 11).

Analyzing all stations and periods were observed rainfall reductions to first, third and fourth quarter periods with values ranging from -0.053 to -5.906 mm year^{-1}. Besides that, except for the Est. Ferrov. Campo Alegre, during the second quarter, a rise in rainfall value was observed. Spite of the fact of simple regression evince possible changes in the rainfall, the changes were not statistically significant for almost periods and stations analyzed.

Using the same method to identify changes in rainfall patterns, Penereiro and Ferreira (2017) analyzing 11 locations spread the São Paulo state, obtained b coefficient that indicated reductions and increases in the annual rainfall, similar results those obtained in the present research. The authors also identified a reduction trend for this variable in the municipally of São Carlos, where is located the Hydrographic Basin of the Ribeirão do Lobo, once more confirming the results observed in this research.

Even as the air temperature data, the run test was applied to the rainfall data to confirm the randomly of the data and, just for the first quarter period to the Ribeirão do Feijão the rainfall data did not present randomness (p-value ≤ 0.05), thus the modified Mann-Kendall test was applied. To the other periods and locations, due to the randomly of the data the Mann-Kendall test was used (Table 3).

Table 3. Values of p-values calculated by the use of the run test in different periods of time in climatological and rainfall stations: CRHEA (1), Est. Ferrov. Campo Alegre (2), Itaqueri da Serra (3), Itirapina (4) and Ribeirão do Feijão (5).

Station	**Annual**	**1st Quarter**	**2nd Quarter**	**3rd Quarter**	**4th Quarter**
	p-value	p-value	p-value	p-value	p-value
1	0.457	0.710	0.710	0.265	0.457
2	0.457	0.457	0.710	0.137	0.137
3	0.710	0.710	0.265	1.000	0.710
4	1.000	0.457	0.710	1.000	0.710
5	1.000	0.026*	0.710	1.000	0.265

*significant – (p-value ≤ 0.05).

Analyzing the tau values an agreement was verified between results of the simple regression and the Mann-Kendall test, except to the second quarter of all stations, where values close to zero was found, which represent an inconsistent trend in the rainfall data. Although no significant results were obtained for the most stations and periods, a reduction trend in rainfall data can be observed.

However, in the CRHEA station for annual, second and fourth quarter periods positive tau values pointed out to an increase for this variable (Table 4). Only to Ribeirão do Feijão for the annual period, a significant reduction trend was verified (p-value ≤ 0.05), a result confirmed by the simple regression (Table 4).

Table 4. Values of tau and p-values calculated by the use of the Mann-Kendall and Mann-Kendall modified tests to the rainfall data in different periods of time in climatological and rainfall stations: CRHEA (1), Est. Ferrov. Campo Alegre (2), Itaqueri da Serra (3), Itirapina (4) and Ribeirão do Feijão (5).

Station	**Annual**		**1st Quarter**		**2nd Quarter**		**3rd Quarter**		**4th Quarter**	
	tau	p-value	tau	p-value	tau	p-value	tau	p-value	tau	p-value
1	0.159	0.225	-0.0713	0.592	0.048	0.721	-0.058	0.669	0.159	0.225
2	-0.182	0.164	-0.099	0.454	-0.016	0.915	-0.184	0.159	-0.141	0.284
3	-0.094	0.475	-0.062	0.643	-0.002	1.000	-0.103	0.432	-0.140	0.284
4	-0.246	0.059	-0.205	0.116	-0.071	0.592	-0.094	0.475	-0.163	0.212
5	-0.283	0.030*	-0.209^{m}	0.108^{m}	-0.021	0.887	-0.152	0.246	-0.140	0.284

*significant – (p-value ≤ 0.05); ^{m} modified Mann-Kendall test.

Resembling the present research, Blain (2010) found negative and positive trends to rainfall in different locations over the São Paulo state between 1948 and 2007. However, the author verified a positive trend during the May periods to Campinas and Ribeirão Preto, moreover, raises also were identified considering the annual scale in Monte Alegre do Sul and Jundiaí. These results were not similar to those obtained in the present research, where no significant increase in rainfall trend was observed (Table 4).

Ferrari et al. (2012) analyzing the rainfall in Pirassununga, São Paulo state, for 1976 to 2008 verified negative trend in the variable in analysis considering the annual scale, however, the results were not significant. Similar results were obtained by Folhes and Fisch (2006) in Taubaté, São Paulo state between 1983 and 2005, where a negative trend was observed at the annual scale and during April.

Considering the results obtained in the present research and other obtained by researchers, considerable variability was observed in different locations all over the São Paulo state, which means that changes are contrasting from each location of the state. Specific for the stations located in analysis herein, the modifications of the rainfall patterns can result in negative impacts into the qualitative and quantitative hydrological aspects of the Hydrographic Basin of the Ribeirão do Lobo of the with direct effect over the quality index and the amount of water flow of the river and their tributaries.

Conclusions

With the current research was possible to conclude that the air temperature showed a positive trend for all periods with an increase between 0.6 °C and 2.1 °C over the 30 years. The raises were noted in Tmin, Tmax and Tmean suggesting a climate change for this period. Considering the rainfall data, inconsistency trends were observed, due to periods with positive and negative trends, moreover, most of the time non-significant trend was observed. However, was confirmed a negative trend in the Ribeirão do Feijão (-10.03 mm $year^{-1}$).

It was possible to conclude that exist a difference between the applied tests to check the presence of trends. The simple regression represented by the *b* coefficient (Student's t-test) was less accurate, once overestimation in trend was calculated. Highest accurate results to indicate trends were observed using the Mann-Kendall test, due to considering that the order of values occurs independently and randomly and that it does not depend on the probability distribution of the data.

Spite of the results obtained with the trend tests in the Hydrographic Basin of the Ribeirão do Lobo between 1998 and 2017 period, it is necessary a more complex analysis to detect the causes of the local climate changes, once these changes may be attributed to deforestation, in the soil management practices, and activities that promote the development in the region. However, it is important to highlight that the changes in air temperature and rainfall observed in this research can promote negative impacts on natural resources, especially in water availability. Thus, these results can indicate the way to environmental studies in the Hydrographic Basin of the Ribeirão do Lobo collaborating with long-term planning.

Acknowledgements

To Coordination for Improvement of Higher Education Personnel (CAPES), to National Council for Scientific and Technological Development (CNPq), and to Araucária Foundation.

References

Alvares, C.A., Stape, J.L., Sentelhas, P.C., de Moraes Gonçalves, J.L., Sparovek, G., 2013. Köppen's climate classification map for Brazil. Meteorologische Zeitschrift 22, 711–728. DOI: 10.1127/0941-2948/2013/0507.

Ávila, L.F., Mello, C.R. de, Yanagi, S. de N.M., Sacramento Neto, O.B., 2014. Tendências de temperaturas mínimas e máximas do ar no Estado de Minas Gerais. Pesquisa Agropecuária Brasileira 49, 247–256. DOI: 10.1590/S0100-204X2014000400002.

Blain, G.C., 2010. Séries anuais de temperatura máxima média do ar no Estado de São Paulo: variações e tendências climáticas. Revista Brasileira de Meteorologia 25, 114–124. DOI: 10.1590/S0102-77862010000100010.

Blain, G.C., Picoli, M.C.A., Lulu, J., 2009. Análises estatísticas das tendências de elevação nas séries anuais de temperatura mínima do ar no Estado de São Paulo. Bragantia 68, 807–815. DOI: 10.1590/S0006-87052009000300030.

Bombardi, R.J., Carvalho, L.M.V. de, 2017. Práticas Simples em Análises Climatológicas: Uma Revisão. Revista Brasileira de Meteorologia 32, 311–320. DOI: 10.1590/0102-77863230001.

Challinor, A., Martre, P., Asseng, S., Thornton, P., Ewert, F., 2014. Making the most of climate impacts ensembles. Nature Climate Change 4, 77–80. DOI: 10.1038/nclimate2117.

Chen, Y., Zhai, P., 2017. Revisiting summertime hot extremes in China during 1961-2015: Overlooked compound extremes and significant changes: Overlooked Changes of Hot Extremes. Geophysical Research Letters 44, 5096–5103. DOI: 10.1002/2016GL072281.

Coelho, C.A.S., Cardoso, D.H.F., Firpo, M.A.F., 2016. Precipitation diagnostics of an exceptionally dry event in São Paulo, Brazil. Theoretical and Applied Climatology 125, 769–784. DOI: 10.1007/s00704-015-1540-9.

Ely, D., Dubreuil, V., 2017. Análise das tendências espaço-temporais das precipitações anuais para o estado do Paraná – Brasil. Revista Brasileira de Climatologia 21, 553–569. DOI:10.5380/abclima.v21i0.48643.

Fante, K.P., Sant'Anna Neto, J.L., 2017. Mudanças nos Padrões da Temperatura do Estado de São Paulo/Brasil nos Últimos 50 Anos. Geography Department University of Sao Paulo 33, 12–23. DOI:10.11606/rdg.v33i0.125767.

Ferrari, A.L., Vecchia, F.A.D.S., Colabone, R.D.O., 2012. Tendência e variabilidade anuais da temperatura e da pluviosidade em Pirassununga-SP. Revista Brasileira de Climatologia 10, 30–46. DOI: 10.5380/abclima.v10i1.30585.

Ferreira, D.L., Penereiro, J.C., Fontolan, M.R., 2015. Análises estatísticas de tendências das séries hidro-climáticas e de ações antrópicas ao longo das sub-bacias do Rio Tietê. Holos 2, 50–68. DOI: 10.15628/holos.2015.1455.

Folhes, M.T., Fisch, G., 2006. Caracterização climática e estudo de tendências nas séries temporais de temperatura do ar e precipitação em Taubaté (SP). Ambiente e Água - An Interdisciplinary Journal of Applied Science 1, 61–71. DOI: 10.4136/ambi-agua.6.

Hamed, K.H., Rao, A.R, 1998. A modified Mann-Kendall trend test for autocorrelated data. Journal of Hydrology, 204, 182–196.

Hipel, K.W., McLeod, A.I., 1994. Time Series Modelling of Water Resources and Environmental Systems. Disponível: http://www.amac.md/Biblioteca/data/30/14/10/56.2.pdf. Acesso: Set 10, 2018

Huber, V., Schellnhuber, H.J., Arnell, N.W., Frieler, K., Friend, A.D., Gerten, D., Haddeland, I., Kabat, P., Lotze-Campen, H., Lucht, W., Parry, M., Piontek, F., Rosenzweig, C., Schewe, J., Warszawski, L., 2014. Climate impact research: beyond patchwork. Earth System Dynamics 5, 399–408. DOI: 10.5194/esd-5-399-2014.

Intergovernmental Panel on Climate Change - IPCC. Climate Change. (2013). The Physical Science Basis. IPCC Working Group I full report. Cambridge, University Press.

James, R., Washington, R., Schleussner, C.F., Rogelj, J., Conway, D., 2017. Characterizing half-a-degree difference: a review of methods for identifying regional climate responses to global warming targets: Characterizing half-a-degree difference. Wiley Interdisciplinary Reviews: Climate Change 8, 01–23. Doi: 10.1002/wcc.457.

Kendall, M.G, 1975. Rank Correlation methods, Charles Griffin, London, 202pp.

Knapp, A.K., Hoover, D.L., Wilcox, K.R., Avolio, M.L., Koerner, S.E., La Pierre, K.J., Loik, M.E., Luo, Y., Sala, O.E., Smith, M.D., 2015. Characterizing differences in precipitation regimes of extreme wet and dry years: implications for climate change experiments. Global Change Biology 21, 2624–2633. DOI: 10.1111/gcb.12888.

Mann, H.B., 1945 Non-parametric test against trend. Econometrica 13, 245–25.

Marengo, J.A., Nobre, C.A., Seluchi, M.E., Cuartas, A., Alves, L.M., Mendiondo, E.M., Obregón, G., Sampaio, G., 2015. A seca e a crise hídrica de 2014-2015 em São Paulo. Revista USP 106, 31–44. DOI: 10.11606/issn.2316-9036.v0i106p31-44.

Marengo, J.A, Espinoza, J.C., Ronchail, J., Alves, L.M, 2016. Tropical South America east of the Andes. [in "State of the Climate in 2015"]. Bulletin of the American Meteorological Society. 97, 192–193.

Myers, S.S., Smith, M.R., Guth, S., Golden, C.D., Vaitla, B., Mueller, N.D., Dangour, A.D., Huybers, P., 2017. Climate Change and Global Food Systems: Potential Impacts on Food Security and Undernutrition. Annual Review of Public Health 38, 259–277.DOI: 10.1146/annurev-publhealth-031816-044356.

Neves, G.L., Virgens Filho, J.S., Leite, M.L., Santos, E. N, 2016. Trend of air temperature in the state of Paraná, Brazil. Revista Brasileira de Climatologia, 18, 180–193. DOI: 10.5380/abclima.v18i0.45639.

Penereiro, J.C., Ferreira, D.H.L., 2017. Ensino de aspectos da climatologia aplicados à engenharia ambiental apoiado por métodos estatísticos. Revista Tecnologia e Sociedade 13, 76–96. DOI: 10.3895/rts.v13n27.4473.

Qian, C., Zhang, X., Li, Z., 2019. Linear trends in temperature extremes in China, with an emphasis on non-Gaussian and serially dependent characteristics. Climate Dynamics 53, 533–550. DOI: 10.1007/s00382-018-4600-x.

Rao, V.B., Franchito, S.H., Santo, C.M.E., Gan, M.A., 2016. An update on the rainfall characteristics of Brazil: seasonal variations and trends in 1979-2011: Rainfall over Brazil. International Journal of Climatology 36, 291–302. DOI: 10.1002/joc.4345.

Reboita, M.S., Oliveira, D.M. de, Freitas, C.H. de, Oliveira, G.M. de, Pereira, R.A. de A., 2015. Anomalias dos padrões sinóticos da atmosfera na América do Sul nos Meses de janeiros de 2014 e 2015. Revista Brasileira de Energias Renováveis 4, 01–12. DOI: 10.5380/rber.v4i4.44141.

Sa'adi, Z., Shahid, S., Ismail, T., Chung, E.-S., Wang, X.-J., 2019. Trends analysis of rainfall and rainfall extremes in Sarawak, Malaysia using modified Mann–Kendall test. Meteorology and Atmospheric Physics 131, 263–277. DOI: 10.1007/s00703-017-0564-3.

Shi, J., Cui, L., Wen, K., Tian, Z., Wei, P., Zhang, B., 2018. Trends in the consecutive days of temperature and precipitation extremes in China during 1961–2015. Environmental Research 161, 381–391. DOI: 10.1016/j.envres.2017.11.037.

Sridhar, S.I., Raviraj, A., 2017. Statistical Trend Analysis of Rainfall in Amaravathi River Basin using Mann-Kendall Test. Current World Environment 12, 89–96. DOI: 10.1007/s00703-017-0564-3.

Verhage, F.Y.F., Anten, N.P.R., Sentelhas, P.C., 2017. Carbon dioxide fertilization offsets negative impacts of climate change on Arabica coffee yield in Brazil. Climatic Change 144, 671–685. DOI: 10.1007/s10584-017-2068-z.

Virgens Filho, J.S. das, Oliveira, R.B. de, Leite, M. de L., Tsukahara, R.Y., 2013. Desempenho dos modelos CLIGEN, LARS-WG e PGECLIMA_R na simulação de séries diárias de temperatura máxima do ar para localidades do estado do Paraná. Engenharia Agrícola 33, 538–547. DOI: 10.1590/S0100-69162013000300010.

Wheeler, T., von Braun, J., 2013. Climate Change Impacts on Global Food Security. Science 341, 508–513. DOI: 10.1126/science.1239402.

Zilli, M.T., Carvalho, L.M.V., Liebmann, B., Silva Dias, M.A., 2017. A comprehensive analysis of trends in extreme precipitation over southeastern coast of Brazil: Extreme precipitation trends over southeastern coast of Brazil. International Journal of Climatology 37, 2269–2279. DOI: 10.1002/joc.4840.